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Yield parameter response of maize (*Oba Super 2*) to earthworm cast and anthill soil under greenhouse condition

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The study of earthworm cast and anthill as plant-soil systems and the surrounding soil is helpful in the appraisal of soil and crop productivity. Therefore, this study was carried out in a tropical and subtropical area to determine the effect of plant-soil systems and the surrounding soil on the yield parameters (plant height, leave surface and dry matter weight) of maize (*Oba Super 2*) under greenhouse condition. Analyses of soil samples of earthworm cast, anthill (termite mound) collected by hand sampling and the surrounding soil collected with core samplers at 10 cm depth and auger samplers at 2 depths (surface, 0 to 15 cm; subsurface, 15 to 30 cm) were examined for chemical and physical properties. Three kilograms each of the soils from three locations (Nsukka, Ede Oballa and Orba) was used for testing maize. Earthworm species (*Eudrilus eugeriae* and *Agrotoreutus nyongii*) and termite species (*Macrotermes* and *Odontotermes* species) that produced the mounds and termite mounds were identified, respectively. The study results found that soil physical and chemical properties were significantly (P<0.05) affected by the plant-soil systems relative to control. Interaction of the plant-soil systems by location and by soil depth was significant (P<0.05) for the measured soil parameters such as soil pH, organic carbon, nitrogen, exchangeable cations (Ca^{+2}, Mg^{+2}, K^{+} except Na^{+}), CEC and available P. Plant height, leaf surface and dry matter yield of maize were found significantly positively (P<0.05) increased. For better and sustainable improvement of soil productivity and yield of maize crop, combined use of earthworm cast and termite mound as plant-soil systems is recommended.

Key words: Maize performance, mounds, termite, cast, earthworm, greenhouse, Nigeria.

INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal crop in the world after wheat and rice with respect to area coverage and productivity (Unagwu et al., 2012). Generally, maize has been in the diet of Nigerians for centuries. In the tropical and subtropical areas, its production derives mainly from three factors: firstly,

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maize can easily be prepared into a variety of meals and this accounts for about 65% of the total daily caloric intake of rural people; secondly, the rising income realizable from the production of maize, and thirdly, that maize not only thrives in intercropping and relay cropping of farmers' cropping system but has quicker biomass recovery with a low economy of production (Ezeaku et al., 2002). In addition, maize provides good sources of raw materials for industries. However, uncertainties and risks associated with agricultural production such as scarcity of inputs, poor morpho-agronomic characteristics of varieties grown, inadequate agro-techniques, high production costs and poor mineral nutrition pose serious problem in meeting maize output levels in tropical and subtropical areas (Ezeaku et al., 2002). It is reported that the high production potential of maize largely depends on availability of essential nutrient elements particularly that of nitrogen, phosphorus and potassium, its nutrient requirement and management (Kang, 1978).

Report had shown that low soil fertility associated mainly with soil acidity is the most important cause of low yield for many crops (Lucia et al., 2010). Hoekenga and Pineros (2004) have reported that about 30% of the world's soils are acidic, and 60% of them are in tropical and subtropical areas associated with long periods of hot and moist weather. Increasing problem of acidification is due to acid rain, removal of natural plant coverage from large production areas and the use of ammonium-based fertilizers (Johnson et al., 1997). Sommers and Lindsa (1979) noted that soil acidity threat to crop production is common in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil.

Adequate nutrient, especially N, P and K, supply is essential for optimum production of maize. Most farmers in rural Nigeria hardly afford the use of chemical fertilizers due to scarcity at time of need and high cost when available. Of concern is the acidifying effect of nitrogen component of chemical fertilizer when used without liming. This necessitates research on organic wastes that are cheap, readily available and environmentally friendly, which can be used as fertilizer. Current trend in agriculture supposed to tend towards making the best use of the resources locally available to raise soil fertility and increase food production. Termite mounds and earthworm cast would properly fit into this category.

Cast of earthworm is a digested material that is excreted back into the soil by different species of earthworm. Termite mound is a mixture of soil, organic debris or living plant tissues collected, often over extensive foraging areas, transported to their domain and subjected to intense degradation when it is digested by the termites (Ekundaye and Orhue, 2011). Orhue et al. (2007) noted that plant nutrients and organic material are withheld from circulation in the plant-soil system until they finally decay. Detailed studies of termite mound have been reported in Western (Kang, 1978; Lal, 1988) and the Niger Delta region of Nigeria (Ekundayo and Orhue, 2011). Study on wormcast in relation to soil fertility is limited in eastern region of Nigeria (Mba, 1978). However, study on the effects of combined use of wormcast and termite mound on soil and crop productivity in tropical and subtropical area is lacking.

Reports have shown the benefits of using earthworm cast and termite mound as soil plant-soil system amendments. These include: contribution of nutrients to improve soil fertility and crop productivity (Debruyn and Conacher, 1997); improvement of soil porosity, soil nutrient availability and uptake by plants, minimizing production costs and maximizing yield and profit (Aziz et al., 2010). Increased levels of organic carbon, nitrogen and the formation of water-stable aggregates had been reported (Lal, 1988). Studies have shown significant higher amount of exchangeable cations, micronutrients, organic matter and pH in termite mound soils (Ariha, 1979; Frageria and Baligar, 2004; Ekundayo and Orhue, 2011). Semhi et al. (2008) identified termites as common biological agents that produce significant physical and chemical modifications to tropical and subtropical soils. It is also reported that termite activity increases the content of organic matter in the soils they use for the construction of their nest and also modifies the clay mineral composition of these minerals (Jouquet et al., 2002).

