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Soil organic matter and its active pools as affected by legume/cereal cropping systems under some agronomic practices in the derived savannah zone of Nigeria

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ABSTRACT

Introduction of grain legumes facilitates farmers' acceptance in adopting legume cropping system. This study evaluated effect of four cropping systems on soil organic carbon (SOC), total vesicular arbuscular mycorrhiza (VAM) spore count, soil microbial biomass carbon (SMBC), soil microbial biomass nitrogen (SMBN) and soil microbial biomass phosphorus (SMBP) within two locations (Nsukka and Moniya) of the derived savannah zone of Nigeria. The experiment was set up in a 4 x 2 x 2 factorial in randomized complete block design (RCBD), representing 4 cropping systems, 2 fertilizer application rates (0 and 60 kg N ha^{-1}) and 2 residue management methods (incorporated and not-incorporated). This set-up was replicated three times and the experiment was repeated the following year (2008 and 2009). At the end of the experiment, soil samples for laboratory analyses were collected from 0 – 20 cm soil depth using auger. The result showed that SOC was not significantly ($p \leq 0.05$) affected by all factors and their interaction at both locations. In Nsukka, cropping systems and their interaction with residue management significantly ($p \leq 0.05$) affected SMBP and total VAM spore count. Continuous maize had the highest total VAM spore count (280), which was statistically the same with cowpea/maize rotation (277). Soybean/maize cropping system had the least value (259). Velvet bean/maize cropping system had the highest SMBP (0.0007 mg g^{-1}). In Moniya, SMBC, SMBN and SMBP were significantly ($p \leq 0.05$) affected by the cropping systems with velvet bean/maize plots having highest values (0.053, 0.006, 0.0007 mg g^{-1}). Residue incorporation and fertilizer application (60 kg ha^{-1}) significantly ($p \leq 0.05$) increased SMBC and SMBN at Moniya. Interaction between cropping systems and residue managements at this location also significantly affected SMBC, SMBP and SMBC. In this study, SMBP distinguished the effect of the factors on soil quality better than the other measured parameters. Velvet bean-based cropping system improved soil microbial properties better than other cropping systems.

1. Introduction

Soil organic carbon (SOC) is an important soil resource in several ways. It affects all aspects of the soil; the physical, chemical and biological properties. Consequently, it is very important in maintaining the ecosystem ((Lal 2011). Soil organic matter regulates soil aeration, nutrient and water supply to plants and resources to soil organisms including soil microbes. During decomposition of organic matter, mineralization occurs leading to release of nutrients in plant available form. In determining the effect of crop and soil management systems on soil, SOC has undoubtedly been used. Anthropogenic factors are often associated with a rapid decline in carbon (C) stored in biomass and soil (Batlle-Bayer et al. 2010).

Several studies have shown that soil microbial properties are potential early indicators of the changes in soil quality because unlike the chemical and physical properties of soil, they are more sensitive (Brookes 2001; Geisseler and Horwath 2009; Salinas-Garcıa et al. 2002). The quality and quantity of SOC usually takes a considerable amount of time to respond to changes in management because of the large pool size of SOC and spatial variability of soils (Rovira et al. 2010). This makes it difficult to detect short-term changes in soil quality when SOC is used as an indicator of soil quality. However, soil microbial biomass (SMB) as an active fraction of organic C responds more rapidly than total SOC to changes in management practices (Powlson et al. 1987). Therefore, SMB is now being used extensively to determine the sustainability of any agro-ecosystem or the level of degradation of the soil (Tan et al. 2007).

Soil microbial biomass positively correlates with soil organic matter, and is the living part of soil organic matter (Omeke 2016). It is involved in the decomposition of organic substances and hence in cycling of crop nutrients in soils. In addition, it is regularly used as an early warning sign of changes in soil physico-chemical properties. Management systems that have high inputs of organic matter and easily mineralizable organic matter usually have high SMB. Soil microbial biomass C is about 1- 3% of total soil C and SMBN up to 5% of the total soil nitrogen (N), yet they are the most labile C and N pools in soils. As a result, nutrient availability and productivity of agricultural systems rely majorly on the size and activity of the microbial biomass.

