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Full Length Research Paper

Soil Water Relations of an Ultisol amended with Agro-wastes and its effect on grain yield of maize (*Zea mays L.*) in Abakaliki, Southeastern Nigeria

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Soil water relations of an ultisol amended with agro-wastes and its effect on grain yield of maize (*Zea mays L.*) was studied for three cropping seasons. The field was laid out in randomized complete block design using four treatments of control and three agro-wastes at 8kg/plot. The texture of soil remained sandy loam throughout the period of study. Agro-wastes amended plots had significantly (P<0.05) lower bulk density and higher total porosity for two seasons and in residual season. There were significantly (p<0.05) higher effect of bulk density, total porosity and aggregate stability on moisture retention, availability and transmission for 2013 and 2014 cropping seasons as well as in 2015 study season except for aggregate stability on hydraulic conductivity in 2013 season. Plot amended with burnt rice mill waste was higher in water retention, available water capacity and hydraulic conductivity by 2, 3, 2%: 4, 5, 3%: 2, 3, 1% and 11% respectively compared to those of fresh rice mill waste and saw dust amended plots for the three cropping seasons. Grain yields of maize were significantly (P<0.05) higher in plots amended with agro- wastes compared to control for three seasons. Agro- wastes amendment of soil should be carried out for enhanced soil physical conditions, soil water relations and for sustainable productivity.

Keywords: Agro-wastes, Effect, Grain Yield, Maize, Soil Water relations, Utisol

INTRODUCTION

Soil–water relationship is imperative for storage and retention or transmission (Obi 2000) as well as its release to crops. This essentially depends on the physical conditions of the soil. For instance, good soil porosity and pore size distribution, texture and enhanced structure promote water absorption, retention, storage and release. Hillel (1986) noted that texture, structure and compaction influenced the capacity of soil to store and transmit water. Perhaps, the importance of soil water relationship does not only lie on the amount it is able to store but how much is available to crops. According to Ngala *et al.* (2015) soil water retention capacity as well as its conductivity have tremendous agronomic and ecological implications. Drainage, evaporation, water uptake by roots of crops (Ngala *et al.,* 2015) and general water economy of crop plants (Folorunso, 1986) are just few examples where knowledge of soil–water relationship play important role in soil productivity.

Similarly, Obi (2000) noted that presence of organic matter in the soil increased water sorptivity. In their earlier studies, Obi and Asiegbu (1985) reported that incorporation of organic materials in the soil improved soil conditions and increased water storage pores. Several authors including Nnabude and Mbagwu (2001), Anikwe *et al.* (2007) and Nwite (2013) corroborated that organic wastes amendment improved soil texture, porosity, compaction, structure and increased water retention and transmission. Normally, when water absorption and retention is increased it gains higher matric potential and becomes available to crops (Obi, 2000).

Agro- wastes such as rice mill wastes (burnt, fresh and saw dust) are commonly generated from rice mill and timber industries in different parts of the state. The wastes have been reported to be subjected to burning and in so doing become potential source of environmental hazard (Ohaekwiro, 2016; Nnabude and Mbagwu, 2001) due to ignorance of their proper usage. However, Hornic and Parr (1987) as well as Karikari and Yayock (1987) pointed out that these agro- wastes have potentials to restore degraded soil and improve water availability in soil. The objectives of this research were to study soil–water relation of soil amended with burnt rice mill waste, fresh rice mill waste and saw dust and its effect on grain yield of maize (*Zea mays L.*) in Abakaliki southeastern Nigeria.

MATERIALS AND METHODS

Experimental Site

The study was carried out at the Faculty of Agriculture and Natural Resources Management, Teaching and Research farm, Ebonyi State University, Abakaliki. The site is located by latitude 06° 4/N and longitude 08° 65 /E in the derived savannah zone of the southeast agro-ecological area of Nigeria. The rainfall pattern is bimodal (April-July and September-November), with a short dry spell in August normally referred to as "August break". The total annual rainfall in the area ranges from 1500 to 2000 mm, with a mean of 1,800 mm. At the onset of rainfall, it is torrential and violent, sometimes lasting for one to two hours (Okonkwo and Ogu, 2002). The area is characterized by high temperatures with minimum mean daily temperature of 27 °C and maximum mean daily temperature of 31 °C throughout the year. Humidity is high (80%) with lowest (60%) levels occurring during the dry season between December to April, before the rainy season begins (ODNRI, 1989). Geologically, the area is underlain by sedimentary rocks derived from successive marine deposits of the cretaceous and tertiary periods. According to the Federal Department of Agricultural Land Resources (FDALR, 1985), Abakaiiki agricultural zone lies within Asu River group and consists of olive brown sandy shales, *fine-grained sandstones and mudstones. The* soil is shallow with unconsolidated parent materials (shale residuum) within 1 m of the soil surface. It belongs to the order ultisol and is classified as Typic Haplustult (FDALR, 1985).