Despite the benefits derivable from the use of plant-soil systems in tropical and subtropical areas, they have their limitations to use by farmers. It is reported that the problem associated with the use of earthworm casts and termite mounds is how to get the huge quantities required to satisfy the nutritional needs of crops. The transportation and handling costs are often beyond the farmer's economy (Lal, 1988). Report by Lee and Wood (1971) showed that the rates of production of the resources materials (earthworm casts and termite mounds) are too small to be used for yearly seasonal crop production and by large commercial farmers.

In spite of the limitations, the long-term benefits in terms of improving soil fertility and enhancing food production cannot be over-emphasized (Fragoso and Lavelle, 1992; Kang, 1978). Studies ascertaining the yield of maize affected by combined use of earthworm cast and termite mound as plant-soil systems are scanty in Nsukka, eastern region of Nigeria. The study aims to provide information on the effects of earthworm cast and termite mound (plant-soil systems) properties on the growth parameters (plant height and leaf surface) and dry matter weight of maize (*Oba Supper 2*).

MATERIALS AND METHODS

Description of study area

The study was conducted in the green house of the University of Nigeria, Nsukka using earthworm cast and termite mound soils collected from three locations: Nsukka, Ede Oballa and Orba. Nsukka and Ede Oballa are situated in Nsukka Local Government

Area (LGA), while Orba is in Udenu LGA. Nsukka LGA lies by latitude 6°51'24" and longitude 7°23'45"E with land area of 45.38 km^2. Udenu LGA lies between coordinates 6°55'N and 7°31'E with a total land area of 897 km^2 (http://www.nipost.gov.ng/postcode.aspx).

Rainfall is bi-modal, the rainy (April - October) and the dry season (November - March). There is usually a short break in August. Average annual rainfall is about 1600 mm. Average minimum and maximum temperature is 22 and 30°C, respectively. The relative humidity is rarely below 60% (Unagwu et al., 2012).

The geomorphology of the study areas is of the highlands stretching through the undulating hills to plain lands. The vegetation belongs to the semitropical rainforest type and complemented by typical grassy vegetation (Ezeaku and Egbemba, 2014).

The soils are very deep, dark reddish brown at the top layer and reddish in the subsoil. They have coarse to medium texture, granular in structure at the top soil, acid in reaction and low in nutrient status. The top soil is characterized by rapid to very rapid permeability (Obi and Asiegbu, 1980). The predominant clay mineralogy is composed mainly of kaolinite and quartz (Akamigbo and Igwe, 1990). The soils are classified in the order of ferrallitic ultisol and entisol which belong to Nkpologwu and Uvuru series, respectively (Mbagwu, 1995; Nwadialo, 1989).

Field work

The study was conducted in 3 ha (300 x 100 m) blocks in each location (Nsuuka, Ede Oballa and Orba). Each block of 1 ha consisted of four land use types: Cassava/yam cultivated field, fallow land, oil palm land, and residential area with land area of 1250, 1250, 2500 and 5000 m^2, respectively. This delineation was done for the 3 ha blocks to avoid the overlap of land use systems.

Prior to sampling in each land use type, the location of earthworm casts and anthills (termite mounds) in each 1 ha block was determined by mapping on a 3 x 3 m grid. Earthworm casts and termite mound soils were collected through hand sampling in the grids replicated trice to cover the 3 ha blocks. Earthworm species predominantly identified were *Eudrilus eugeriae* and *Agrotoreutus nyongii* (Mba, 1978; Fragoso and Lavelle, 1992), while the genera *Macrotermes* and *Odontotermes* species were identified in the termite mounds (Arihad, 1979). The number of earthworm casts and termite mounds in each land use type was recorded. The population count was done within the grid size (3 x 3 m) for the 3 ha block. The collected earthworm casts and termite mounds were carefully put into plastic polyethylene bags, properly labelled and taken to the laboratory for air-drying.

Soil auger samples were randomly taken from the surrounding soils at the depth of 0 to 15 and 15 to 30 cm within an area measuring 50 × 50 m. The surrounding soil is at least 4 m from the grid perimeter. All the soil sampling was done within the field where the earthworm and termite mound sampling were carried out. The depths (0 to 15; 15 to 30 cm) represented the depth of tillage where most nutrients and organic matter are found and usually related to cereal crop yield (Ezeaku et al., 2002). Soil samples from the surrounding field were composited and bulked. Core ring (inner volume of 96.6 cm^3) samples were taken at soil depth of 0 to 10 cm. All soil samples were used for soil property determinations and maize planting in the green house.