Soil fertility management has for decades been tackled by farmers. It is currently a global issue challenging food security and sustainability. Agro-ecosystems that improve soil health and productivity are of interest to scientists and farmers. Soil and crop management practices, including rotations and nitrogen (N) fertilization can influence soil biological activities through their effects on the quantity, structure and distribution of soil organic matter. More so, including leguminous crops in rotation can increase crop productivity, reduce inorganic nitrogen (N) fertilizer input (Kirkegaard and Ryan 2014) and improve N use efficiency (Kröbel et al. 2014). Crop diversification with legumes can enhance overall agro-ecosystem sustainability on the long run (Gan et al. 2015). Herbaceous legumes such as velvet bean have evidence of successful use in cropping systems but farmers' adoption rates have been very poor. Increased cost of input in planting the herbaceous legume without getting financial benefit has been the reason. Grain edible legumes such as cowpea and soybean have been thought to be able to fill this gap. In addition to its use in cropping systems, farmers still make profit from its sale. Therefore, grain legumes and velvet bean rotation with maize were employed in this research as a management tool.

The objective of this research was to evaluate the effect of different cropping systems involving grain and herbaceous legumes rotations with a cereal, as well as a continuous cereal cropping system, on soil quality parameters. The result of the study is expected to help recommend sustainable soil and crop management options for the southeastern and southwestern regions of the derived savanna zone of Nigeria.

2.0 Materials and Methods

2.1 Soil characterization

This research was carried out in two locations of the derived savanna zones of Nigeria; one at the University of Nigeria, Nsukka (UNN) teaching and research farm (South-east), the second was at the Dominican centre for human resources and development, Moniya (South-west). Fig 1 shows the position of these locations on Nigerian map. Moniya is an out sketch of Ibadan, it is located on 7° 30^{l} N and 3° 25^{l} E. Nsukka is located on 6°51^{1}N and 7°24^{1}E. The soil in Moniya is full of stone, dark brown to grey in colour and classified as a Plinthic Paleustalfs (Soil Survey Staff 2003). The soil in University of Nigeria, Nsukka is degraded, dark reddish brown on the topsoil and red in subsoil and classified as Typic Paleustult (Nwadialo 1989). Fig 2 shows the monthly rainfall amount at both locations within the period of the study. The two locations exhibit tropical wet (March to October) and dry (November to February) seasons. They are under the derived savannah zones of Nigeria. Nsukka has a mean annual rainfall of 1250 mm and a mean annual temperature of 26°C while Moniya, Ibadan had average annual rainfall of 1119.55 mm and mean temperature were 27°C.