The vegetation of the place is primarily derived savannah, with bush regrowths and scanty economic trees. The site has history of previous cultivation of yam *(Dioscorea spp)* and cassava *(Manihot spp).* There is growth of native vegetation such as *Tridax spp, Odoratum spp, Aspilla africana, Imperata cylindrica, Panicum maximum, Pennisetum purperum, Sporobulus pyramidalis* and other herbs and shrubs. These were cleared manually using matchet and hoe. The debris left after clearing was removed before seedbed preparation.

Field Methods

Field design/layout and treatment application

An area of land that measured 14 m x 7 m (0.021ha) was used for the study. The land was demarcated into plots and replicates. The plots were laid out in Randomized Complete Block Design (RCBD). The plots measured 2 m x 2 m and were separated by 0.5 m spaces while the four replicates were separated by 1 m alley. The treatments consisted of control (C) *i.e* no application of organic wastes, burnt rice mil waste at 20 t ha^{-1} equivalent to 8 kg/plot fresh rice mill waste at 20 t ha^{-1} equivalent to 8 kg/ plot and sawdust at 20 t ha^{-1} equivalent to 8 kg/plot. The treatments namely burnt rice mill waste, fresh rice mill waste and sawdust were sourced from the agro-rice mill industry and timber shade market, Abakaliki, respectively. The organic wastes namely: burnt rice mill waste, fresh rice mill waste and sawdust were spread on the plots and were incorporated into the soil during seedbed preparation using traditional hoe. The beds were allowed to age for two weeks after incorporation of treatments before planting the test crop. The treatments were replicated four times to give a total of twenty plots in the study.

Maize seed (suwan-1-SR-hybrid variety) sourced from Ebonyi State Agricultural Development Programme (EBADEP) was planted (2 seeds per hole) at 5cm depth and spacing distance of 25x75cm. Two weeks after emergence (WAE), the plants were thinned down to one plant per hole while lost stands were replaced. Weak plants were rogued out and replaced leaving a plant population of approximately 53, 000 stands per hectare. There was application of NPK (20:10:10) fertilizer at 400 kg ha^{-1} to all the subplots two weeks after plant emergence (WAPE). The fertilizer was banded and placed 5cm away from the maize plants. Weeds were removed at three-weekly intervals up till harvest. In the second year, the procedure was repeated while residual effect was tested in the third year of study without fresh application of treatments.

Agronomic Data

The cobs were harvested at plant maturity. This was when the husks were dried. The cobs were dehusked and further dried before shelling and grain yield determined at 14% moisture content. Agronomic yield data were taken on twelve tagged plants representing 25% of plant population per plot.

Soil Sampling

Initial soil samples were collected from the 0-20 cm depth using auger at different points in the study site before application of organic wastes and cultivation. The auger samples were composited and used for routine laboratory analysis. Core and auger samples were collected at 0-20 cm from each plot at three points i.e. 3 cores and 3 augers in each plot after the planting for post harvest soil analysis. Core samples were used to determine some soil physical properties while auger samples were air-dried at room temperature (about 26°C) and passed through 2 mm sieve. These were used for chemical analysis.

Laboratory Determinations

Soil Physical Properties

Dry bulk density was determined as described by Blake and Hartge (1986). The method as described by Carter and Ball (1993) was used to measure total porosity (S_t) as follows:

$$\text{Thus, } S_t = \left(1 - \frac{P_b}{P_s} \times \frac{100}{1}\right) \text{---} 1$$

Where:
Pb = bulk density
Ps = particle density
Particle size distribution was determined by the hydrometer method as described by Gee and Or (2002). The result was reported as percentage sand, silt and clay respectively. The distribution of aggregates was estimated by the wet sieving technique described by Kemper and Rosenau (1986). In this procedure, 50g of the <4.76mm aggregates were placed on the topmost of a nest of sieves of diameters 2, 1, 0.5 and 0.25mm. The samples were pre-soaked in distilled water for 10 minutes before oscillating vertically in water 20 times (along a 4cm amplitude). The resistant aggregates on each sieve were dried at 105°C for 24hours and weighed. The mass of <0.25mm fraction was obtained by difference between the initial sample weight and the sum of sample weight collected on the 2, 1, 0.5 and 0.25mm sieve nests. The percent water-stable aggregates (WSA) on each sieve was determined using the formular:

$$WSA = \left(\frac{M_a + S - M_S}{M_t - M_S}\right) X \frac{100}{1} \text{----------------------------------} 2$$

