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ORIGINAL ARTICLE

Multivariate analysis of soil productivity indicators in the northern guinea savana agro-ecology of Nigeria

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A trial was conducted at the Research Farm of the Institute for Agricultural Research, Ahmadu Bello University (IAR/ABU), Samaru, Zaria during the year 2011 and 2012 cropping seasons to determine the productivity of the Alfisol using multivariate data analysis. The result indicated that the factor loadings of the soil properties for the PCA analysis showed their contribution to soil productivity, which was explained by 55.38% of the proportion in PCI being higher than other PCs. Among the soil properties evaluated, ECEC, CEC, Ca, Mg, OC, TN, pH (chemical properties), bulk density and porosity (physical properties) dominated in PC1, which cumulatively contributed 55.38% of the total variation in soil productivity. However, negative loading was only observed in bulk density and soil pH. Generally, the factor loading of the soil properties indicated that individual contribution to soil productivity was in the order of: ECEC>CEC>Ca>OC>TN>pH>Porosity>BD>Mg>P in PC1 which was contrary under PC2 in terms of P. The results of stepwise multiple regression revealed that in step 1; N uptake (x_3) was retained with R^2=0.92, while other 5 variables were removed. A similar trend was observed in step 2 (x_3 and x_5; R^2=0.97) and 3 (x_2, x_3 and x_5; R^2=0.97). But in step 4, four independent variables were retained (stover dry matter x_1, harvest index x_2, N uptake x_3 and N utilization efficiency x_5) with R^2=0.98, which justified the maximum maize grain yield changes. This implies that integration of inoculated soybean in maize-based cropping systems in combination with minimum disturbance of the soil would enhance soil productivity.

Keywords: Multivariate Aanalysis, Soil properties, Productivity indicators, Savana agro-ecology.

Introduction

Soil is an important natural resource for sustainable development of any nation. The quality of soil for agricultural production depends on its sustainable supply of plant nutrients. Crops and soil are interconnected; subsequently exert mutual effects on one another for effectiveness of its productivity. This is because soil gives support in terms of moisture, nutrient and anchorage to crop to grow effectively on the one hand, and on the other, crop provides protective cover for soil, suppresses soil erosion as well as helps to maintain soil nutrient through litter accumulation and subsequent decay (Eni*et* al., 2011; Omeke, 2016). Litter decomposition influences the nutrient dynamics and serves as one of the inputs of nutrients in the planted forests (Bargali et al., 1993a, Bargali, 1996) and in agroecosystems (Pant et al., 2017; Vibhuti et al., 2020). Both the leaf quantity and the nutrient release pattern determine nutrient budget and their impact on the ecosystems (Bargali et al., 1993b and 2015; Gonzalez- Quinones et al., 2011). The physico-chemical properties of soil in any ecosystem depend upon the topography, vegetation pattern, microclimate, weathering processes of rocks, decomposition of litter etc which later on affects the production capacity (Bargali et al., 2018; Manral et al., 2020; Awasthi et al., 2022). Both soil and plant are multivariate in nature, as such, the relationships of soil and plant components can be analysed by multivariate statistical methods (Iwara et al., 2011). This reciprocal relationship between soil and crop demands a multivariate approaches in order to determine critical management practices and soil properties that would sustain this integrative association. On this premise, multivariate analytical techniques (principal component analysis, canonical correlation analysis, factor analysis, and canonical correspondence analysis among others) are very useful in the analysis of soil and vegetation as each consists of data corresponding to a large number of variables. Thus, analysis *via* these techniques produces easily interpretable results (Iwara et al., 2011).

Intensive cultivation causes important changes in soil physico-chemical and biological characteristics, and can rapidly diminish soil productivity (Vibhuti et al., 2018; Padalia et al., 2018; Bargali et al., 2019). This follows Amana et al., (2012) who reported that ecologically sensitive components of tropical soils are not able to buffer effect of intensive agricultural practices. Thus, severe deterioration of soil properties may lead to degradation of land productivity. However, initially cultivated soil remain productive for some periods but yields tend to decline in later years, especially continuous cropping with little or no replenished of lost soil nutrients. Also, since crop growth and productivity are a reflection of soil properties, any degradation of the soil can be expected to adversely affect the stability of soil system in the tropics (Ezeaku, 2013). The spatial distribution of any soil has a marked influence on its agricultural productivity (Obasi et al., 2011), while the extent and impact of soil degradation can also lead to the reduction of biological and economic productivity potentials of rain-fed or irrigated croplands, pasture and forested land, including social and political instability (Adaikwu et al., 2012; Ezeaku and Iwuanyanwu, 2013).

