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Northern Guinea Savanna Edaphic Properties and Nutrients Combination Impact on Maize Mycorrhizal Colonization and Biomass Yield

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ABSTRACT

The variability in soil properties informs the need for verification of their potential suitability for continuous cropping. A maize variety (Oba super 1) was evaluated for biomass yield and root colonization by Arbuscular Mycorrhizae Fungi (AMF) in a screen house at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Soil samples were collected from six farmers' fields within Northern Guinea Savanna of Nigeria and seven nutrients formulation were applied to each sample. The replicated experiment was laid out in a split plot design with soil in the main plot. There was significance ($P \leq 0.05$) among the soil samples from six farmer's field and the seven nutrient combinations. Soil and nutrient combination differed significantly ($P \leq 0.05$) for shoot biomass yield and AMF colonization. Soil from field 5 with loam textural characteristic gave the significantly ($P \leq 0.05$) highest shoot (20.17 g/plant) and root (5.26 g/plant) biomasses but the same had the lowest significant ($P \leq 0.05$) AMF colonization of 39.86%. Stability variance identified in soils from fields 1 (loam), 2 (loam), 3 (loam) and 5 (loam) to be more stable in the support for shoot biomass and AMF colonization. Porosity and un-enhancement of the soils favored AMF root colonization while amendment of the soil with nutrient improved the biomass yield of maize. Inherent physical properties of the soil are primary determinants of its variability in response to alien factors.

Key words: AMF, Nigerian savanna, nutrient interactions, Oba super 1, rhizosphere, soil fertility

INTRODUCTION

Maize, a cereal next to rice in popularity and importance, is a food security crop in Sub-Saharan African countries. The largest production of maize in West Africa comes from Nigeria; 70% of which come from small scale farmers (Olaniyan, 2015). Maize provides food for humans and animals and raw materials for some industries. Although increased production of maize in the Northern Guinea Savanna (NGS) of Nigeria is evident; declining soil fertility is a prominent constraint to its sustainable production in the region.

The high solar radiation and well distributed rainfall with low pest incidence in the NGS supports maize cultivation. The production potential within the region is very high. However, reports have indicated that biotic and abiotic constraints are responsible for dwindling maize yield in the NGS. Salami *et al.* (2011) and Olaniyan (2015) had documented soil fertility decline to be most remarkable for low yield among the many factors. Assessment of different soil characteristics (within the region) and their response to some notable essential nutrients for growth, development and improved edaphic environment is appropriately imperative. Arbuscular Mycorrhizae Fungi (AMF), a symbiotic association in the rhizosphere, creates a significant rhizospheric environment for suitable crop production. Within the association plant supply energy for AMF while AMF in turn supplies inorganic nutrients, hormones and protect roots against soil pathogens (Barakah and Heggo, 1998).

Soils of the savanna region of Nigeria are physically fragile (Salako, 2003), this could be due to the large proportion of sand in the topsoil which is an important factor for weak aggregation and low organic matter content. Consequently, high infiltration rate with poor water retention is usually evident. Other features with limiting influence on the physical properties of the Nigerian savanna soils are: gravelly texture, shallow depth (Adeoye and Mohammed-Saleem, 1990; Salako *et al.*, 2002). Soils in the NGS are characterized by low Nitrogen (Salako *et al.*, 2002). Maize production demands high nutrient particularly Nitrogen, Phosphorus and Potassium, hence the need for fertilization as pointed out by Halvin *et al.* (2014).

The inconsistency in the performance of crop growing under the same nutritional management has remained a source of frustration to farmers (Olaniyan *et al.*, 2011). In the effort to enhance soil productivity, most farmers have subscribed to fertilizer application, however, poor production despite fertilizer application has led some to abandon of their farmlands. The knowledge of the characteristics of the soil and its response to making nutrient available for crop productivity is lacking to majority of the farmers.

Although the relationships between plant and soil is very complex (Karamanos, 2013), the understanding of the variable response of crop to the environment is vital to crop management in agricultural system (He *et al.*, 2014). With reference to wheat, soil texture is an important factor that is evidently significant on both ecological and hydrological processes (Chaudhari *et al.*, 2008). Moreover, a good combination of plant nutrients within the soil is very crucial to achieve high yield from maize (Koochaki, 1992).

