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Physico-chemical Properties in Rhizosphere of Some Field Crops at Different Growth Stages in a Sandy Clay Loam Soil in Sourthern Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The effects of different cultivated crops and their growth periods on some hydraulic and chemical properties of a sandy clay loam soil at the University of Port Harcourt, Teaching and Research Farm, in Choba, Rivers State, Nigeria was studied. The objective was to understand the changes in soil physical and chemical properties near the plant environment during the growing period for optimum management. Four (4) crops: Maize (*Zea mays* L.), Okra (A*belmoschus esculentus*), Pepper (*Capsicum annuum*), and Garden egg (*Solanum melongena* F.) were planted to native fallowed soil and the soil properties measured at three (3) growth stages of the crops viz: Establishment, Flowering, and Maturity. Results revealed that the plants did not modify the soil textural class. Significant changes in bulk densities and saturated hydraulic conductivity were found during the flowering stage of the crops. Bulk density of 1.36 and 1.34 g cm^{-3} were significantly ($p<0.05$) low at during flowering and maturity stages, respectively, in Garden egg soils. The highest saturated hydraulic conductivity (K_{sat}) values of 22.9 and 27 cm h^{-1}, respectively, were significant ($p<0.05$) during the same periods for garden egg, followed by Maize and Okra. Results also revealed that Okra, Pepper and Garden egg significantly ($p<0.05$) reduced the soil acidity at flowering growth period. Maize contributed significant additions of soil organic matter to the soil at flowering and maturity periods. Maximum removal of available plant nutrients was at flowering stage for maize when more than 80% of the plant had shown tasselling and cob formation. Therefore, monitoring the growth stages of specific plant could help in nutrient and soil management and changes in soil physical and chemical properties.

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1. INTRODUCTION

"Rhizosphere is the region of soil in the vicinity of plant roots in which the chemistry and microbiology is influenced by their growth, respiration and nutrient. Introducing crops such as maize, okra, pepper and garden egg to the soil affects physic-chemical properties of the soil environment close to the growing roots" [1]. Production of exudates in the rhizosphere by plant roots can increase microbial biomass, microbial activity, and microbial community different from those found in bulk soil. This phenomenon is referred to as the "rhizospere effect" [2]. Soil physical conditions, particularly in the rhizosphere, are continually modified by the release of plant root exudates and microbial metabolites [1]. "However, the effect of biological exudates on soil physical properties might depend on their characteristics and age of the plant" [3].

The mucilage secreted by plant root helps in binding the soil particles to form aggregates which maintain hydraulic conductivity in the soil system [4,5], thus improving soil quality by increasing water infiltration and aeration. Significant increase in the aggregate stability of soil with different substrates such as polygalacturonic acid, soluble and maize root exudate was also reported [6].

"Formation of the soil structure occurs when soil is wet and particles are mobile; therefore, rheological measures of wet soil movement under stress are more relevant physically to understanding how mechanical stresses from root growth and exudation affect soil structural development" [7]. "Living roots exude a wide range of compounds into the rhizosphere soil. Some compounds such as malate in root exudates are important in chelating cations which may be phytotoxic to plants" [8,9]. "Organic exudates such as organic acids can affect availability Fe and P in the rhizosphere and assist in the uptake of nutrients by plants. On the other hand, plant exudates in the rhizosphere can liberate nutrients through dissolution of insoluble mineral phases or desorption from clay and organic matter surfaces into the soil solution" [10]. "Plant roots can exude organic acids such as malic and citric acids into the rhizosphere which have positive effect in reducing rhizosphere pH, thus, solubilizing phosphorus bound in mineral soils" [11].

Plant secrets 10-30% of photosynthates through the root system into the rhizosphere soil [12], which help to modify the soil physico-chemical properties. Organic matter derived from plant debris and mucilages and extracellular polymeric substances of plants influences the soil environment, modifying local soil chemistry and properties to provide conditions conducive for specific needs of the plants [13] Polysaccharides contribute to mineral particle adhesion, resulting in large transiently stable aggregates [14]. Plant residue is also an important source of carbon, providing soil microbes and soil fauna with substrates for the production of stabilizing material as well as providing physical protection of the soil surface against structure-altering processes like rainfall.

"Understanding relationship between soil rhizosphere, soil microbial community and nutrient cycling is increasingly presented as essential for the ecosystem sustainability. Previous studies have reported that the species, age and abundance of host plants can shape the rhizosphere soil properties and the ability of plant to tolerate stress" [15,16]. However, very few studies have investigated the effect of plant growth stages on properties of soil within the rhizosphere [17]. As a result of this, we speculate that the rhizosphere of field crops at different growth stages can modulate soil physical and chemical properties. Therefore, the objective of this study was to determine the physical and chemical properties of rhizosphere soils of four field crops at three developmental phases of the crops viz: seedling, flowering and maturity. This will improve our knowledge on the effective management of certain crops in order to sustain soil productivity.

2. MATERIALS AND METHODS

2.1 The Study Area

The field study was conducted at the Faculty of Agriculture Teaching and Research Farm, University of Port Harcourt, (Lat. 4^{O} 45′N, Long. 7^{O}30′E) (Fig. 1). The mean annual rainfall in the area is more than 2700 mm in the months of July and October [18]. Mean annual minimum and maximum temperatures are 22° C and 31° C; while relative humidity is 85-90%. The soil is sandy clay loam, low in total nitrogen, developed from the recent alluvium, in the low-lying coastal plain sands of the Niger Deltaic [19]. The dry bulk density is about 1.53 g cm^{-3}. Some physical and chemical properties of the site are shown in Table 1.