Greenhouse studies

The air-dried earthworm casts from each of the location land use types were bulked to form a composite sample. Similar repeated measure was done for termite mound soils. The dried earthworm and termite mound soils were separately crushed to disintegrate the lump structures into smaller aggregate particles and thereafter variously combined to serve as treatments. Composite soil samples from the surrounding field served as control for standardization.

The experimental design was complete randomized design (CRD). The treatments were arranged in CRD and replicated three times. Treatment details were as follows:

T1. Nsukka earthworm cast; T2. Ede Oballa earthworm cast; T3. Orba earthworm cast; T4. Nsukka anthill (Termite mound); T5. Ede Oballa anthill (Termite mound); T6. Orba anthill (Termite mound); T7. Mixture of all earthworm casts; T8. Mixture of all termite mounds; T9. Control soil for Nsukka; T10. Control soil for Ede Oballa; T11. Control soil for Orba.

Phyto assessment

Three (3) kilogram of each site soil was measured into perforated plastic buckets measuring 3.299 cm^3 and allowed for 2 weeks period of incubation. Thereafter, soil in each bucket was turned and properly mixed and watered (200 ml) prior to maize sowing. *Oba Super 2* spp of improved maize seeds were sown into each bucket at the rate of three seeds to a depth of 3 cm, and thinned down to 2 seedlings per bucket after seedling had attained 2-leaf stage. Management that was employed included water application to the soil buckets at intervals and constant weeding during the experiment. Measurements were made on the growth parameters (height and leaf surface) at 2, 4 and 6 weeks after planting. Dry matter yield was determined at the end of the 6 weeks.

Laboratory analysis

Bulk density (Bd) and saturated hydraulic conductivity (Ksat) were determined using Grossman and Keinch (2002) method. The auger soil samples were air-dried in the laboratory ground and passed through a 2 mm sieve. Sieved samples < 2 mm soil fraction was bagged for routine analysis. The fraction of sand, silt and clay was determined using hydrometer method (Gee and Or, 2002) with NaOH as dispersant. Soil pH was determined by McLean (1982) method. Total nitrogen was determined using micro- Kjeldahl (Bremner and Mulvaney, 1982) method. Soil organic carbon was measured by combustion at 840°C (wet-oxidation method) (Wang and Anderson, 1998). Exchangeable bases, Ca^{2+} and Mg^{2+} were obtained by ammonium acetate (NH_4 OAC) method, and Na^+ and K^+ by flame photometer. Cation exchange capacity (CEC) was obtained using Blakemore et al. (1987) method. Exchangeable acidity was determined titrimetrically using 0.05 N NaOH. Available phosphorus was obtained using Bray 11 bicarbonate extraction method as described by Olsen and Sommers (1982).

Data analysis

Data on maize yield variables, soil physical and chemical properties were subjected to analysis of variance (ANOVA) using Genstat Discovery Edition 3, while significant variations in the means were determined using least significance difference ($LSD_{0.05}$) test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Distribution of earthworm casts and termite mounds

The population of wormcast and termite mounds (determined from population counts) in four land use

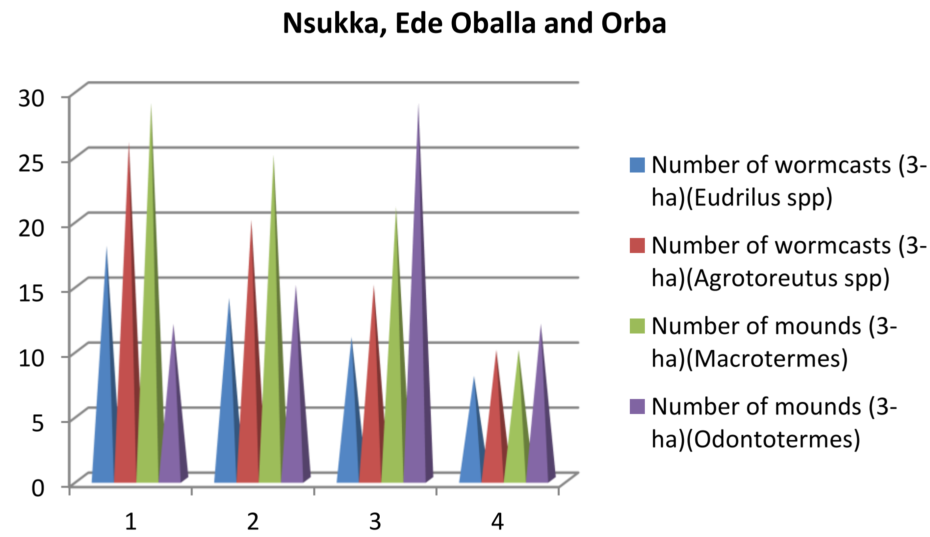

Figure 1. Number of wormcasts and termite mounds across the study location LUTs.

types (LUT 1= cassava/yam cultivated fields, LUT2 = fallow land, LUT 3 = oil palm land and LUT 4 = residential) across the three sites are presented in Figure 1. Generally, wormcast population was higher on fallow and oil palm lands than in other land use types across the locations. Figure 1 shows that total number of casts produced by *Agrotoreutus* spp. (244) was significantly higher ($p<0.05$) than that of *Eudrilus* spp. (194) by 34.7%. This suggests that the benefits derivable from the activities of *Agrotoreutus* spp. could be more useful in improving soil and crop productivity in tropical and subtropical area. This finding accords earlier report that had shown that the number of earthworms can indicate the extent of macropores (earthworm burrows) that are able to quickly drain surface water (Karlen et al., 1997). The report further indicated that earthworm number is 'Level 1' indicator of a soil's ability to accommodate water entry for prolonged periods during high intensity rainfall and frequent irrigation events.