The inherent, varied textural and fertility gradient in farms within NGS vegetation of Nigeria earlier reported by Okogun *et al.* (2004) provided a platform for this study. Hence, the interaction of the varied soil types with different nutrient compositions to support biomass yield and create environment for AMF colonization within the maize root zone was investigated in this study. The limiting influence of each of the two factors and their interaction were assessed on Oba super 1 maize variety.

MATERIALS AND METHODS

The present study was carried in a screen house at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Soil samples were collected from six farmer's fields at Kaya (7° 31E, 11° 31N), Giwa Local government area of Kaduna State in the Northern Guinea savanna of Nigeria. The selected farmer's fields had earlier been reported by Okogun *et al.* (2004) to exhibit diversity for cropping history, such as; growing legume in rotation or in mixed cropping with maize and variability for N fertilizer application.

Soil samples were randomly collected within 0 to 15 cm depth from each of the six farmer's fields using soil auger. All samples within each farm were composited, mixed thoroughly and bulked. Sub-sample from each of the six fields were air-dried and ground to pass through a 2 mm sieve for physical and chemical properties analysis. Soil characteristics assessed included: pH in water (1:1) following IITA (1982) protocol, organic carbon estimation as described by Heanes (1984), total N using macro-kjeldahl method (Bremner and Mulvaney, 1982), available Phosphorus was estimated following Mehlich 3 extraction method (Mehlich (1984) while exchangeable bases were colorimetrically determined using Technicon AAII Auto-analyser and Atomic Absorption spectrophotometer (Model Buck 200A). Particle size distribution was determined using the hydrometer method (Bouyoucos, 1951).

Two Oba super 1 maize seeds of were sown per pots filled with 8 kg weight of soil and thinned to one after two weeks prior to nutrient application. The experiment was laid out in split plot design with three replications. Soils from the six farmer's fields (see detail in Table 1) were in the main plot, while the seven nutritional compositions (Table 2) were the sub-plot treatments. Watering and weeding was done regularly. The experiment was terminated at 8 weeks after planting (WAP).

Data recorded include; shoot and root biomasses, AMF colonization percentage and Nitrogen uptake. For biomass measurement, maize shoots were cut above soil level; roots were evacuated and carefully washed using a 4 mm sieve under tap water. Root sub-samples of 1 g were collected in glass vials for AMF colonization assessment as described by Giovannetti and Mosse (1980). Maize roots and shoots were oven-dried at 80 ºC for 48 hours and their dry weight was recorded. Dried shoot was used for estimation of shoot N- uptake using IITA (1982) protocol.

Differences among the soils from the six farmer's fields were established by 15 paired comparisons by paired t-test statistics. Data matrix on the differential physico-chemical properties of the soils from the six farmer's fields were subjected to Gower genetic distance in SAS (Version 9.3, SAS, 2011). The resultant distances were further presented to SAS for Principal Component Analysis (PCA). The obtained PCA scores of the first three axes were employed to generate the tri-dimensional figure using PROC 3gd in SAS (Version 9.3, SAS, 2011). Data on root and shoot biomass, AMF colonization and Nitrogen uptake were subjected to analysis of variance, using a fixed model of PROC ANOVA in SAS (version 9.3, SAS, 2011). The significant means of the two main effects were separated using the honest significant difference of Tukey at 0.05 probability level. The PROC ANOVA generated standard deviation along with the means of the interaction values between levels of farmers' fields and nutrient composition. Standard error and hence, the least significance difference (LSD) at 0.05 and 0.01 were estimated for each mean from the standard deviation. The significant farmers' field by nutrient composition interaction observed for shoot biomass and AMF colonization were further partitioned using the Shukla variance stability statistics (Shukla, 1972) to understand the stability of the soil of each farm.

RESULTS

For the thirteen physico-chemical properties estimated for each of the six soils from the fields, significant ($p<0.05$) to highly significance ($p<0.01$) differences existed between each paired comparison (upper diagonal, Table 3) of the fields. The lower diagonal (Table 3) presents similarity among pairs of the six soil samples by Gower distance techniques. The highest similarity (0.736) was between fields 3 and 5. Fields 1 and 4 had the lowest (0.397) similarity. Distance (i.e. 1-S; S meaning similarity) among the six soils was between 0.264 and 0.603 (Table 3). The tri-dimensional figurative display of the relationship or similarity of the six fields as captured by the first three principal component axes accounted for 89.9 of the total variation. Association among the soils of the six fields as revealed in Figure 1 was very loose.