St = (1 - Pb) x 100 - - - - - 1

St = (1 - Pb) x 100 - - - - - 1

where 1 1

Pb = bulk density

Ps = particle density assumed at $2.65gcm^{-3}$

$\frac{\%Bs}{Ps} \times \frac{100}{1}$ - - - - - - - 8

All soil samples that fell within 4.76 and < 0.25 mm were used to express WSA>0.25 mm as the index of stability. Water retention was determined by the hanging water column technique as described by Obi (2000). Hanging water column procedure involved collection of undisturbed core soil samples. The metal cores used had dimensions of 4.8 cm (internal diameter, ID) and 5.6 cm height. After saturation for 24hours, the cores were used to measure soil retention using matric potentials of $-6kp_a$ and then oven-dried at 105°C for 24 hours. Soil water content was measured gravimetrically. Moisture retained at -10 and -1500kp_a matric potentials were estimated based on the saturation water percentage (S_p) models of Mbagwu and Mbah (1998). The models are:

Θ.01 (FC) = -6.22 + 0.79 (Sp). ----------------------------3
Θ.100 = -10.95 + 0.65(Sp). --------------------------------4
Θ.15 (PWP) = 8.65 + 0.51 (S_p). ------------------------5

Available water capacity (AWC) was computed as the difference between moisture retained at 10kP_a and 100kP_a matric potentials where

FC = Field capacity
Sp = Saturation percentage
PWP = Permanent wilting point
Saturated hydraulic conductivity (K_s) was determined by the constant-head soil core method of Reynolds (1993) as adapted from Elrick *et al.* (1981). This is transposed as:

$$K_s = \frac{Q}{At} \times \frac{\Delta H}{L} \text{--} 6$$

Where

$$K_s = \frac{\text{Mean volume of water conducted x Hydraulic head change}}{\text{Cross sectional area of core x Time x soil sample Length}}$$

Soil Chemical properties

Soil pH was determined in duplicates both in distilled water and in 0.1N KCl solution using a soil/water ratio of 1:2.5. After stirring for 30 minutes, the pH values were read off using a Beckman Zeromatic pH meter (Peech, 1965). Total nitrogen was determined using the micro-kjeldhal distillation method of Bremner (1996). The ammonia from the digestion was distilled with 45% NaOH into 2.5% boric acid and determined by titrating with 0.05N KCl. Available phosphorus was determined by the Bray-2 method as described by Page *et al.* (1982). The available phosphorus was read off from the standard curve obtained from optical density using a colorimeter. Organic carbon was determined using the method described by Nelson and Sommers (1982). The percentage organic matter was calculated by multiplying the value for organic carbon by the "Van Bemmeler factor" of 1.724 which is based on the assumption that soil organic matter (SOM) contains 58% C (Allison, 1982). Calcium (Ca) and magnesium (Mg) were determined by titration method (Mba, 2004). Sodium (Na) and potassium (K) were extracted with 1N ammonium acetate solution (NH_4OAC) and determined using flame photometer. The titrimetric method using 1 NKCL extract of McLean (1982) was used in the determination of total exchangeable acidity (Al^{3+} and H^+). Effective cation exchange capacity (ECEC) was evaluated by the summation method as follows:

ECEC = TEB + TEA -- 7

Where

ECEC = Effective cation exchange capacity (cmolkg^{-1} soil)
TEB = Total exchangeable bases (cmoikg^{-1} soil)
TEA = Total exchangeable acidity (cmolkg^{-1} soil)

Cation exchange capacity was determined by ammonium acetate (NH_4OAC) displacement (Jackson, 1958). Base saturation (BS) was calculated by dividing total exchangeable bases (TEB) with cation exchange capacity value and multiplying by 100. The expression is thus:

$$\%BS = \frac{TEB}{CEC} \times \frac{1\text{-}00}{1} \text{---} 8$$

Organic Wastes of burnt rice mill waste, fresh rice mill waste and sawdust were analyzed for sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Nitrogen (N), Phosphorus (P), Organic carbon (OC) and C:N ratio using Juo (1983) method.

Data analysis

The data collected from this experiment were subjected to Statistical Analysis System (SAS, 1985) method. Significant treatment effect was reported at 5% probability level. Bar chart was used to express soil-water relationship.

RESULTS AND DISCUSSION

Properties of the Soil at initiation of the study

Table 1 shows some properties of soil at the initiation of study. The particle size distribution analysis indicates that the textural class is sandy loam. The pH in KCL was 5.1 indicating that the soil was slightly acidic according to the rating of Schoeneberger *et al.* (2002). The percentage organic matter was 3.17 and rated low *(*FMARD, 2002*)*. The percentage total N (0.16) was low (Asadu and Nweke, 1999). The soil exchange complex was dominated by calcium and magnesium (5.20 and 3.80 cmolkg^{-1}), respectively).