However, studies on the application of multivariate statistics in understanding the soil properties supporting crop productivity have not been properly documented in the northern guinea savanna agro-ecology, Nigeria. But several studied have been conducted on soil-vegetation interrelationships. Ukpong (1994) and Alakpodia (1992) studied soil-vegetation interrelationships in mangrove swamps and riparian micro habitant of River Ethiope Basin of southern Nigeria. While Iwara et al., (2011) studied soil-vegetation interrelationships in the South-Southern secondary forest of Nigeria. These studies identified varying soil proprieties like organic matter, clay, silt and salinity to influence the distribution or zonation of vegetation; as well tree size, vegetation cover, tree density, tree height and proportion of mesophanerophytes as vegetation components that influenced soil nutrient. However, the complex interrelationship between soil and arable crop productivity in the Northern region of Nigeria has not been fully documented in the literature. It is on this premise that this study was conducted to assess soil properties on maize production under integrated management practices in the Northern Guinea Savanna agro-ecological of Nigeria; using multivariate statistical techniques notably principal component analysis (PCA), canonical correlation analysis (CCA), multiple regression analyses (MRA) and Simple coefficient of correlation (r) analysis. The study would identify the soil properties and maize variables that mostly promote, sustain and influence the soil productivity.

Materials and Methods

Experimental site

The study was conducted at the Research Farm of the Institute for Agricultural Research, Ahmadu Bello University (IAR/ABU), Samaru, Zaria during the 2011 and 2012 cropping seasons. The research field was located at longitudes 11°11'N and latitudes 007°37'E. Samaru is about 686 m above sea level and is located in the Northern Guinea savanna of Nigeria, having a total rainfall of 1207 mm (2011) and 1333 mm in 2012, distributed between April and October with a mono-modal rainfall pattern. The rainfall and temperature data obtained for both seasons fell within the long-term range temperature of 21.05°C (minimum) and 33.47°C (maximum) and annual rainfall of 1011 ± 161 mm concentrated almost entirely in the five months (May/June-September/October) of the cropping season (Oluwasemire and Alabi, 2004). The main soil sub-group is TypicHaplustalf (Awujoola, 1979) or Chromiccambisols according to the FAO system of soil classification (FAO, 2001). The study area was dominated by fire-tended and fire-tolerant trees with an understory of shrubs and grasses.

Soil sampling

At the end of the field experiment in 2012, four disturbed surface soil samples (0-15 cm depth) were taken at alternate points from four inner ridges per plot using a soil auger. The samples were bulked to form a composite sample per plot. The sub-samples taken were split into two, bagged and properly labelled. A part was air-dried, crushed lightly and sieved through the 2 mm and 0.5 mm sieves in readiness for chemical and physical analysis. The other part was stored in the refrigerator and used for microbial carbon and nitrogen analysis. Undisturbed soil samples were taken from the net plot, comprising two inner rows per plot using core sampler; these were used to determine the bulk density and total porosity.

Treatments and experimental design

The experiment was a split-split plot arrangement in a randomized complete block design with three replicates in both 2011 and 2012 cropping seasons. The 2011 field experiments was established mainly to create enabling soil environment to carry out effect of the following cropping systems; inoculated rotation, uninoculated rotation, inoculated intercrop and uninoculated intercrop in 2012 field experiments. It is for this reason that no soil and plant samples were collected 2011 field experiments. The treatments were two tillage practice as main plots (reduced and conventional tillage), four cropping systems as sub-plots (inoculated soybean-maize intercrop, uninoculated soybean-maize intercrop, inoculated soybean-maize rotation and uninoculated soybean-maize rotation) and four nitrogen fertilizer rates as sub-sub plots (0, 40, 80 and 120 kg N ha^{-1}). The conventional tillage (CT) was manual ridging at 0.75 m apart using hoe and was remoulded at 8 weeks after sowing. For reduced tillage (RT) treatment seeds were sown directly without ridging at 0.75 m interval between the ridges after the field was demarcated into plots. Each plot measured 6 m by 5 m (eight ridges; 5 m long) and a total of 96 plots were used for the research. The intercropping system was maize/soybean intercrop in the order of 2 rows maize to 2 rows soybean (2:2); this was maintained for both seasons. The crop rotation system was soybean–maize rotation, with soybean planted in 2011 (1:0), followed by maize in 2012 (0:1). Soybean (TG x 1448-2E) and maize (SAMMAZ 14) were used as test crops.