The levels of the two effects (farmers' field and nutrient composition) exhibited highly significant ($p\leq0.01$) variation for the four characteristics under study (Table 4). Moreover, only shoot biomass and AMF colonization had significant ($p<0.05$) field x nutrient composition interaction. From Table 4, coefficient of variation ranged between 9.17 and 62.74 for AMF colonization and Nitrogen uptake. The characteristic performance of the levels of each main effect in enhancing the four characteristics studied is presented in Table 5. Field 5 produced the significantly ($p<0.05$) highest (20.17 g/ plant) shoot biomass and the least AMF colonization. The significantly ($p<0.05$)lowest quantity of shoot biomass (8.39 g/ plant) and Nitrogen uptake (0.02 mg kg^{-1}) were recorded in Field 4. The significantly ($p<0.05$) highest (69.41%) AMF colonization was in Field 3 while Field 5 had the significantly ($p<0.05$) lowest value (39.86%). Among the seven nutrient compositions, nutrient 1 and 7 had perfect opposite display of performances for the four characteristics studied.

Nutrient 7 had the highest percentage production (58.39 %) of AMF colonization as well as the lowest Nitrogen uptake, shoot and root biomass production. Contrary to the above; nutrient 1 produced the lowest AMF colonization (47.79 %), but exceeded other nutrients with respect to the remaining three characteristics (Table 5). The treatment interaction with the highest biomass production in this study was Field 3 x Nutrient 6, whose shoot biomass was 25.03 g/ plant (Table 6). Other Field x Nutrient combinations with significantly higher biomass yield included: Field 6 x Nutrient 3 (23.97 g/ plant), Field 5 x Nutrient 4 (24.33 g/ plant), Field 5 x Nutrient 5 (23.50 g/ plant) and Field 6 x Nutrient 1 (21.33 g/ plant). The treatment combination with the lowest shoot biomass production (3.20 g/plant) was Field 4 x Nutrient 7 (Table 6). Mean biomass production for the six farmer's fields followed a declining trend of: Field 5 > Field 6 > Field 3 > Field 1 > Field 2 > Field 4 (Table 6). The least stability variance (0.01) in this study was recorded in Field 1. Fields 4 and 5 had 0.50 and 0.50 stability variances, respectively; the two fields displayed less stability for the seven nutrient composition treatments. The highest (74.73%) AMF colonization was recorded by the combination of Field 3 x Nutrient 5 (Table 7).

Table 1: Chemical and physical characteristics of soil samples from farmers' fields in Kaya Northern Guinea savanna, Nigeria

Soil Properties	Farmer's Field						
	1	2	3	4	5	6	Mean
pH (H_2O) 1:1	5.9	5.5	5.8	5.6	5.3	5.2	5.6
Org C (g kg^{-1})	8.8	5.5	7.9	5.2	7.5	10.4	7.6
Total N (g kg^{-1})	0.07	0.05	0.07	0.05	0.01	0.08	0.1
P (mg kg^{-1})	51.7	4.4	3.1	2.7	10.5	4.5	12.8
Ca (Cmol kg^{-1})	3.5	2	2.2	1.3	1.8	1.6	2.1
Mg (Cmol kg^{-1})	0.6	0.5	0.8	0.3	0.5	0.5	0.5
K (Cmol kg^{-1})	0.3	0.2	0.2	0.2	0.2	0.2	0.2
Na (Cmol kg^{-1})	0.3	0.2	0.3	0.3	0.3	0.3	0.3
Mn (mg kg^{-1})	0.1	0.04	0.02	0.1	0.02	0.03	0.1
ECEC (Cmol kg^{-1})	5.4	3.2	3.8	2.4	3.1	3.3	3.5
Sand (g kg^{-1})	430	470	430	570	450	350	450
Silt (g kg^{-1})	440	400	440	340	460	500	430
Clay (g kg^{-1})	130	130	130	90	90	150	120
Textural class	Loam	Loam	Loam	Sandy loam	Loam	Silt loam	

Table 2: Description of the seven fertilizer treatments.