Low values of 0.17 and 0.18 cmolkg^{-1} (Asadu and Nweke ,1999) were recorded for sodium and potassium, respectively. The available phosphorus was low with value of 4.70 mgkg^{-1} (Landon, 1991). The soil was moderately (68%) in base saturation (Landon, 1991). Exchangeable acidity (EA) was 0.7 cmolkg^{-1}. The soil cation exchange capacity (CEC) and effective cation exchange capacity (ECEC) were 10.3 and 7.97 cmolkg^{-1}, respectively and rated low (Asadu and Nweke, 1999; Landon, 1991).

Nutrient Composition of Amendments

The nutrient compositions of organic wastes applied to the soil is presented in Table 2. The nutrient contents of organic wastes were generally low. Exchangeable cations were low in burnt rice mill (BRMW) waste, saw dust (SD) and fresh rice mill waste (FRMW) compared to the soil (Table 1). The values of exchangeable cations were low in BRMW, SD and FRMW according to (Howeler, 1996; London, 1991). The percentage organic carbon and total N ranged from 6.92 to 16.39 and 0.28 to 0.48 in the organic wastes and rated high (FMARD, 2002). Available phosphorus ranged from 3.00 to 14.00 mgkg"^{1} in the organic wastes and rated low according to Enwezor *et al.* (1989) and London (1991). The C:N

Table 1. Some properties of the Soil at the initiation of the study

Soil Properties	Unit	Values
Sand	%	66
Silt	%	21
Clay	%	13
Textual class		Sandy loam
pH kcl		5.1
OC	%	1.84
OM	%	3.17
N	%	0.16
Na	$cmolkg^{-1}$	0.17
K	$cmolkg^{-1}$	0.18
Ca	$cmolkg^{-1}$	5.20
Mg	$cmolkg^{-1}$	3.80
Available P	$mgkg^{-1}$	4.70
Base saturation	%	68.0
CEC	$cmolkg^{-1}$	10.3
EA	$cmolkg^{-1}$	0.7
ECEC	$cmolkg^{-1}$	7.97

OC – organic carbon, OM – organic matter, CEC – cation exchange capacity, N – nitrogen, EA – exchangeable acidity, ECEC – effective cation exchange capacity.

Table 2. Some Properties of Organic Wastes

Treatment	Parameter	Unit	Value
BRMW	Na	$cmolkg^{-1}$	0.04
	K	$cmolkg^{-1}$	0.06
	Ca	$cmolkg^{-1}$	1.17
	Mg	$cmolkg^{-1}$	0.27
	OC	%	6.92
	N	%	0.10
	P	$mgkg^{-1}$	14.00
	C:N		23
S D	Na	$cmolkg^{-1}$	0.07
	K	$cmolkg^{-1}$	0.13
	Ca	$cmolkg^{-1}$	0.30
	Mg	$cmolkg^{-1}$	0.10
	OC	%	8,99
	N	%	0.28
	P	$mgkg^{-1}$	3.00
	C:N		32

Table 2: Continue

FRMW	Na	$cmolkg^{-1}$	0.07
	K	$cmolkg^{-1}$	0.24
	Ca	$cmolkg^{-1}$	0.50
	Mg	$cmolkg^{-1}$	0.12
	OC	%	16.39
	N	%	0.48
	P	$mgkg^{-1}$	7.00
	C:N		34

BRMW-burnt rice rice waste, SD-sawdust, FRMW- Fresh rice mill waste , OC-organic carbon, C:N-carbon-nitrogen ratio

Tables 3. Effect of agro-wastes amendment on particle size distribution

	2013 %				2014 %				2015 %			
Trt	**Sand**	**Silt**	**Clay**	**Texture**	**Sand**	**Silt**	**Clay**	**Texture**	**Sand**	**Silt**	**Clay**	**Texture**
Control	66	25	10	SL	57	30	13	SL	65	21	14	SL
BRMW	63	25	12	SL	58	29	13	SL	62	28	10	SL
FRMW	64	22	14	SL	56	26	18	SL	60	27	13	SL
SD	65	25	10	SL	59	27	14	SL	63	25	12	SL

Trt – Treatment, BRMW – burnt rice mill waste, FRMW – Fresh rice mill waste, SD – saw dust, SL- Sandy loam

ratios were 23, 32 and 34 for BRMW, SD and FRMW, respectively.

Particle sizes Distribution

Table 3 shows particles size distribution of soil following amendment of agro–wastes. Although, the results indicate that particle size distribution did not vary appreciably under different agro–wastes amendment for the three cropping seasons, sand was the dominant fraction. Silt fraction generally increased in second cropping season and decreased under residual study. The trend of silt fraction was obtained in clay fraction except in control during residual season. The textural class consistently remained sandy loam under the different agro – wastes amendment and control for the three cropping seasons.