In terms of termite mounds, results in Figure 1 show that the total numbers of *Macrotermes* spp. mounds in LUT 1 and LUT 2 across the study locations (total no. 216) were significantly higher ($p<0.05$) than that of *Odontotermes* (141) by 53.2%. However, total number of mounds produced by *Odontotermes* spp. under LUT 3 (Oil palm land) was higher ($p<0.05$) than in LUT 4.

Effects of worm cast, termite mound, location and soil depth on soil physicochemical properties

The percentage of finer particles in wormcasts and termite mounds could probably be the main effect on physico-chemical properties of soils. The statistical mean values of the physical and chemical properties of wormcasts and termite mounds are presented in Table 1. The textural analysis showed that significantly higher clay contents were obtained in the earthworm cast ($p<0.01$) and termite mound soils ($p<0.05$) than the surrounding soils. The higher clay fractions of wormcast and termite mound soils could be associated with the preferential incorporation of clay by the species of earthworms and termites identified. This confirms earlier report by Kang (1978) and Debruyn and Conacher (1987) who reported significantly higher clay content in termite mounds than the surrounding soil.

In contrast, higher silt content was recorded in the surrounding soil than in the plant-soil systems. This divergent result could be due to variation in site characteristics, soil types, land use and physiographic positions. The physiography of the 3 ha land in the study locations ranged from undulating hills to undulating plains.

The physical properties by location (Table 1) showed that clay, silt and sand fractions were variable but significant ($p<0.05$). Fraction of sand decreased with soil depth, while clay and silt contents increased with depth and could be attributed to illuviation/eluviation phenomena caused by percolating water through the soil column. This is synonymous with report of Obi and Asiegbu (1980). Variation of soil texture from sandy loam to sandy clay loam could be attributed to nature of parent materials and high rainfall that could favor washing away and leaching of silt-sized and clay-sized fractions (Mbagwu, 1995; Lal, 1988).

Soil bulk density (Bd) value recorded in Table 1 was significantly higher ($p<0.05$) in the surrounding soil (1.52 gcm^{-3}) as compared to the earthworm and termite mound soils. Soil Bd decreased by 13.2% in wormcast soil and 5.3% in termite mound soil relative to surrounding soil.

Table 1. Effects of earthworm cast, anthill, location and soil depth on the soil physicochemical properties.

Soil sample	Texture	Clay (%)	Silt (%)	Sand (%)	Tp (%)	Ks cms^{-1}	Bulk density (gcm^{-3})
Plant-soil system							
Earthworm cast	SL	19.5	7.6	72.9	42.6	2.66	1.52
Anthill	SL	22.0	7.5	70.5	45.7	2.82	1.44
Control	SCL	9.7	8.8	81.5	50.2	4.06	1.32
LSD (P<0.05)		13.20**	8.68*	4.64*	-	3.24*	o.14*
Location							
Nsukka	SL	16.0	8.0	76.0	44.2	2.50	1.48
Ede Oballa	SCL	22.0	7.5	70.5	47.5	4.26	1.39
Orba	SCL	21.0	8.0	71.0	46.0	2.43	1.43
LSD (P<0.05)		4.64*	10.6*	15.31*	-	2.80*	0.15*
Soil depth							
0-15 cm	SL	16.0	9.0	75.0	Nd	Nd	Nd
15-30 cm	SCL	20.0	11.0	69.0	Nd	Nd	Nd
LSD (P<0.05)		3.80*	1.38*	Ns	Nd	Nd	Nd

Ks, soil saturated hydraulic conductivity; Bd, soil bulk density; TP, total porosity; NS, not significant; Nd, not determined; SL, sandy loam; SCL, sandy clay loam; LSD (P<0.05), least significant difference at 5% level of probability, *p<0.05, **p<0.01.

Though value of Bd in the termite mound soil (1.44 gcm^{-3}) was higher than in the wormcast soil (1.32 gcm^{-3}), both values are statistically similar.

The higher Bd in the surrounding soil may be associated with seasonal flooding of soils; resulting to continued wetting and drying of soils. There is also the possibility of soil surface crusting and crusting by compaction through raindrop impact and surface erosion. It is quite possible that the higher content of sand in the control soil (Table 1) was due to washing away of clay and silt sized-fractions by rainfall and runoff water and may have contributed to the higher bulk density obtained. The soil bulk density values by location (Table 1) varied from 1.39 to 1.49 gcm^{-3}. Interestingly, all the mean values of soil Bd obtained in the plant-soil systems are within the allowable limit (1.50 gcm^{-3}) for crop production in the subtropics (Lal, 1990).