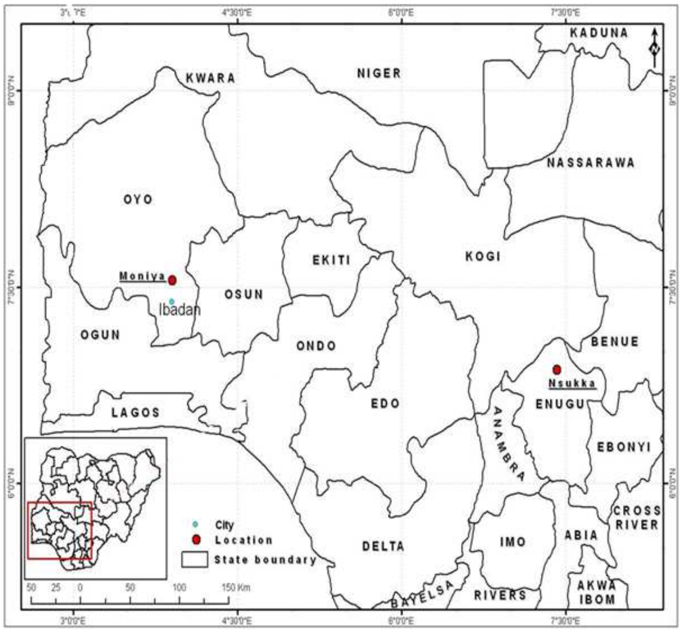

Fig. 1: Map of Nigeria showing locations of the experiment

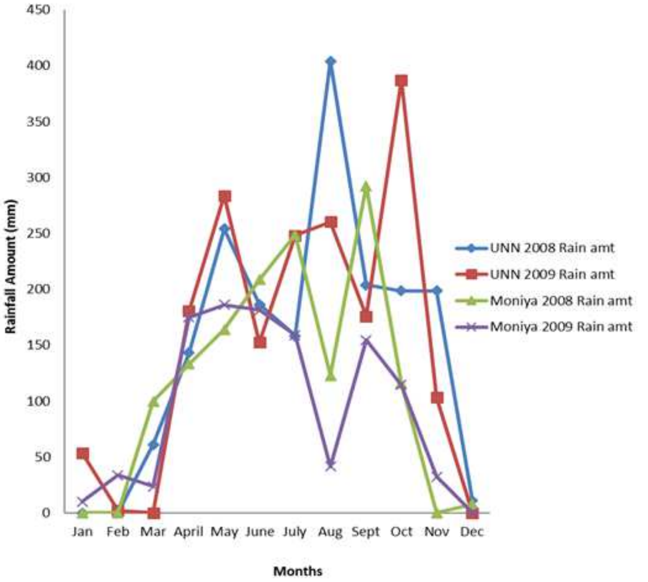

Fig 2: Rainfall amount for 2008 and 2009 at Moniya and UNN

2.2 Field methods

The field experiments were carried out in 2008 and 2009, at UNN (Nsukka) and Moniya, Ibadan. In each year, two cropping sessions were established, first was the cultivation of the sole legumes (herbaceous legume -velvet bean (*Mucuna pruriens*), cowpea (*Vigna unguiculata*) and soybean (*Glycine max*)) and maize (*Zea mays*). Second was planting of maize in all the plots with and without residue incorporation and nitrogen application. The experimental design was 4 x 2 x 2 factorial in randomized complete block design (RCBD), having three factors: factor A= cropping system (4) namely; velvet-bean/maize, cowpea/maize, soybean/maize and maize/maize, factor B = nitrogen application (2) namely; 0 kg N/ha and 60 kg N/ha, and factor C = residue management method (2) namely residue incorporated and residue not incorporated. This factorial design was replicated in three blocks resulting in a total of 48 plots.

The treatments were randomly applied to the plots within each block. Three seeds of hybrid maize (Oba Super II), dual -purpose cowpea (03k-374-4), early duration soybean (TGX 1448) and velvet bean were planted per hole during treatment establishment. These were thinned down to one seed after two weeks of germination. The plant spacing adopted for each crop was was 75 cm by 25 cm. The total area for Nsukka and Moniya plots was 0.05 and 0.08 hectares respectively. The normal routine field maintenance practices such as weeding were carried out when required. In 2008, the first and second planting in University of Nigeria, Nsukka was carried out on 23 May and 5 September while in Moniya it took place on 27-28 May and 27 -28 August respectively. Maize was harvested on 18 November in Nsukka and on 21 November in Moniya. In 2009, the first and second cultivation in Nsukka was on 8 June and 9 September while in Moniya, it was carried out on 12 - 14 June and 21 September respectively. The plants were harvested at maturity in November.

2.3 Observations and data collection

At onset of this experiment, soil samples were collected from 0 – 20 cm depth at several points within the location using soil auger to form a composite soil sample. This was used for determination of initial soil properties. Also at the end of the last maize cultivation in 2009, soil samples were collected from the topsoil of each plot and kept separately. The soil samples were air-dried, sieved with 2 mm sieve and subjected to mycorrhizae spore count, soil C and microbial determination.

2.4 Laboratory analysis

2.4.1 Soil chemical analysis

Soil pH was measured in 1: 2.5 soil to water ratio with the glass electrode pH meter (McLean 1982); organic carbon (OC) by the Walkley and Black wet dichromate oxidation method (Nelson and Sommers 1982), organic matter (OM) was determined by multiplying %OC by the convention Van Bemmeller factor of 1.724; exchangeable bases by extraction with neutral 1N NH_4OAc. Potassium (K) in the extract was determined with flame photometer (Kundsen et al, 1982), calcium (Ca) and magnesium (Mg) by atomic absorption spectrophotometer (L). Exchangeable acidity was determined by the KCl displacement method described by Page and Page (1982). Effective cation exchange capacity (ECEC) was obtained from the sum of the exchangeable bases and exchangeable acidity. Available phosphorus (P) was extracted by Bray II method; the P concentration in the extract determined colorimetrically using the spectronic 70 spectrophotometer method (Olsen et al. 1982). Total N in soils was determined by the Micro-Kjeldahl digestion procedure (Bremner and Mulvaney 1982).