Fertilizer Treatments	Description	Source
T1	Complete (5 Plant Nutrients – N, P, K, Mo and Zn)	-
T2	Complete Nutrient combination minus N	N as Urea at 90 kg N ha^{-1}
T3	Complete Nutrient combination minus P	P as Triple Superphosphate at 30 kg P ha^{-1}
T4	Complete Nutrient combination minus K	K as Muriate of Potash at 30 kg K ha^{-1}
T5	Complete Nutrient combination minus Mo	Mo as Sodium Molybdate at 5 kg Mo ha^{-1}
T6	Complete Nutrient combination minus Zn	Zn as Zinc Sulphate at 5 kg Zn ha^{-1}
T7	Control – No nutrient	-

Table 3: T-test comparison (upper diagonal) and the similarity (lower diagonal) of the paired soil samples from the six farmer's field.

	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6
Field 1	-	5.91**	3.89*	14.68**	5.13**	8.99**
Field 2	0.482	-	4.53**	9.87**	6.01**	12.61**
Field 3	0.655	0.731	-	14.14**	3.97*	8.16**
Field 4	0.397	0.645	0.543	-	13.60**	22.30**
Field 5	0.469	0.723	0.736	0.624	-	9.88**
Field 6	0.42	0.596	0.661	0.482	0.656	-

*, ** - Significance at $P = 0.05$ and 0.01 respectively.

Table 4: Summary of the Analysis of variance for the four traits by split plot design.

Sources of variation	DF	Mean Square			
		Shoot Biomass	Root Biomass	AMF	N-Uptake
Model		72.75***	5.01**	335.86***	0.003***
Rep	2	29.9	4.23	1.82	0.002
Farmer's field	5	333.53***	10.63**	2902.52***	0.011***
Error(a)	10	4.27	2.09	46.62	0.001
Nutrients	6	188.36***	11.61***	225.47***	0.013***
Farms*Nutrients	30	31.85*	3.77	48.85*	0.002
Error(b)	72	17.03	2.57	25.17	0.002
CV (%)		28.58	38.34	9.17	62.74
Mean		14.43	4.18	54.69	0.063

N-Uptake – Nitrogen uptake, Farms*Nutrients = Interaction between the levels of the farm and the Nutrients, CV = Coefficient of variation. *, ** , ***- Significance at $P = 0.05$, 0.01 and 0.001 respectively.

Table 5: Mean separation for shoot and root biomass, AMF and N-Uptake among the farmers' fields and the nutrients using Tukey grouping method.

Farmer's field	Means with Tukey Grouping			
	Shoot biomass (g/plant)	Root biomass (g/plant)	AMF (%)	N-uptake
1	13.07b	3.57ab	42.31d	0.067a
2	12.82b	3.89ab	56.38c	0.047ab
3	15.81b	3.81ab	69.41a	0.081a
4	8.39c	3.66ab	64.57b	0.024b
5	20.17a	5.26a	39.86d	0.076a
6	16.34b	4.89ab	55.61c	0.081a
Nutrients	Shoot biomass	Root biomass	AMF	N-uptake
1	15.87a	4.73a	47.79c	0.078a
2	11.22bc	3.77ab	52.64bc	0.033bc
3	17.06a	4.82a	55.75ab	0.083a
4	15.09ab	3.78ab	56.36ab	0.067ab
5	16.73a	4.68a	54.81ab	0.078a
6	16.46a	4.81a	57.10ab	0.083a
7	8.63c	2.70b	58.39a	0.017c

Means followed by the same letter within parameter for each treatment are not significantly different at $P \leq 0.05$

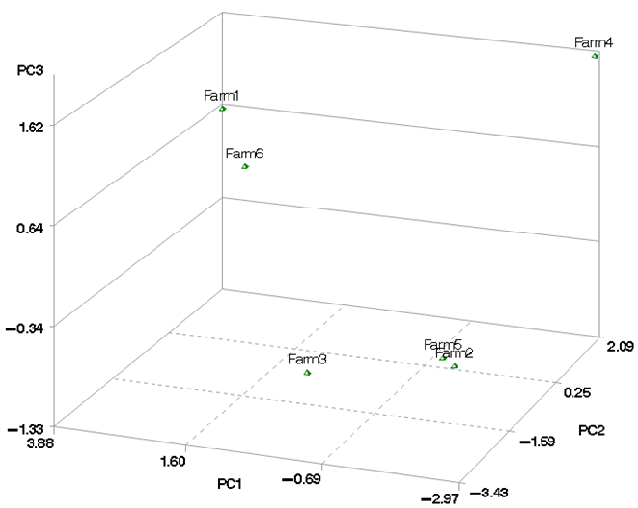

Figure 1: Tri-dimensional plane showing the divergences among the soils of the six farmer's fields.