Soil saturated hydraulic conductivity (Ks) is one of the most important hydrologic properties that could be used to estimate the internal drainage of soils. Results in Table 1 show that Ks was significantly higher (P<0.05) in earthworm cast soil by 34.5% relative to the surrounding soil. The higher Ks (4.06 cms^{-1}) and total porosity (50.2 %) values obtained in the wormcast soils could be attributed to the low soil Bd (1.32 gcm^{-3}) (Table 1). This has implication of lowering run-off and erosion, while increasing aeration and internal drainage. It also suggests that the soil-plant systems present non-limiting conditions in terms of structure as reflected by low Bd, adequate airspaces and higher water transmission. These important soil parameters promote easy crop root growth and proliferation for enhanced crop production. This accords Ezeaku and Egbemba (2014) report that low Bd is a positive productivity indicator as it helps in easing root penetration, and encourages downward movement of water through old root channels. Similarly, the burrow channels created by the activities of earthworms and termites increase soil depth and regulate water flow into the soil. This implies more soil water retention and availability for greater water use efficiency by crops (van Schaik et al., 2014)

The results of measured soil physical properties (Table 1) are corroborated by several study reports. It had been shown that in the presence of earthworms, the hydraulic conductivity increases and soil bulk density decreases due to formed earthworm channels (Lavelle, 1997; Francis and Fraser, 1998; Chan, 2004). Thus, macropores formed by earthworms probably become more important for buffering strong precipitation events in future in humid areas. Next is the formation of macropores earthworm and termite activity creating and stabilizing of soil structure (Six et al. 2004). However, earthworms can also have a negative effect on soil structure and other soil parameters (Laossi et al., 2010).

Effects of earthworm cast, termite mound, location and soil depth on soil chemical properties

The results in Table 2 show that soil pH was slightly acidic in the plant-soil systems (higher soil pH range: 6.2 to 6.3) but more acidic in the surrounding soil (low soil pH of 5.2). Soil pH appreciated by 17.5% in wormcast soil and 16.6% in termite mound soil due to significant (P <

Table 2. Effects of earthworm cast, anthill, location and soil depth on the soil chemical properties.

Soil sample	pH (H_2O)	Kcl	EA	OC	TN	Ca	Mg	K	Na	CEC	Av P
			Cmolkg^{-1}	%		← Cmolkg^{-1} →					Mgkg^{-1}
Plant-soil system											
Earthworm cast	6.3	5.7	1.26	4.26	1.128	4.2	1.40	0.42	0.38	20.40	22.6
Anthill	6.2	5.4	1.30	3.30	1.113	4.6	1.20	0.36	0.29	18.00	18.4
Control	5.2	4.8	1.80	2.47	0.166	3.5	0.61	0.12	0.20	12.20	12.1
LSD (P<0.05)	0.29	0.38	Ns	1.46	0.03	0.24	0.01	0.01	0.06	1.68	2.30
Location											
Nsukka	6.3	5.1	1.51	4.08	0.136	3.7	1.20	0.29	0.19	9.20	18.5
Ede Oballa	6.0	5.0	1.40	3.47	0.122	4.2	1.00	0.42	0.34	13.1	16.4
Orba	6.1	5.4	1.22	2.09	0.09	1.2	1.60	0.16	0.18	17.0	13.1
LSD (P<0.05)	Ns	Ns	Ns	0.22	1.37	2.16	0.05	0.01	0.03		2.67
Soil depth											
0-15 cm	6.6	5.0	1.35	4.43	o.12	4.5	1.34	0.33	0.33	20.8	20.0
15-30 cm	6.4	5.5	1.40	4.88	0.32	4.2	1.38	0.38	0.31	22.1	20.20
LSD (P<0.05)	ns	Ns	Ns	0.31	0.01	2.11	0.02	0.06	Ns	1.06	2.54

EA, exchangeable acidity; OC, organic carbon; TN, total nitrogen; Ca^{2+} = calcium; Mg^{2+} = magnesium; Na^{+} = sodium; CEC, cation exchange capacity; Av. P, available phosphorus; Ns, not significant; LSD (P<0.05), least significant difference at 5% level of probability.

0.05) increase in exchangeable cation (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) contents in the soil colloidal complex (Table 2). Low pH value of 5.2 obtained in the control soils might be associated with loss of exchangeable bases resulting from displacement reactions in the soil colloidal complex. Soil acidity has been partly associated with excessive rainfall that necessitates eluviations and leaching loses of cations (Akamigbo and Igwe, 1990) but under field condition.

Organic carbon contents in wormcast soil and termite mound soil were significantly higher (P<0.05) than in the surrounding soil (Table 2). Soil organic carbon (SOC) of wormcast soil increased by 42.0%, while SOC in the termite mound soil increased significantly (P<0.05) by 25.2% relative to control. This increase could be linked to high content of carbon in the plant-soil system (earthworm cast and anthill). Ekundayo and Orhue (2011) and Jouquet et al. (2002) have shown that higher SOC found in termite mound soils could be due to the fact that during the periods of mound construction, organic debris or living plant tissue were collected over extensive foraging area, transported to mounds and subjected to intensive degradation.