The high sand content of the soil seems to be related to the parent material and climate of the region (FDALR, 1985). Sand content of the soils in southeastern region of Nigeria is a characteristic of soil formed on unconsolidated coastal plain and sand stones from “Asu river” (FDALR, 1987). Texture remained unchanged for three cropping seasons since it is “a permanent property” of soil which is not affected by cultural practices (Obi, 2000). Texture has good relationship with nutrient storage, water retention, porosity (Foth and Turk, 1972) and specific surface area, soil compatibility and compressibility (Smith et al., 1998) which affect inherent productivity of the soil. Sandy loam texture is a characteristic of highly weathered parent material under tropical climate (Nwite, 2015) and is associated with high water retention, nutrient storage and high crop yield. Lower silt and clay fractions compared to sand could be attributed to processes of eluviation and/or erosion (Akamigbo, 2010) due to cultivation. The general reduction in values of particle size distribution in residual season relative to first and second cropping seasons could be due to effect of continuous cultivation that accelerated processes of erosion and/or soil degradation.

Effect of Agro-Wastes amendment on Bulk density, total porosity and Aggregate stability

Table 4 shows effect of agro-wastes amendment on bulk density, total porosity and aggregate stability in relation to moisture retention, availability and transmission for three cropping seasons. Results showed that plots amended

Table 4. Effect of agro-waste amendment on bulk density, total porosity and aggregate stability

Trt	Bulk density (mgm^{-3})			Total porosity (%)			Aggregate stability (%)		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Control	1.61	1.69	1.69	39.34	37.16	37.16	65.8	66.0	48.5
BRMW	1.54	1.56	1.56	42.07	41.23	41.23	72.0	70.3	55.4
FRMW	1.58	1.59	1.59	40.56	40.09	40.09	70.9	69.7	56.8
SD	1.59	1.59	1.59	40.19	39.91	39.91	70.2	69.5	49.2
FSLD(0.05)	0.02	0.02	0.02	0.92	1.54	1.54	2.9	NS	3.0

Trt – Treatment, BRMW – burnt rice mill waste, FRMW – fresh rice mill waste, SD – saw dust.

with agro-wastes had significantly (P<0.05) lower bulk densities and higher total porosities for two seasons of amendment and during residual study when compared to control. The plot receiving burnt rice mill agro waste had significantly (P<0.05) lower bulk density compared to the values obtained for those amended with fresh rice mill and saw dust agro wastes for two cropping seasons and then in residual season, respectively. This accounted for 3-3% and 2–2% reductions in bulk density in plot treated with burnt rice mill agro waste relative to plots amended with fresh rice mill and saw dust agro wastes for 2013 and 2014 cropping season.

In 2015 cropping season, bulk density was lower by 2 % each in plot treated with burnt rice mill agro waste compared to plots amendment with fresh rice mill and sawdust agro wastes. Total porosity was significantly (P<0.05) higher in plot amended with burnt rice mill agro waste in 2013 cropping season when compared to plots amended with fresh rice mill and saw dust agro-wastes, respectively. This translated to **4** and **5%** increments in total porosity in plots receiving fresh rice mill and saw dust agro-wastes in 2013 cropping season. Plot treated with burnt rice mill agro waste had significantly (P<0.05) higher total porosity compared to plot receiving saw dust agro-waste in 2014 and 2015 cropping seasons. These were **3** and **3%** higher in total porosity in plot amended with burnt rice mill agro- waste when compared to plot amended with saw dust agro waste for the seasons.

Conversely, aggregate stability was significantly (P<0.05) higher in plots receiving agro- wastes amendment in 2013 cropping season and then during residual study. The plot amended with saw dust agro- waste had significantly (P<0.05) higher aggregate stability compared to plots receiving burnt rice mill and fresh rice mill agro- wastes in residual season. The plot amended with burnt rice mill agro-waste was higher by **2**–**3%** and 1-1% in aggregate stability and 11 % compared to plots amended with fresh rice mill and saw dust agro-wastes for 2013 and 2014 cropping seasons as well as 2015 residual study for saw dust agro-waste, respectively. Generally, bulk densities increased after first cropping season in all the treatments while total porosities and aggregate stability were reduced.