2.4.2 Physical parameters determination

Particle size distribution was determined by Bouyoucous hydrometer method (Gee and Or 2002).

2.4.3 Microbial biomass analysis

The fumigation-extraction methods described by Anderson and Ingram (1993) and Mazzarino et al. (1993) was used for the determination of soil microbial biomass C, N, P. Field moist soil sample, 2 mm-sieved was used for the analysis. Three sets of 10 g soil samples were weighed; one set was fumigated by putting them inside desiccators with reagent grade ethanol free chloroform. The commercial chloroform was removed of ethanol by washing it with 5 % by volume concentrated sulphuric acid in a separating funnel and then rinsed with water severally. Water saturated filter paper was placed in the desiccators to keep the samples moist. After 5

Table 1: Initial soil properties of the different locations

Parameter	Locations	
	UNN	Moniya
Clay (%)	38.6	15.9
Silt (%)	17.6	9.6
Sand (%)	48.9	74.6
Textural class	Sandyclay loam	Sandy loam
pH	5.2	6.4
Total N % ()	0.11	0.16
OC (%)	0.86	1.39
OM (%)	1.48	2.40
P (mg/kg)	16.48	6.4
Ca (cmol kg^{-1})	0.8	4.04
Mg (cmol kg^{-1})	0.6	1.37
K (cmol kg^{-1})	0.09	0.4
Na (cmol kg^{-1})	0.07	0.16
EA (cmol kg^{-1})	1.4	0.08
ECEC (cmol kg^{-1})	2.96	6.05
CEC (cmol kg^{-1})	5.3	12.5
BS (%)	52.7	98.7
C/N	9.8	3.25

days, the desiccators were opened to allow the chloroform to dissipate, then the soils were extracted with 0.5N K_2SO_4. Another set was put in the oven at 105°C for 24 hours for gravimetric water content determination and the last set extracted immediately with 0.5 M K_2SO_4 to estimate the initial amount of C and N. Extractable C and N were determined on the extract. Total C and N in the extract were determined by the Walkley and Black, (Nelson and Sommers, 1982), and micro-Kjeldahl (Bremner and Mulvaney, 1982) methods respectively.

Microbial biomass C was estimated by multiplying the difference in extractable C between fumigated and non-fumigated samples by a conversion factor of 2.64 (Vance et al. 1987). Microbial biomass N was estimated by multiplying the difference in extractable N between fumigated and non-fumigated samples by a conversion factor of 1.46 (Brookes et al. 1985). The microbial biomass P was determined using 0.40 conversion factor (Brookes et al. 1984).

2.5 Statistical analysis

Analysis of variance (ANOVA) was carried out to detect significant main effects and interactions. Mean separation was achieved with Fischer's least significant difference (F-Lsd) at 5% probability level as described by Obi (1990).

3.0 Results and Discussion

3.1 Characterization of soils of the study locations

Table 1 shows the physico-chemical characteristics of the soils of the study area. Moniya soil had higher sand content (74.6%) compared to Nsukka soil (48.9%) while soils of Nsukka had higher clay (38.6%), and silt (17.6%) compared to Moniya clay (15.9%) and silt (9.6%). Therefore, the soil in Moniya for the field experiment was a sandy loam while Nsukka was sandy clay loam. The pH of Nsukka soil was strongly acidic (5.1), while that of Moniya was slightly acidic (6.4). The exchangeable Ca, Mg, K, Na, and cation exchange capacity of Nsukka soil were very low in comparison to Moniya soils which had moderate Ca, Mg, and K concentrations and a high base saturation (99%). Total N was higher in Moniya soil (0.16%) than Nsukka soil (0.11%) (Landon 2014), but available P was higher in Nsukka soil (6.48mg/kg) than Moniya soil (4mg/kg).