In terms of earthworms, they contribute to build-up of organic matter in the soil through a sequence of actions. Earthworms feed on organic materials found on the soil surface and subsurface. At the soil surface, they ingest vegetation, organic materials (fresh and dried) and some fine earth fractions. Earthworms also burrow into the soil subsurface to nibble partially decayed organic materials such as plant roots, twigs and leaves and soil.

The biodegradation of the ingested materials is facilitated by enzymatic reactions from the salivary secretions (Mba, 1978). The waste digests are excreted as casts, which are composited of fine earth materials (clay) and high nutrient elements particularly organic matter and cations that buffer the soil systems. This may have been the reason for the increased clay fractions obtained in both worm cast and termite mound soils (Table 1). Again, earthworm burrowing activity could have advantages of creating more airspace and channels for water transmission, possibly disintegrate hard soil structure for ease of root growth and better crop performance.

The report by Akinrinade et al. (2000) as cited by Ezeaku (2011) had shown that soil organic carbon content of 1.74% or 17.4 gkg^{-1} was suggested as critical level for crop production in the tropic and subtropical soils. The results in this study (Table 2) showed that SOC contents obtained in wormcast (4.26% or 42.6 gkg^{-1}), termite mound (33.0 gkg^{-1}) and surrounding soil (24.7 gkg^{-1}) were above the critical limit and may be related to higher amount of organic residue taken and digested by earthworms and termites. It is also probable that higher quantities of residue are produced in the surrounding soil.

Soil organic carbon mediates nitrogen in the soil. Soil nitrogen increased significantly (P<0.05) by about 85.0% in the two plant-soil systems relative to control (Table 2). The values of total N in the wormcast soil (1.12% or 11.2 gkg^{-1}) and termite mound soil (11.1 gkg^{-1}) were more than 0.15 or 1.5 gkg^{-1} total N at which response to N fertilization is not expected in subtropical soils (Ezeaku, 2011). The value of total N obtained from the surrounding soil was very close to the critical value, suggesting negative implication for crop production. Response to N fertilization is required.

All exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ except Na^+) had significant ($P<0.05$) increases in the soil (Table 2), an insinuation that amendment soils had effect on the measured parameters. Exchangeable Ca^{2+} increased by 16.7% in wormcast soil and 85.1% in termite mound. Mg^{2+} appreciated by 57.1 (earthworm cast soil) and 50.0% (termite mound). Exchangeable K^+ values are higher in wormcast soil (0.42 $cmolkg^{-1}$) and termite mound soil (0.36 $cmolkg^{-1}$) relative to the control. Exchangeable K^+ increased by 71.4% in wormcast soil and 66.6% in termite mound soil. The values of K^+ in the wormcast soil and termite mound soil are higher than the critical values of 0.16 to 0.20 $cmolkg^{-1}$ for crop production (Isirima et al., 2003; Ezeaku, 2011). Johnson et al. (1997) show that the increases in exchangeable cations suggest displacement of active exchangeable Al^{+3} in the cation exchange site by the cations, and could have contributed to the increased soil pH obtained in this study. The increase in exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ except Na^+) is synonymous with Ekundayo and Orhue (2011) report that showed significantly higher ($p<0.05$) exchangeable cations on termite mound surfaces and mound perimeters than the surrounding soils under some land use types. Similar report in terms of earthworm cast soils had been made (Mba, 1978).

Available P increased significantly ($P<0.05$) by 46.5% in wormcast soil and 34.4% in termite mound soil (Table 2) relative to control. This could be attributed to high P content in the decayed organic debris or living plant tissues digested (plant-soil system) by the earthworm and termite species. Similar observation has been reported (Kang, 1978; Lal, 1988; Ekundayo and Orhue, 2011).

For the soils of the tropics, 8-12 $mgkg^{-1}$ of available P was considered critical limit for crop production (Ezeaku, 2011). The values of available P obtained in wormcast soil (22.6 $mgkg^{-1}$) and termite mound (18.4 $mgkg^{-1}$) (Table 2) were higher than the critical limit. This suggests that available P (12.1 $mgkg^{-1}$) obtained in the surrounding soil is marginal. Such soil needs phosphorus fertilization.

Enwezor et al. (1990) report as cited in Ezeaku (2011) showed that values of CEC below 6-8 $cmolkg^{-1}$ is low, 6-11 $cmolkg^{-1}$ (medium) and >12 $cmolkg^{-1}$ is considered high. Based on these limits, the amounts of CEC obtained in the plant-soil systems and the surrounding soil (range: 12.2 to 20.4 $Cmolkg^{-1}$) are generally high (Table 2). The high levels signify no response to N, P and K fertilization for the crop in the tropical and subtropical area.

From Table 2, it can be observed that interaction of wormcast soil and termite mound soil (plant-soil systems) by location and by soil depth was significant ($P<0.05$) for soil organic carbon, nitrogen, all exchangeable cations (except Na^+) including CEC and available P. The significance of the interaction is a positive soil productivity indicator, suggesting that the nutrients inherent in wormcast and termite mound soils are quite high and could be used as fertilizer to improve crop productivity. These findings are corroborated by Kang (1978), Ariha (1979), Lal (1988), Fragoso and Lavelle (1992), Frageria and Baligar (2004) and Ekundayo and Orhue (2011).