The same field had the highest grand mean of 69.41%. Moreover, Field 5 x Nutrient 1 produced the lowest (26.47%) AMF colonization. By stability variance estimate in Table 7, the most stable field was Field 1, then followed by Field 5 with respective estimate of -0.06 and 0.36. Field 3 was the most unstable field, because it had the highest stability variance estimate of 4.31 (Table 7).

DISCUSSION

The loose association among the soil from the six farms' fields in this study revealed that wide differences exist among them. Differences in the nutritional and physico-chemical properties of each soil may be implicated for this. This justifies the remark of Havlin *et al.* (2014) that different soil exhibit varied nutritional requirements because soil (a very significant factor in crop production) is highly heterogeneous. The heterogeneity character of soil was identified by Olaniyan (1998) as the cause of differential rates of growth and yield on a parcel of land planted to the same crop at the same time and with the same management practices. Different soils respond differently to fertilizer application(s). Olaniyan *et al.* (2011) demonstrated that the parent material is a major determinant of soil's response to management. According to Karamanos (2013), nutrient uptake within the soil by the plant depends on a number of factors, including plant species, environmental conditions, nutrient supply and interrelationship among nutrients and between plant and soil, presence of microorganisms (e.g., fungi) in association with plant roots, etc.

Maize biomass production and Nitrogen uptake across the six farmers' fields were affected by different nutrient combinations. Complete nutrient application (presence of N, P, K, Zn and Mo) significantly favoured maize shoot biomass. Omission of individual nutrient element in each nutrient composition led to decline in the shoot and root biomass production. This agrees with the remark of Uchida (2000) that plants are unique, having optimum and minimum nutrient ranges, below which plant starts to show nutrient deficiency symptoms as well as decline in biomass production. Treatment without any nutrient addition had the lowest biomass production; by inference, absence and unavailability of nutrient may limit growth and development in plant. This is an indication that Nitrogen and the other nutrients were generally low in the soils from the six farmers' fields. This result clearly substantiates the fact that biological yield of crop increases with fertilizer addition as opined by Ghazvineh and Yousefi (2012). The nutritional treatment whose performance was next to the one with the lowest result was nutrient 2 (in which nitrogen was omitted). This reveals the importance of Nitrogen as a major nutrient element in maize production. Miao *et al.* (2007) observed that Nitrogen is also the most important limiting nutrient for maize yield in various part of the world. Also, Uchida (2000) noted that Nitrogen improves the quality and quantity of dry matter in leafy vegetables. The relatively

Table 6: Mean separation of Interaction between Farmer's field x Nutrient and stability estimate for each farmer's field for Shoot Biomass

Farmer's field	Nutrients							Grand mean	$LSD_{0.05}$	$LSD_{0.01}$	Stability Variance
	1	2	3	4	5	6	7				
1	13.87	7.3	15.53	16.87	17.13	14.87	5.97	13.08	3.58	4.28	0.01
2	11.3	12.37	13.6	15.27	13.37	12.67	11.23	12.83	6.64	7.94	0.08
3	16.37	14.13	18.87	12.4	15.13	25.03	8.77	15.81	3.68	4.39	0.14
4	11.43	3.63	9.6	10.43	11.3	9.13	3.2	8.39	2.57	3.07	0.49
5	20.9	13.57	20.77	24.33	23.5	24.57	13.57	20.17	3.39	4.05	0.49
6	21.33	16.33	23.97	11.27	19.97	12.5	9.03	16.34	4.01	4.79	0.24
Grand mean	15.87	11.22	17.06	15.1	16.73	16.46	8.63				
$LSD_{0.05}$	4.07	4.32	3.26	4.03	4.65	4.54	2.98				
$LSD_{0.01}$	4.87	5.16	3.89	4.81	5.56	5.43	3.56				

Table 7: Mean separation of Interaction between Farmer's field x Nutrient and stability estimate for each farmer's field for AMF colonization