Moniya had average annual rainfall of 1119.55 mm and maximum and minimum average relative humidity of 92% and 48.88% in 2008 and 89.91% and 50.62% in 2009. The mean annual minimum and maximum temperature were 23° C and 31°C. Rainfall at Moniya was heavier in 2008 than in 2009. Generally, soil at Moniya had higher nutrient content and productive potential than the soil at Nsukka. The low nutrient content of Nsukka soil may be due to very high rainfall that leaches these nutrients. For instance in August 2008, there was 404.15mm of rainfall in 18days and in October 2009 there was 387.1 mm of rainfall in 17days. However in Moniya the maximum rainfall amount was 292.35 mm and it occurred in 21days. It was also observed that in both locations, rainfall was higher than that required for optimal performance of the grain legumes.

3.2 Effect of cropping systems on VAM, soil C and soil microbial biomass C, N and P

Soil C was not significantly ($p \leq 0.05$) affected by cropping systems at the end of the experiment in both locations. In Nsukka, the result showed that cropping systems signifi-

Table 2: Effect of the treatments on soil properties at the end of the experiment in UNN

Treatments	OC (%)	Total VAM	MBC (%)	MBN (%)	MBP (mg/g)
Cropping systems					
Velvet bean-maize	0.95	269	0.048	0.0035	0.0007
Cowpea/maize	0.99	277	0.05	0.0034	0.0006
Soybean/Maize	0.94	259	0.03	0.0032	0.0004
Maize/maize	0.89	280	0.03	0.0028	0.0004
LSD (0.05)	ns	10^{**}	ns	ns	0.0002^{**}
Nitrogen application (N)					
Zero N	0.93	270	0.040	0.0032	0.00058
60Kg/ha N	0.95	272	0.039	0.0032	0.00048
LSD (0.05)	ns	ns	ns	ns	ns
Residue					
Zero Residue	0.94	263	0.027	0.003	0.0005
Residue addition	0.93	279	0.052	0.003	0.0005
LSD (0.05)	ns	5^{xx}	0.016^{**}	ns	ns

cantly ($p \leq 0.05$) affected only SMBP (Table 2). Velvet-bean/maize rotation had the highest SMBP (0.0007 mg g^{-1}), which was statistically the same with cowpea/maize rotation (0.0006 mg g^{-1}) whereas soybean/maize rotation and continuous maize had the least value (0.0004 mg g^{-1}). Other parameters (SMBC and SMBN) though not significant ($p \leq 0.05$) in Nsukka, were also higher in legume/maize rotation than continuous maize. Total VAM spore count was significantly ($p \leq 0.05$) higher in continuous maize (280), which was statistically the same in cowpea/legume rotation (277), followed by velvet bean/maize rotation (269), which was statistically the same with soybean/maize rotation (259).

In Moniya, SMBC, SMBN and SMBP were significantly ($p \leq 0.05$) affected by the crop rotation systems (Table 3). Soil MBC and MBP were higher in legume-cereal rotations with velvet-bean/maize rotation having the highest value (0.053 mg g^{-1}, 0.0007 mg g^{-1}), followed by cowpea/maize (0.036 mg g^{-1}, 0.0005 mg g^{-1}) and soybean/maize rotation (0.032 mg g^{-1}, 0.0003 mg g^{-1}). Continuous maize plots had the least SMBC and SMBP: 0.025 mg g^{-1}, 0.0002 mg g^{-1}. In addition, SMBN though not significant ($p \leq 0.05$) was least in continuous maize plots. With regards to total VAM spore count, there was no significant cropping system effect.