Effects of earthworm cast and termite mound on plant height, leaf area and dry matter yield of maize

The effects of earth worm cast and termite mound (anthill) soils on yield indicators (plant height and leaf area) and maize dry matter yield are shown in Figure 2. The plant-soil systems showed no significant ($P<0.05$) effect on plant height and leaf area index (LAI) except at 4^{th} and 6^{th} week of sowing (WAS). Soil at T7 (mixture of all earthworm casts) gave the highest plant heights and LAI followed by T8 (mixture of all termite mounds) soil across the measurement periods (2, 4, 6 WAS) (Figure 2). Taking parameter measurements at 6^{th} week for discussion, control soil (T10) had the least plant height value (38.2 cm) and LAI (1.028). In subsequent discussions, T10 would be used as reference standard (control). T7 and T8 increased plant height significantly ($P<0.05$) by 72.4 and 67.1%, respectively, relative to T10. Also, LAI of soils in T7 and T8 was higher significantly ($P<0.05$) by 51.6 and 47.1%, respectively as compared to control (T10). The significant ($P<0.05$) increases in plant height and LAI could be associated with increases in the contents of organic carbon, nitrogen, and exchangeable cations released into the soil exchange site by plant-soil systems (earthworm cast and termite mound soils).

Earthworm cast and termite mound soils had significant ($P<0.05$) effect on dry matter weight of maize. Though dry matter yield obtained in T7 and T8 soils were statistically similar, T7 soil gave the highest dry matter yield (22.81 g) relative to T10 (9.11 g) (Figure 2). Dry matter yield in T7 and T8 soil increased significantly ($P<0.05$) by 60.1 and 50.4%, respectively than yield obtained in T10 soil. The significant increases in dry matter yield of the two plant-soil systems (T7 and T8) could be due to high contents of nutrients, their availability and higher assimilation by the roots of the maize plants. This finding agrees with other reports (Aziz, 2010; Ekundayo and Orhue, 2011; Debruyn and Conacher, 1987) which showed that addition of soil-feeding termite nest structures amendments improves soil nutrient availability and uptake by plants.

However, low dry matter yield (9.11 g) obtained in control soil (T10) (Figure 2) could be attributed to inherent low nutrient contents of the surrounding soils. Low nutrient values in soils have been associated with high temperature, high rainfall and leaching loses which characterize tropical soils (Lal, 1988). Most tropical soils have been identified to have coarse to medium texture,