The significantly higher treatment effect of agro- wastes on bulk density, total porosity and aggregate stability relative to control indicates that these agro-wastes could improve studied physical properties of soil on one hand. On the other, these agro-wastes could also impart long-residual effect on the studied soil properties. Low bulk density and high total porosity as well as aggregate stability could have positive effect on soil moisture and productivity. For instance, low bulk density could reduce water run-off and increase water infiltration and storage (Mbah and Nwite, 2008). Total porosity and aggregate stability were improved due to organic wastes amendment (Adeleye *et al.,* 2010). The improvement recorded in total porosity increased water storage pores (Obi, 2000). Incorporation of agro-wastes into soil is ameliorative measure. In line with this observation, several authors (Asadu *et al.,* 2008; Adesodun *et al.,* 2005 and Nnabude and Mbagwu, 2001) corroborated that agro-wastes added to the soil reduced soil bulk density and increased total porosity and enhanced aggregation and water holding capacity of soils. Agro-wastes amendment improved soil physical properties and water distribution and retention (Singh *et al.,* 2007; Razzi *et al.,* 2004). The increase in bulk density and reduction in total porosity and aggregate stability after first cropping season could be attributed to effect of continuous cultivation. Anikwe *et al.* (2003) and Mbah *et al.* (2009) reported that bulk density increased after tillage as a result of trafficking during field operations and other natural forces like alternate wetting and drying circles that caused large effective stress under tropical climates. Continuous cultivation generally caused soil degradation (Obi, 2000). Higher soil compaction decreases pore volume and water storage (Anikwe *et al.,* 2007; Obi, 2000). Generally high bulk density, low total porosity and aggregate stability could be limiting to water retention and accessibility by crops and cause low productivity of soil.

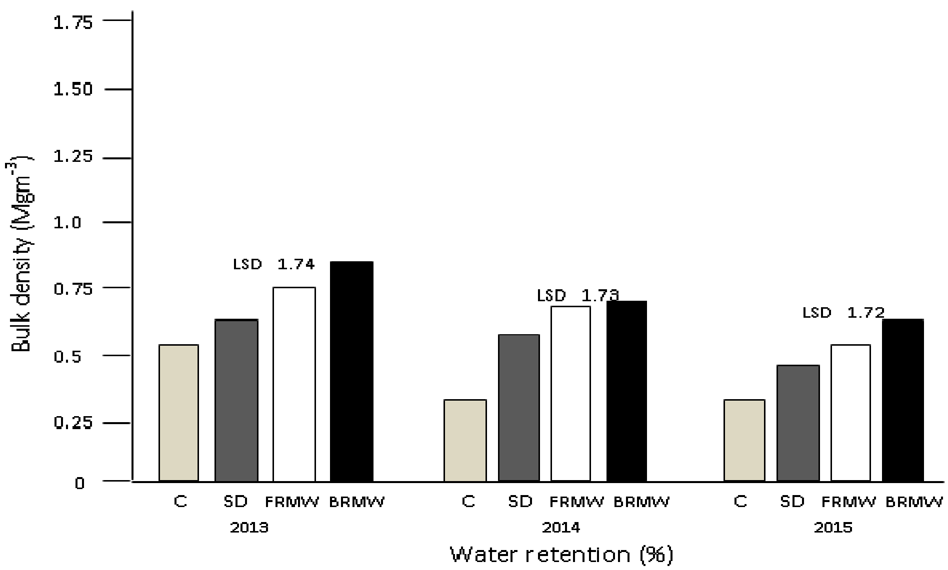

Figure 1: Effect of bulk density on soil water retention

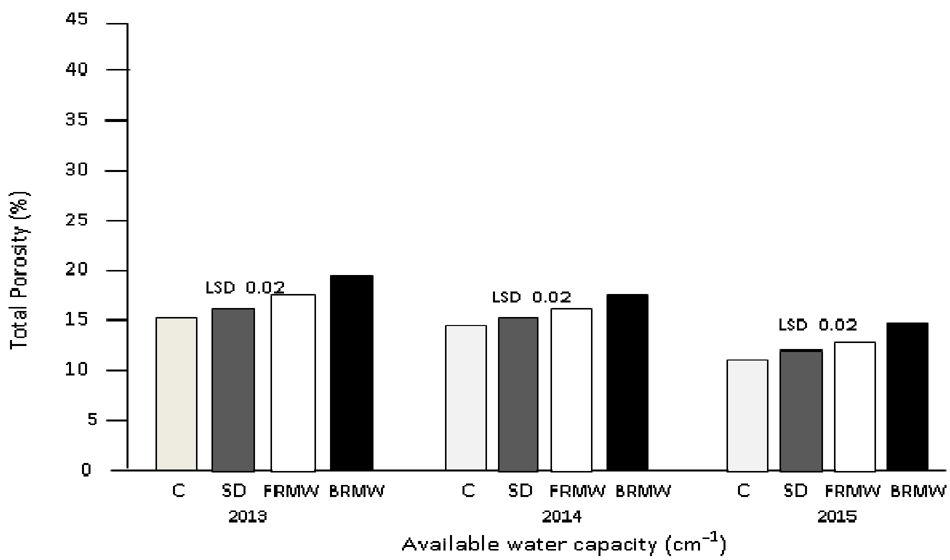

Figure 2: Effect of total porosity on available water capacity

Effect of Bulk Density, Total Porosity and Aggregate Stability on Soil-Water Relations