The result showed that cropping systems involving legumes were more sustainable and improved soil quality better than continuous maize. Velvet bean/maize cropping system had better soil quality than the grain legumes. Studies by Granatstein et al. (1987) and Moore et al. (2000) have shown that soils under crop rotation system usually have greater microbial biomass than soils under monoculture systems. In an experiment on the effect of crop rotation and N fertilization on soil chemical and biological properties, Adeboye et al. (2006) demonstrated that crop rotations do not necessarily influence the gross soil microbial biomass but may influence physiologically distinct subcomponent of the microbial biomass such as SMBC, SMBN and water soluble organic carbon (WSOC). In line with previous studies involving legumes (Adeboye et al. 2006; Granatstein et al. 1987), this present study gives evidence that legume rotations improve soil microbial properties. The magnitude of this increase depends on the location. For instance, Moniya location had higher microbial properties than Nsukka location. This resulted from the higher inherent soil fertility and also favourable climatic conditions of Moniya over Nsukka. The rainfall events in Nsukka were more erratic with heavy pours unlike Moniya where the rainfall events were more spread over the period of cultivation. As shown in Tables 2 and 3, VAM spore count was significantly ($p \leq 0.05$) affected by cropping systems in Nsukka, but not in Moniya. The poor fertility status of Nsukka soil favoured the growth of mycorrhizae. This aligns with other research findings that my-

Table 3: Effect of the treatments on soil C and microbiological properties at the end of the experiment in Moniya

Treatments	OC (%)	Total VAM	MBC (%)	MBN (%)	MBP (mg/g)
Cropping systems					
Velvetbean/Maize	1.48	208	0.053	0.006	0.0007
Cowpea/maize	1.43	212	0.036	0.004	0.0005
Soybean/Maize	1.51	219	0.032	0.003	0.0003
Maize/maize	1.51	207	0.025	0.003	0.0002
LSD (0.05)	ns	ns	0.006^{**}	0.0008^{**}	0.0002^{*}
Nitrogen application(N)					
Zero N	1.41	213	0.03	0.0037	0.0004
60Kg/ha N	1.40	210	0.04	0.0043	0.0005
LSD (0.05)	ns	ns	0.004^{**}	0.0006*	ns
Residue					
Zero Residue	1.47	211	0.030	0.003	0.0004
Residue addition	1.49	212	0.043	0.005	0.0005
LSD (0.05)	ns	ns	0.004^{**}	0.0006^{**}	ns

corrhizae is more prominent in poor soils where it assists the crops in nutrient uptake (Batlle-Bayer et al. 2010; Smith and Smith 2011). The total VAM spore count was also higher in Nsukka than Moniya.

3.3 Effect of residue management and fertilizer (urea-N) application on soil C and microbial properties

In Nsukka, fertilizer application (60 kg N/ ha) did not significantly affect soil microbial properties and organic C. On the other hand, residue management significantly affected total VAM spore count and SMBC, which were higher in the residue-incorporated plots (279, 0.052 mg $g^{-1`}$) compared to the plots without residue incorporation (263, 0.027 mg g^{-1}).

In Moniya, fertilizer application (60 kg N/ ha) significantly ($p \leq 0.05$) increased SMBC and SMBN (0.04 mg g^{-1} and 0.0043 mg g^{-1}) compared to the control (0.03 mg g^{-1} and 0.0037 mg g^{-1}). Similarly, residue incorporated plots had significantly ($p \leq 0.05$) higher SMBC and SMBN (0.043 mg g^{-1} and 0.005 mg g^{-1}) compared to the plots without residue incorporation (0.030 mg g^{-1} and 0.003 mg g^{-1}). Total VAM spore count and SMBP were not significantly affected by either of the treatments at this location. It is known that increased soil microbial biomass results from the quantity and type of residue applied. Moore et al. (2000), in their study found that higher SMBC and SMBN in crop rotation over continuous cropping resulted from type and quantity of crop residues added to the soil. It has also been reported that increase in microbial biomass in residue added plots gives premise to priming effect which is the increase in native soil organic matter as a result of added easily decomposable residue (Hamer et al. 2009)

3.4 Effect of interaction of cropping systems and residue management on soil microbial properties

There were no significant ($p \leq 0.05$) interactions between cropping system and fertilizer application. However, significant ($p \leq 0.05$) interactions existed between cropping system and residue management, and this depended on the location and microbial parameter being measured (Tables 4 and 5).