Soybean seed inoculation and planting

The soybean seeds were surface sterilized, as outlined by Vicent (1970) and inoculated with commercial rhizobium inoculants, Legume-fixed, as directed by the producer at 400 g ha^{-1}. Both maize and soybean seeds were sown on 1st July 2011 and 5th July 2012. The maize seeds were sown manually, two seeds per hole at an intra-row spacing of 25 cm. The seedlings were thinned to one plant per stand at two weeks after sowing to give a plant population of approximately 53,333 plants ha^{-1}. Soybean seeds were drilled on the lines or ridges and covered lightly with soil. The uninoculated soybean rows were sown first in order to avoid cross contamination. The seedlings were thinned to one plant per hill at a spacing of 5cm to achieve a population of approximately 266,667 plants ha^{-1}.

Weed control

Weeds were controlled by the application of glyphosate at two weeks before land preparation. Subsequently, manual weeding, which involved the use of hoe, was twice employed in all the 96 plots (at 4 WAS and 6 WAS) before harvesting. However, weeding was cautiously done to avoid a transfer of rhizobium inoculant from inoculated plots to uninoculated plots by spraying the hoe with 70% alcohol after weeding each plot.

Fertilizer application

Phosphorus (single super phosphate; SSP) and potassium (Muriate of potash; MOP) fertilizers were applied to all the plots planted with maize at the rate of 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}, whereas those of soybean received 40 kg P_2O_5 ha^{-1} and 20 kg K_2O ha^{-1} at planting in both seasons, respectively. The sub plots were divided into four; only maize plots in both cropping seasons received urea fertilizer application at the rates of 0 kg N/ha, 40 kg N/ha, 80 kg N/ha and 120 kg N/ha. Nitrogen fertilizer rate was applied in two splits; first application was done at four weeks after sowing, while the remaining part was done as second application at eight weeks after sowing in the ratio of 1:2.

Plant sampling

Maize plants within the net plot were cut at ground level, at crop physiological maturity (when 95% of plant was brown), partition into ear and stover. The maize ear harvested was sun-dried, threshed, cleaned, weighed and the grains expressed on per hectare basis. The maize stover was recorded after sun-drying of the stalks harvested from net plot area and expressed on per hectare basis. The maize ear and stover harvested were sun-dried and subsamples were taken in readiness to laboratory analysis for nitrogen.

Laboratory analysis

Soil microbial biomass C and N

The soil microbial biomass C and N were estimated by the fumigation-extraction method (Brookes et al., 1985; Sparling and West, 1988), using freshly sampled moist 2 mm sieved soil sample and the results were corrected to dry weight basis. The extractable C and N in both fumigated and unfumigated samples were determined. Microbial biomass C was estimated by multiplying the difference in extractable C of fumigated and unfumigated samples, using a conversion factor of 2.64 (Vance et al., 1987). Microbial biomass N was calculated by multiplying the difference in extractable N of fumigated and unfumigated sample using a conversion factor of 1.46 (Brookes et al., 1985).

Particle size distribution

Particle size distribution was determined by the hydrometer method, as described by Gee and Bauder (1986), using sodium hexametaphosphate as a dispersing agent. The textural classes were obtained from the USDA textural triangle.

Bulk density

Bulk density was measured using core method (Grossman and Reinsch, 2002). The moist core soil sample was oven-dried at 105°C, until a constant dried weight was obtained.

Bulk density (BD Mg m^{-3})=Oven dry soil sample/Volume of core cylinder ……….(3.1)

Porosity (P)

Soil porosity was calculated using a mathematical relationship between bulk density and particle density (Foth, 1984).

Porosity (P) was computed as follows:

P (%)=1-(BD/PD x 100) ………(3.2)

Where, P=Porosity (%), BD=Bulk density (Mg/m^3), PD=Particle density (2.65 Mg/m^3).