Figures 1-3 show respective effects of bulk density, total porosity and aggregate stability on soil–water relations for three seasons. Water retention was significantly ($P<0.05$) higher in agro-wastes amended plots compared to control for the three seasons. There were significant ($P<0.05$) differences in water retention among the treatments in the first cropping season. There was general reduction in water retention after first season giving least values in residual season except for burnt rice mill agro-waste amended plots and control for third cropping season. The plot amended with burnt rice mill agro-waste had the highest value of water retention for 2013-2014 and 2015 cropping seasons respectively compared to values obtained for fresh rice mill and sawdust agro-wastes amended plots.

In Figure 2, result showed that plots amended with agro-wastes had significantly ($P<0.05$) higher available water capacity when compared to control for two seasons and

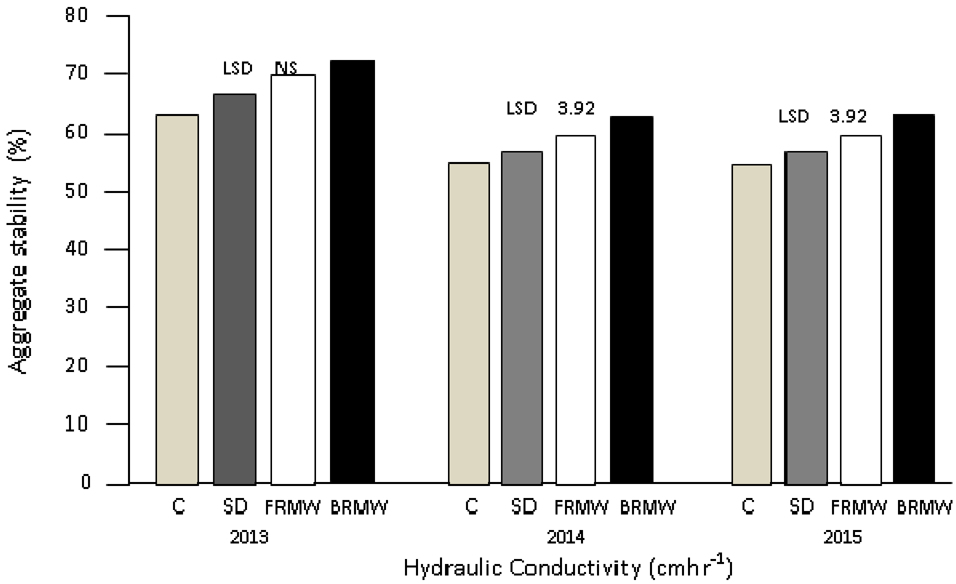

Figure 3: Effect of Aggregate stability on hydraulic Conductivity

during residual studies. Available water capacity varied among the treatments in first cropping season. Even though, available water capacity decreased after 2013 cropping season, the plot amended with burnt rice mill agro-waste had higher value for the three seasons compared to values recorded for plots receiving fresh rice mill and sawdust agro-wastes.

The result of Figure 3 showed that there was no significant treatment effect of aggregate stability on hydraulic conductivity in first cropping season. However, in second cropping and residual seasons, the plots amended with agro- wastes had significantly ($P<0.05$) higher hydraulic conductivity than control. The values of hydraulic conductivity were higher in agro-wastes amended plots relative to control in first cropping season and generally decreased in subsequent seasons. The plot amended with burnt rice mill agro- waste had highest hydraulic conductivity values for three seasons compared to plots receiving fresh rice mill and sawdust agro-wastes, respectively.

Significantly higher water retention, available water capacity and hydraulic conductivity in plots amended with agro-wastes compared to control could be attributed to positive effect of the treatments on bulk density, total porosity and aggregate stability in relation to soil water status. The agro –wastes loosened soil compaction by increasing its volume and this not only increased total porosity but water storage pores as well as water transmission in soil column. Improvement in soil moisture retention due to agro -wastes amendment had been earlier reported by Mbah (2004) and Nnabude and Mbagwu (2001). Furthermore, significantly higher moisture retention and available water capacity in agro-wastes amended plots could be linked to specific surface area and coloidal properties released to the soil as well as hydrophilic nature of the agro-wastes. This is in consonance with the earlier observation of Nwite et al. (2011) and Nyamagara (2001) that water retention and availability was significantly higher in plots receiving agro -wastes amendment relative to control.