In Nsukka, the interaction between cropping system and residue management significantly ($p \leq 0.05$) affected total VAM spore count and SMBP (Table 4), with higher values observed in the residue-incorporated plots compared to plots without residue incorporation. The interaction between the continuous maize system and residue incorporation resulted in higher total VAM spore count compared to the interaction between the legume cropping systems and residue incorporation. However, the reverse was the case for SMBP.

In Moniya, the interaction between cropping system and residue incorporation significantly ($p \leq 0.05$) affected SMBC, SMBN and SMBP (Table 5). The interaction between velvet-bean/maize cropping system and residue incorporation resulted in the highest values for these parameters, followed by that between cowpea/maize and residue incorporation, before soybean/maize and residue incorporation. The interaction effect with the least values of these parameters was that for continuous maize without residue incorporation (NR). Cropping systems involving legume rotation combined with residue incorporation resulted in higher microbial

Table 4: Interaction effect of cropping systems and residue application on soil C and microbiological properties in UNN

Cropping system X Residue	OC (%)	Total VAM	MBC (mg/g)	MBN (mg/g)	MBP (mg/g)
Ve/Ma X R	0.98	284	0.07	0.004	0.0005
Cp/Ma X R	0.95	279	0.05	0.003	0.0007
Sb/Ma X R	0.93	260	0.05	0.003	0.0005
Ma/Ma X R	0.91	291	0.04	0.003	0.0004
Ve/Ma X NR	0.92	253	0.03	0.003	0.0009
Cp/Ma X NR	0.98	275	0.04	0.004	0.0006
Sb/Ma X NR	0.95	258	0.02	0.003	0.0003
Ma/Ma X NR	0.90	269	0.02	0.003	0.0004
LSD (0.05)	ns	10**	ns	ns	0.0002**

Note, Ve = velvet-bean, CP= cowpea, SB = soybean Ma = maize

* = significant at 5%, **= highly significant at 1%, ns = not significant

Table 5: Interaction of cropping systems and residue application on soil C and microbiological properties in Moniya

Cropping system X Residue	OC (%)	Total VAM	MBC (%)	MBN (%)	MBP (mg/g)
Ve/Ma X R	1.54	209	0.064	0.008	0.0008
Cp/Ma X R	1.43	219	0.041	0.005	0.0005
Sb/Ma X R	1.46	217	0.038	0.004	0.0003
Ma/Ma X R	1.55	202	0.027	0.003	0.0003
Ve/MA X NR	1.42	207	0.041	0.004	0.0006
Cp/Ma X NR	1.44	205	0.031	0.005	0.0006
Sb/Ma X NR	1.57	217	0.026	0.003	0.0003
Ma/Ma X NR	1.48	211	0.023	0.002	0.0002
Lsd (0.05)	ns	ns	0.007**	0.001**	0.0003**

Note Ve = velvet-bean, CP- cowpea, SB- soybean MA- maize *significant ** highly significant, ns not significant

This resulted from higher input and diversity of residue (Biederbeck et al. 1984; Robinson et al. 1996).

Cropping systems involving legume rotation combined with residue incorporation resulted in higher microbial properties, which attests to the beneficial effect of crop rotation. This resulted from higher input and diversity of residue (Biederbeck et al. 1984; Robinson et al. 1996).

4.0 Conclusion

Based on the findings of this research, there was improvement of the soil microbial properties by legume/cereal rotation cropping systems. The soil properties affected by the legume/cereal rotation cropping system in Nsukka were SMBP and total VAM spore count, while SMBC, SMBN and SMBP were significantly affected in Moniya. Most of these properties were higher in legume/cereal plots than in continuous maize plots, with the cropping system involving the herbaceous legume (velvet-bean/ maize) having the highest values of these parameters. Soil OC was not significantly affected by cropping systems, fertilizer application and residue management. There were significant interaction effects between the cropping system and residue management, with residue incorporation showing better results compared to the absence of residue incorporation Soil microbial attributes were better able to determine effect of crop and soil management factors on soil quality than the soil organic C.

Recommendation

Grain legumes should be planted with the first rain before the rains become constant. This is because high rainfall amounts adversely affected grain legumes with low biomass production. Therefore, with increased biomass production, grain legumes could be utilized efficiently in rotation cropping to improve soil quality like herbaceous legumes (e.g. velvet bean).

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