Soil pH

Soil pH was determined electrometrically in distilled water and 0.01 M calcium chloride solution. A soil-solution ratio of 1:2.5 was used and read on pH meter (Hendershot et al., 1993).

Total nitrogen organic carbon, carbon/nitrogen ratio and available phosphorus

The soil nitrogen and total nitrogen in the maize grain and stover were determined by micro-Kjeldahl digestion method, as described by Bremner and Mulvaney (1982). Soil organic carbon was measured using the method described by Nelson and Sommers (1982) and carbon/nitrogen ratio was computed by dividing percent soil organic carbon by percent total nitrogen. Available phosphorus in soil was estimated using Bray 1 method (Olsen and Sommers, 1982).

Exchangeable bases and exchangeable acidity

Exchangeable bases (Ca, Mg, K and Na) were extracted with one normal (1N) ammonium acetate buffered at pH 7.0 (Chapman, 1965). Exchangeable Ca and Mg were determined using Atomic Absorption Spectrophotometer (AAS), while exchangeable K and Na were estimated using Flame Photometry (FP) (Jackson, 1958). Exchangeable acidity was determined by extraction and titration method, using 1N potassium chloride with 0.1N sodium hydroxide (McLean, 1982). The Effective Cation Exchange Capacity (ECEC) was estimated using a summation of exchangeable acidity and exchangeable bases.

Micronutrients

Extractable micronutrients zinc (Zn), iron (Fe), manganase (Mn), and copper (Cu) were extracted with 0.1M HCl (Bruce and Whiteside 1984) and determined using Atomic Absorption Spectrophotometer (AAS).

Data computation and statistical analysis

Nitrogen efficiency indices in maize

The terminology of N efficiency parameters were computed using the equation as given by Delogu et al., (1998) and Lopez-Bellido and Lopez-Bellido (2001):

Nitrogen uptake efficiency (NUpE, kg kg^{-1})=Nt/N supply ………(3.3)

Where, Nt=total plant N uptake.

Nt was determined by multiplying dry weight of plant parts by their N concentration and summing total plant uptake. N supply was defined as the sum of N applied as fertilizer and total N uptake in control (0 N applied).

Nitrogen utilization efficiency (NUtE, kg kg^{-1})=Gy/Nt ………(3.4)

Where, Gy=grain yield in kg ha^{-1}

Nitrogen use efficiency (NUE, kg kg^{-1})=Gy/N supply ………(3.5)

Harvest index (HI)

HI=Gy/By ………(3.6)

Where, HI=Harvest index, Gy=Grain yield ($kgha^{-1}$), By=Total biomass yield ($kgha^{-1}$) at harvest.

By=Gy+Hy ………(3.7)

Where, By=Total biomass yield ($kgha^{-1}$) at harvest, Gy=Grain yield ($kgha^{-1}$), Hy=Stover yield ($kgha^{-1}$).

Nitrogen recovery fraction (NRF)

The recovery percentages fraction of applied N by maize plant at harvest was calculated using the following relationship:

Nitrogen recovery fraction (NRF%)=(N_x-N_0)/Applied N rate x 100

Where, N_x=N uptake at plots with nitrogen fertilizer.

N_0=N uptake at plots without nitrogen fertilizer (control).

Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) using the mixed linear model MIXED Procedure of SAS, Institute Inc., (2009). Duncan's multiple range test procedures was used when the F-cal of the ANOVA for each variable was found to be significant and their interactions were compared by computing least square means and standard errors of difference (SED) at 5% level of probability. Simple coefficient of correlation (r) analysis between microbial biomass and some soil properties were also performed. Stepwise regression analysis was used to determine the significance of the independent variables on the dependent variable (maize grain yield). Moreover, principal component analysis (PCA) was performed on soil properties to evaluate their respective contribution to soil productivity.