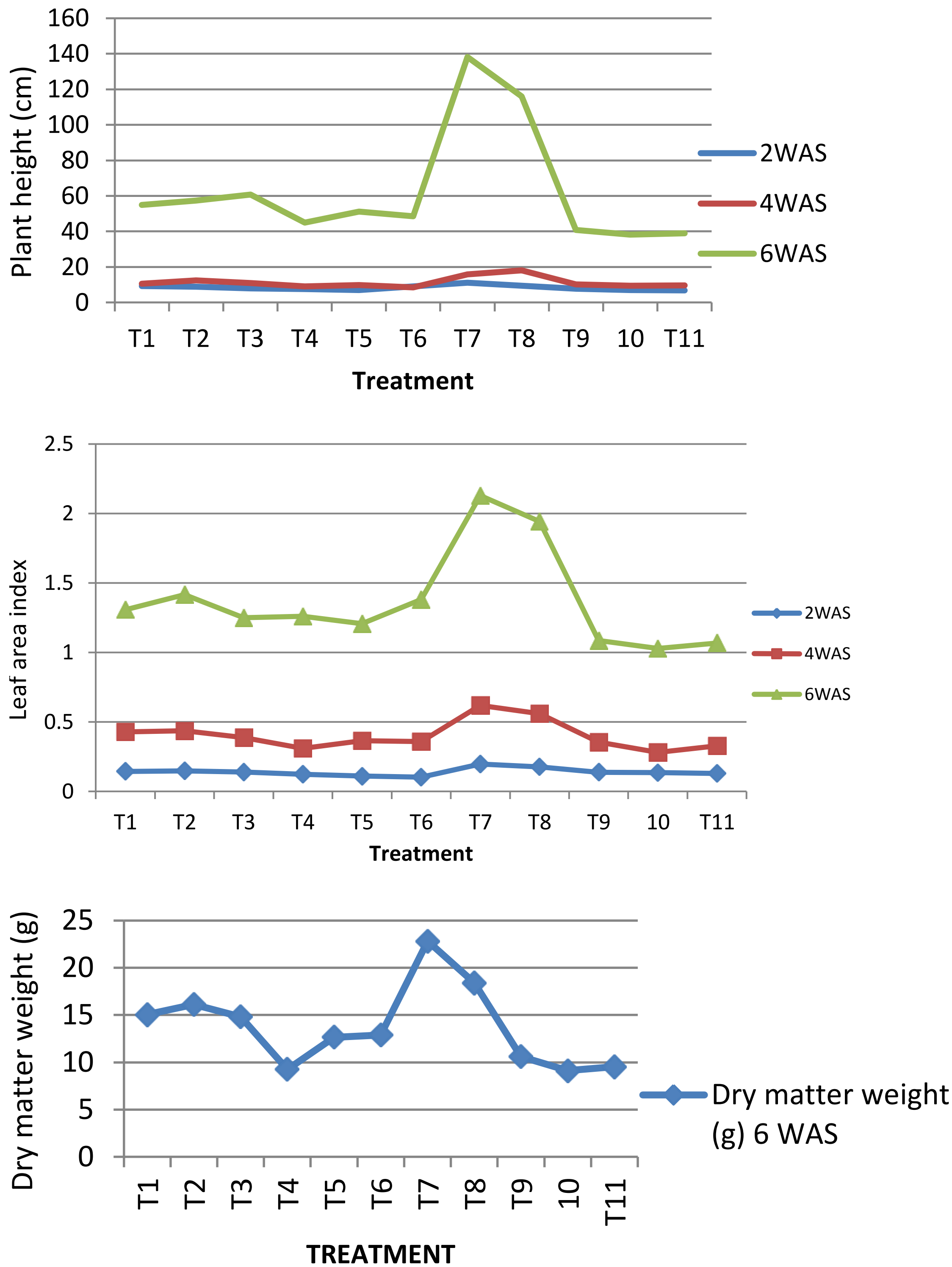

Figure 2. Effects of earthworm cast and anthill on plant height, leaf area index and dry matter yield of maize.

granular in structure, acidic in reaction and low in nutrient status (Akamigbo and Igwe, 1990), hence resulting to low soil and crop productivity. Acid soil as was seen in the control (pH of 5.2) (Table 3) could have contributed to the low dry matter yield of maize. Acid soils have been identified as the main cause of low yield in many tropical crops (Obi and Asiegbu, 1980; Hoekenga and Pineros, 2004).

Table 3. Effects of earthworm cast and anthill on plant height, leaf area index and dry matter yield of maize across the locations.

Treatment	Plant height (WAS) (cm)			Leaf area index (WAS)			Dry matter weight (g)
	2	4	6	2	4	6	6 WAS
T1	9.2	10.5	55.0	0.144	0.429	1.308	15.04
T2	8.8	12.5	57.3	0.148	0.436	1.416	16.12
T3	8.0	11.0	60.8	0.139	0.388	1.249	14.81
T4	7.6	9.0	44.9	0.124	0.310	1.260	9.26
T5	6.9	9.8	51.1	0.110	0.365	1.206	12.65
T6	9.0	8.4	48.5	0.103	0.359	1.381	12.89
T7	11.2	15.8	138.2	0.198	0.620	2.128	22.81
T8	9.5	18.0	116.0	0.177	0.560	1.942	18.39
T9	7.7	10.2	40.8	0.138	0.355	1.086	10.61
10	7.0	9.4	38.2	0.135	0.281	1.028	9.11
T11	6.8	9.6	38.9	0.130	0.329	1.068	9.53
LSD ($P<0.05$)	ns	1.428*	2.921*	ns	0.0712*	0.1928*	2.071*

WAS, weeks after sowing; T1, Nsukka earthworm cast; T2, Ede Oballa earthworm cast; T3, Orba earthworm cast; T4, Nsukka anthill; T5, Ede Oballa anthill; T6, Orba anthill; T7, Mixture of all earthworm casts; T8, Mixture of all anthills; T9, Control soils (Nsukka); T10, Control soils (ede Oballa); T11, Control soils (Orba); LSD (P<0.05), least significant difference at 5% level of probability, 2, 4 and 6 means the week of measurement.

Conclusion

The results of this study show that clay contents in worm cast and termite mounds soils, regarded as plant-soil system, were higher than the surrounding soils. Silt content, however, was found higher in control soils. Application of the plant-soil systems decreased soil bulk density and increased porosity and saturated hydraulic conductivity.

The study also found that the applied plant-soil systems had significant positive effect on measured soil chemical parameters such as soil pH, OC, total N, exchangeable cations (except Na), CEC and available P. Plant-soil systems (earthworm cast and anthill) by location and by soil depth interaction was significant ($P<0.05$) for the aforementioned measured soil parameters.

It was also shown that a mixture of all earthworm cast soils (T7) gave higher value in the crop parameters measured than the value obtained in the mixture of all anthill soil (T8), although the difference is not significant. Maize growth performance parameters (plant height and leaf surface) and dry matter yield were significantly increased ($p<0.05$) in the plot with a mixture of T7 and (T8) than the soils of the surrounding (T10). Thus, the combined use of T7 (mix of all earthworm cast soils) and T8 (mix of all anthill soils) plant-soil systems is recommended for their great potentials to increase soil and crop productivity.

Any soil management practices for optimizing nutrient balance in soil should aim at maintaining vegetation and soil organic materials on the soil surface (mulch). The practices will increase the activities of earthworms and termites, resulting to increases and improvements on soil fertility to maintain the soil nutrients above the threshold values as obtained in the current study. There is need for further research on the effects of the plant-soil systems (earthworm cast and termite mound soils) on maize or any other related crop at field scale in tropical, subtropical and temperate regions so as to explore further their productivity potentials.

Conflict of interest

The authors have not declared any conflict of interest.

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