Similarly, increased hydraulic conductivity could be due to formation of a larger number of water stable aggregates through links between smaller particles (Razzi et al., 2004) in plots amended with agro-wastes relative to control that was able to withstand dispersion action of water and increased water transmission. Several authors including Mbah et al. (2009), Ezeaku and Anikwe (2006) and Anikwe (2000) corroborated that hydraulic conductivity was higher in plots amended with agro-wastes compared to control. Significantly higher moisture retention and available water capacity are positive indicators of soil productivity as water could be available to crops for growth and physiological process. Significantly higher hydraulic conductivity implies greater water transmission in soil and this could result to well drained soil devoid of water logging. The generally decreased values of moisture retention, available water capacity and hydraulic conductivity after first cropping season is attributed to continuous cultivation. Continuous cultivation could cause re-alignment in soil particles orientation and increase soil density with consequent decrease in pore volume as well as increased dispersion in soil particles. Increase in soil density due to continuous cultivation is in line with the report of Anikwe et al. (2003) and Mbah et al. (2009). According to Anikwe *et al.* (2007)

Table 5. Effect of agrowastes amended on grain yields of maize

Treatment	2013	2014	2015
Control	2.10	2.00	2.00
BRMW	2.28	2.25	2.24
FRMW	2.26	2.25	2.24
SD	2.22	2.21	2.20
FLSD (0.05)	0.07	0.11	0.09

BRMW –Burnt rice mill agrowaste, FRMW – Fresh rice mill agrowaste, SD – Sawdust agrowaste.

high bulk density decreases soil pore volume and water available to crops. Obi (2000) noted that continuous tillage increased vulnerability of soil to mechanical breakdown which affected its formation of aggregate stability. Poor structural stability cause dispersion which reduce water transmission and increase water logging (Obi, 2000; Anikwe, 2000). The significantly higher moisture retention, available water capacity and hydraulic conductivity in residual season indicates that these agro-wastes could have positive long residual effect on these soil properties and soil-water relations. This is supported by the report of the Adeleye *et al.* (2011) and Mbah (2004) that water retention, available water capacity and aggregate stability were significantly higher in agro-wastes amended plots relative to control. Long residual effect of agro-wastes on water retention, availability and transmission could be economical as it would save time and conserve wastes in terms of sourcing the agro-wastes as well as reduce frequency of application. The non-significant treatment effect obtained in hydraulic conductivity in first cropping season could be attributed to comparable impact of agro-wastes amendment on soil or due to error of sampling and analysis.

Grain yield of maize

Table 5 shows grain yield of maize for three cropping seasons. The grain yield of maize ranged from 2.00 to 2.28 t ha^{-1} for 2013 and 2014 cropping seasons and 2.00 – 2.24 t ha^{-1} for residual season, respectively. The plots amended with agro-wastes had significantly higher grain yield of maize ($P<0.05$) in plots amended with agro-wastes relative to control for the three cropping seasons. Grain yields of maize were lower after first season with lowest values in residual study. The plot amended with burnt rice mill agro-waste had highest grain yields of maize for the three cropping seasons. The grain yield of maize was 8, 11 and 11% higher in BRMW amended plot compared to control for 2013, 2014 and 2015 seasons, respectively. The significantly higher grain yields of maize in plots amended with agro-wastes are supported by results of Table 3-4 and Figures 1-3, respectively. Significant agro-wastes treatment effect on studied soil properties acted as boost to grain yields of maize in plots receiving amendment relative to control. The grain yields of maize in agro-wastes amended plots are comparable to average global maize yields of 2.5 t ha^{-1} (Harper, 1999) and medium to high values (NPAFS, 2010) as obtained in southeast ecological environment of Nigeria. The failure to sustain the increase in grain yields of maize after first season could be attributed to low nutrient reserve (Aulakh *et al.,* 2007) and continuous cultivation (Mbah *et al.,* 2009).

Furthermore, low grain yields of maize in subsequent years after 2013 cropping season could also be adduced to be in line with the trends obtained in soil water relations as shown in Figures 1-3 and Tables 3-4. This is further supported the findings of Molua and Lawbi (2006) that water was the most critical factor affecting crop yield. Consequently, Anikwe *et al.* (2007) had noted that high bulk density and low porosity could reduce root proliferation and cumulative feeding area of crops giving rise to low yield.

CONCLUSION

This research has shown that soil water relations of an ultisol amended with agro-wastes and its effect on grain yield of maize (*Zea maize L.*) could be studied under Abakaliki agroecological environment. The results showed that soil physical conditions could affect water retention, availability and transmission. Agro-wastes due to their hydrophilic nature when used to amend the soil increased moisture retention, availability and transmission unlike in control. The positive effect of good soil water relations in agro-wastes amended plots is translated in significantly higher grain yields maize in the soil for three cropping seasons.

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