Results

Principal component analysis of the soil properties of the study site

The data obtained for principal component analysis (PCA) of the soil properties; sand, silt, clay, BD, porosity, OC, TN, Avail. P, pH, Ca, Mg, K, Na, CEC, ECEC, Cu, Fe, Mn and Zn) as influenced by tillage, Bradyrhizobium inoculation in soybean-maize cropping system and N fertilizer application rates are presented in Table 1; not shown in this article. The result indicated that only principal components with Eigen values greater than one (>1) explained at least 5% of the total variance, which accounted for nine PCs being retained. The factor loadings of the soil properties for the PCA analysis showed their contribution to soil productivity, which was explained by 55.38% of the proportion in PCI being higher than other PCs. Among the soil properties evaluated, ECEC, CEC, Ca, Mg, OC, TN, pH (chemical properties), bulk density and porosity (physical properties) dominated in PC1, which cumulatively contributed 55.38% of the total variation in soil productivity. However, negative loading was only observed in bulk density and soil pH. Also, PC2 was dominated by negative bulk density and positive porosity, which explained 12% of the total variance; but Mn dominated in PC9 with negative loading and contributed 5% of the total variance in soil productivity. Generally, the factor loading of the soil properties indicated that individual contribution to soil productivity was in the order of: ECEC>CEC>Ca>OC>TN>pH>Porosity>BD> Mg> P in PC1 which was contrary under PC2 in terms of P.

Table 1. Principal component analysis of soil properties of the study site.

Measurements	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**PC8**	**PC9**
Eigen values	3.54	2.80	2.37	2.22	1.81	1.51	1.36	1.13	1.06
% Contribution	55.38	12.16	10.29	9.67	7.86	6.55	5.91	4.92	4.62
% Cumulative	55.38	57.54	59.83	61.50	65.36	68.90	77.82	82.74	97.35
Soil properties	Rotated scores of ten retained Eigen vectors								
Sand	-0.06	0.15	-0.08	-0.56	-0.24	-0.20	-0.01	0.13	-0.09
Silt	-0.04	-0.13	-0.03	0.52	0.03	0.30	0.03	-0.03	0.06
Clay	0.25	-0.08	0.25	0.25	-0.02	-0.20	0.13	-0.33	0.05
Bulk density	-0.57	-0.46	0.25	-0.22	0.07	0.06	-0.13	0.04	0.19
Porosity	0.57	0.46	-0.25	0.22	-0.07	-0.06	0.01	-0.04	-0.19
Organic carbon	0.67	0.58	-0.07	-0.10	-0.05	0.49	0.12	0.45	0.02
Total nitrogen	0.65	-0.48	-0.01	-0.04	-0.04	0.27	0.21	-0.23	0.20
Phosphorus	0.35	0.68	-0.16	0.09	0.02	-0.11	0.54	0.32	0.12
pH	-0.53	-0.14	-0.12	0.13	0.02	0.09	-0.08	0.26	0.31
Calcium	0.77	-0.22	0.19	-0.03	-0.01	-0.1	0.08	0.14	0.17
Magnesium	0.47	-0.12	0.13	0.12	-0.06	0.06	-0.06	0.13	-0.62
Potassium	0.61	0.32	-0.06	0.03	0.25	0.15	0.15	0.21	0.11
Sodium	-0.06	.09	0.02	-0.10	0.30	0.20	0.44	-0.06	-0.15
EA	0.16	0.27	-0.06	-0.11	0.23	-0.05	-0.26	-0.31	0.34
CEC	0.87	-0.59	-0.13	-0.01	0.04	-0.02	0.09	0.20	-0.09
ECEC	0.91	-0.64	-0.16	-0.06	0.15	-0.04	-0.05	0.02	0.09
Copper(Cu)	0.07	0.16	0.19	0.03	-0.40	0.39	0.01	-0.09	0.20
Iron(Fe)	0.16	0.21	0.27	0.07	-0.32	0.22	-0.1	-0.01	-0.72
Manganese(Mn)	0.14	0.07	0.20	0.20	-0.4	-0.18	0.07	0.12	0.34
Zinc (Zn)	-0.07	-0.02	0.04	0.24	-0.12	-0.34	0.43	0.36	0.10

Note: Values in bold (>0.30) represents chosen soil properties that explain variation within the soil properties.