Farmer's field	Nutrients							Grand mean	$LSD_{0.05}$	$LSD_{0.01}$	Stability Variance
	1	2	3	4	5	6	7				
1	35.5	42.6	41.43	45.47	43.13	45.1	42.93	42.31	4.27	5.1	-0.06
2	53.5	53.83	55.9	58.97	50.77	57.7	64.0	56.38	4.58	5.47	0.49
3	66.27	62.67	72.3	73.5	74.73	72.27	64.13	69.41	5.72	6.84	4.31
4	53.83	61.37	66.97	64.87	67.7	69.1	68.13	64.57	5.95	7.11	2.42
5	26.47	39.43	41.23	36.63	44.93	41.97	48.37	39.86	6.33	7.56	0.36
6	51.2	55.93	56.67	58.7	47.57	56.47	62.77	55.61	5.14	6.15	0.41
GM	47.8	52.64	55.75	56.36	54.81	57.1	58.39				
$LSD_{0.05}$	6.18	4.17	4.14	3.68	4.9	4.19	5.1				
$LSD_{0.01}$	8.98	5.78	5.56	4.7	6.37	5.12	6.32				

GM = Grand mean

high biomass production by nutrients 3, 4, 5 and 6 was supported by the results of some earlier research works (Uchida, 2000; Halvin *et al.*, 2014). With respect to these four nutrients (i.e. nutrient 3, 4, 5 and 6), the presence of Nitrogen and its combination with at least any other three nutrient elements (P, K, Mo or Zn) will resulted higher biomass production. This in essence therefore substantiates that Nitrogen, Phosphorus, Potassium, Molybdenum and Zinc are among the essential nutrient elements needed in combination within the soil by maize for higher biomass production.

Root colonization by AMF was significantly higher in treatments without any amendment compared to treatments with complete nutrition and the one in which Nitrogen was omitted. Presence of nutrient from inorganic sources seems to subdue the proliferation of AMF in this study. Nouri *et al.* (2014) had indicated the presence of Nitrogen and phosphorus to influence root colonization by mycorrhizal fungi and symbiotic functioning in the root of Petunia hybrida. The report of Imaz *et al.* (2014) slightly indicted Zinc in maize and they summarily stated that the element in soil could be acting as modulator of mycorrhizae formation. Root colonization by AMF is controlled by a complex factor and may not always translate to improved crop yield (Udaiyan, 2002). Many reports (Caassen and Barber, 1976; Michelsen and Rosendahl, 1990; Faboodi *et al.*, 2011, Nouri *et al.*, 2014) have also identified AMF as an important factor for phosphorus mobilization toward the roots within the soil. High AMF colonization and activity exist under field condition in most tropical agricultural soils (Imaz *et al.*, 2014). With the reports (Barakah and Heggo, 1998; Al-Ghamdi and Jais, 2013; Nouri *et al.*, 2014) of the efficiency of the fungi taxa in nutrient and moisture mining around the rhizosphere for crop use, exploration and utility of AMF in organic agriculture would be very expedient.

The highest AMF colonization in our study was recorded in farmer's fields 3 and 4, both with respective textural characteristics of loam and sandy loam. Zaller *et al.*

(2011) found high sand content in the grassland to enhance AMF colonization. In the report of Al-Ghamdi and Jais (2013), negative correlation was found between the percentage of AMF in the roots and the amount of coarse sand, fine sand and clay, while a positive correlation existed between the percentage of AMF and silt. We therefore conclude in concordance with other reports (Saif, 1981; Carrenho *et al.* 2007; Djuuna *et al.*, 2010) that soil with sufficient aeration (e.g. sand and sandy loam) stimulates and enhances AMF proliferation.

Loam has near or relatively near equal proportions of sand, silt and clay. Fields 1, 2, 3 and 5 in our study had the loam textural characteristics. The stability variance of Shukla (1972) identified them to be most stable in their support for shoot biomass and AMF colonization. We therefore infer that soils with relatively equal proportion of soil particle and high structural aggregation exhibited high stability (i.e. low fluctuation in performance) within the different nutrient element compositions for biomass yield and root colonization by AMF in maize production.

CONCLUSION

The observed wide difference among soils from the six farmer's fields is linked to soil spatial heterogeneity. This accounts for differences in plant development under the same management and varied fertilizer applications. However, soils with relatively equal proportions of particle sizes enhanced high stability (i.e. low fluctuation in performance) for maize biomass yield and root AMF colonization. In addition, soil with sufficient aeration (e.g. sand and sandy loam) will stimulate and enhance AMF proliferation.

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