Stepwise multiple regression analysis of grain yield and yield components and N efficiencies

The results of stepwise multiple regression of grain yield (dependent variable) against six independent variables (stover dry matter yield (stover; x_1), harvest index (HI; x_2), nitrogen uptake (NUpt; x_3), nitrogen uptake efficiency (NUptE; x_4), nitrogen utilization efficiency (NUtE; x_5), and nitrogen use efficiency (NUE; x_6) are presented in Table 2. The results indicated that at every step, any independent variable that did not significantly contribute to grain yield was removed from the model; this implied that those with low R-square values were removed, those with high R-square values were retained. In step 1, N uptake (x_3) was retained with R^2=0.92, while other 5 variables were removed. A similar trend was found in step 2 (x_3 and x_5; R^2=0.97) and 3 (x_2, $x_3$and x_5;

R^2=0.97). But in step 4, four independent variables were retained (stover dry matter x_1, harvest index x_2, N uptake x_3 and N utilization efficiency x_5) with R^2=0.98, which justified the maximum maize grain yield changes. The other two independent variables removed from the equation (N uptake utilization efficiency; x_4 and N use efficiency; x_6) made no significant contribution, irrespective of management practices. Thus, the following prediction equations were obtained in stepwise regression analysis;

Step 1: Grain yield (Y)=78.69+20.58X_3

Step 2: Grain yield (Y)=-1054.74+21.26X_{3+}49.42 X_5

Step 3: Grain yield (Y)=-761.50+616.19X_{2+}17.80X_{3+}30.05 X_5

Step 4: Grain yield (Y)=1317.10+0.36X_{1+}1444.43 X_{2+}8.78X_{3+}22.22X_5

Table 2. Stepwise multiple regression for grain yield (dependent variable) and other traits (independent variables).

Independent Variables	Step 1	Step 2	Step 3	Step 4
Intercept 78.69	-1054.74		-761.50	-1317.10
Stover dry matter (X_1)				0.36
Harvest index (X_2)			616.19	1444.43
N uptake (X_3)	20.58	21.26	17.80	8.78
Nuptake efficiency (X_4)				
N utilization efficiency (X_5)		49.42	30.05	22.22
N use efficiency (X_6)				
R-Square (R^2)	0.9128	0.9681	0.9742	0.9874

Simple correlation coefficient (r) analysis among selected soil properties under green house and field experiments

The results of correlation analysis obtained among the selected soil properties evaluated under greenhouse and field experiments are presented in Table 3. The correlation coefficient (r) found between the selected soils properties were higher in field experiment than greenhouse experiment. Organic carbon was significantly ($P<0.05$) and positively related to TN (r=0.45), C:N (r=0.04), MBC (r=0.20) and MBN (r=0.26), and negatively correlated with SMBC:SMBN (r=-0.32). The result obtained for TN had significant ($P<0.05$) positive relationship with SMBC (r=0.24) and SMBN (r=0.35) and negatively related with C/N ratio(r=-0.47) and SMBC: SBMN (r=-0.21). The SMBC: SMBN ratio positively correlated with SMBC and SMBN, but negative with MBN (r=-0.61and r=-0.77. The same observation was found for SMBC and SMBN, with r=-0.71.

Table 3. Simple correlation coefficient (r) among selected soil properties.

	OC	TN	C:N	SMBC	SMBN
TN	0.45*				
C:N	0.01	-0.47*			
SMBC	0.20*	0.24*	-0.34*		
SMBN	0.26*	0.35*	-0.43*	-0.71*	
SMBC:SMBN	-0.32	-0.21*	0.14	0.64*	-0.77*

TN=Total nitrogen, OC=Organic carbon, C:N=Carbon nitrogen ratio, Av.P=Available phosphorus, K=Potassium, SMBC=Soil microbial biomass carbon, SMBN=Soil microbial biomass nitrogen, SMBC:SMBN=Soil microbial biomass carbon soil microbial biomass nitrogen ratio, *=Significant at P<0.05.

Discussion

Principal component analysis of the soil properties of the study site

The results obtained for principal components analysis of soil properties indicated that the BD, porosity, pH, TN, OC, CEC, ECEC and P were the soil properties that had higher contribution to the productivity of the soil. This captured about 55.38% of the soil variability suggesting that negative effect of these soil properties among other properties would cause drastic reduction in the fertility and productivity of the soil. The finding is consistent with Ogunwole, (2005) who reported that soil quality decreases with increasing bulk density and soil porosity. This also suggested that the higher presence of TN and OC across the PCs among all the soil properties is an indicative of soil productivity improvement due to presence of inoculated soybean in the cropping systems which possess lower C/N ratio than maize crop. Improvement in soil TN justified narrow C/N ratio which implies good decomposition of organic materials (Tarawali et al. 2001) and soil quality improvement (Ogunwole, 2005). This is because the inoculated soybean components in the soybean-maize-based cropping systems helped to increase the amount of nutrient in the soil through litter accumulation, decay of nodules and root biomass and the protection of the arable soil floor from nutrient destruction through the regulation of rainstorm and nutrient cycling. Chen et al. (2004) suggested that crops can alter soil properties through root-microbe interaction resulting in a distinct difference of the chemical composition of soil organic carbon in mixed cultivated area. Thus, the effect of cultivation on soil carbon content is crops species dependent (Smith et al., 2002). Studies from elsewhere by Dumig et al., (2006) showed that particle size distribution strongly affected bulk density because soil texture is often cited as a critical property affecting the response to mechanical soil disturbance (Baumler et al., 2005). Crop cultivation type has significantly affected the physico-chemical and biological properties of the soil. The results of the PCA supported the analyzed soil factors as predictors of quality of soil productivity.

Stepwise multiple regression analysis of maize grain and yield components and N efficiency indices

The results obtained from the stepwise regression indicated that among the six independent variables evaluated, four (stover yield, harvest index, N uptake, and N utilization efficiency) were retained with high R square value of 98.74% considering the four steps together. This implies that they can significantly influence maize grain yield. Whereas, the two (N uptake efficiency and N use efficiency) variables removed had low R square value, perhaps not significant. Existence of significant R square in a successful regression equation indicates the effectiveness of the variables to increase grain yield (Nasri et al., 2014) and importance of harvest index and biomass to grain yield. Therefore, with respect to the positive and significant regression coefficients of stover yield, harvest index, N uptake, and N utilization efficiency; these could be enhance through improvement of the soil productivity and fertility through meaningful agronomic practices like integration of inoculated soybean in the cropping systems and adoption of reduced tillage. This can be supported by employing split application and band placement for N fertilizer management.

Simple correlation coefficient (r) analysis among selected soil properties under field experiments

The soil microbial biomass N and C significantly correlate with OC and TN (positive) as well as, with C:N ratio (negative). The implication of positive correlation is that, as the soil properties (OC and TN) increases, the microbial biomass C and N in soil increases while the negative correlation suggests that as the soil properties (C:N ratio) decreases the microbial biomass in soil increases. This relationship suggests that activity of microbial biomass in soil is strongly influenced by levels of TN in soil due to crops competition with microbes for N. Generally, the nature of correlation relationship found in this study might be due to improvement of soil properties especially TN and OC of the soil by integration of inoculated soybean in the cropping systems in combination of reduced tillage and N fertilizer application. Similar correlation relationship of SMB C and N with soil properties was earlier reported by Moore et al., (2000); Bala et al., (2010) and pH and clay with heavy metal by Orhue et al., (2011). Many factors have been suggested to explain the effects of agronomic activities on microbial biomass in soils (Hackl et al., 2004). Differences in the quantity and quality of substrate inputs *via* varying litter and root types and associated nutrient specificity can be crucial drivers to influence the soil microbial biomass (Feng et al., 2009; Jin et al., 2010). Chen et al., (2006) reported that soil microbial biomass greatly depends on soil organic matter as a substrate; a decrease in soil organic carbon causes reduction in soil microbial biomass. Thus, the higher C mic in the mixed cropping systems stands was mainly attributed to the greater availability of organic matter as evident from the significant positive correlation between soil microbial biomass carbon and soil organic matter. These findings were consistent with those reported by Jia et al., (2005) and Wang and Wang (2011) who also reported strong correlation. This justify that the quantity and composition of microbial biomass carbon is sensitive to changes in the soil physical and chemical properties that contributes to soil productivity. Among these properties bulk density, soil moisture and porosity reflects the physical characteristics which can characterize the activity of soil microbial biomass carbon and soil organic carbon.

Conclusion

Soil microbial biomass N and C significantly correlated with OC and TN (positive) as well as C:N ratio (negative). Results of the stepwise regression indicated that, among the six independent variables evaluated, four (stover dry matter, harvest index, N uptake, and N utilization efficiency) were retained with high R square value (98.74%). The results obtained for principal components analysis of soil properties indicated that BD, porosity, pH, TN, OC, CEC, ECEC and P had the highest contribution to soil productivity among other soil properties considered in this study. Therefore, integration of inoculated soybean in maize cropping system would enhance these productivity soil indicators especially under minimum soil disturbance.

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