2.2 Experiment Layout, Planting and Sampling

The experiment was laid out in a Randomized Complete Block Design (RCBD) consisting of 4 crops in three (3) replications giving a total of twelve (12) plots on a 0.225 ha farm with each plot of 0.025 ha. Four (4) crops: maize (*Zea mays* L.), okra (A*belmoschus esculentus*), pepper (*Capsicum annuum*), and garden egg (*Solanum melongena* F.) were planted as sole crops during the early rains and raised for one growing season. The pepper and garden egg were first raised in the nursery for 4 weeks before transplanting to the field, while the maize and okra were planted directly to the field. The maize was planted at row spacing of 50 x 75 cm, whereas pepper, garden egg and okra were planted at row spacing of 75 x 75 cm. The three (3) developmental phases of the crops were selected because tend to be the critical physiological stages of the crops in terms of nutrient and water demands [20].

Soil samples were collected in triplicates at 0-20 cm at the different growth stages of the crops viz: establishment, flowering and maturity. The growth stages were determined at 80% physiological appearance. Soil samples at the plant rhizosphere were collected in triplicates from two plant stands in each plot, by carefully uprooting and shaking the soil adhering to the roots into a labeled polybag at each growth stages, and bulked to obtain composite samples. Twelve (12) soil samples were collected at each growth stages, placed in labeled polythene bags, and transferred to the laboratory for analysis. Cylindrical metal cores of 6 x 5 cm (height x diameter) were used to collect undisturbed soil samples for determining some of the physical properties.

2.3 Laboratory Analyses

Particle size distribution was determined by hydrometer method [22] after the removal of gravel from the fine earth material (< 2 mm). Total organic carbon was determined by the wet oxidation dichromate method with H_2SO_4 - $K_2Cr_2O_7$, followed by residual titration with 1 N HCl [23], and was converted to organic matter by multiplying the organic carbon values by the Van Bemmelen factor of 1.724. Total nitrogen was determined by the modified macro Kjeldhahl digestion method [24]. Soil pH in water was measured with glass electrode using a 1:2.5 soil/water aqueous suspension. Bulk density was determined with core samples using the method of [25]. Total porosity was calculated with core samples using the method [26]. Saturated hydraulic conductivity was measured using the constant head soil core method [27], and calculated by rearranging the Darcy's equation for constant head condition as:

$$Ksat = \frac{V}{AT} \, x \, \frac{L}{\Delta H} \tag{1}$$

where, *V* is the volume of water collected at steady state (cm^3), *L* is the length of the soil core (cm), *A* is the cross-sectional area (cm^2), *T* is the time (h) and ∆H is the hydraulic head difference (cm).

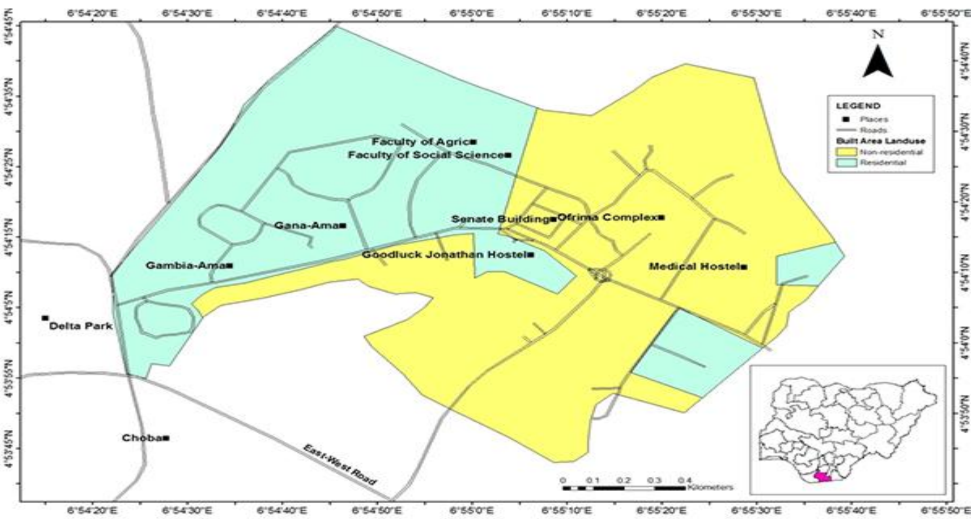

Fig. 1. Map of university park showing the sampling location [21]

2.4 Data Analysis

Data collected were analyzed by general analysis of variance using Genstart, while means were separated by Fisher least significant difference (LSD) at 5% probability level.

3. RESULTS

3.1 Effects on Physical Properties

The mean values of the physical properties of the soil at different growth stages showed that there was no significant ($p>0.05$) different in the soil during the growing periods. Bulk densities were not significantly different at the establishment growth stage of the crop, but was significantly low ($p<0.05$) being 1.36 and 1.34 g cm^{-3} during flowering and maturity, respectively in Garden egg plots (Table 1). Total porosity was consistently higher during flowering and maturity growth stages of Okra, with values of 50.2% at flowering and 51.7% at the crop maturity. Saturated hydraulic conductivity (K_{sat}) ranged from 9.94 cm h^{-1} Okra plots at establishment period to 27 cm h^{-1} under Garden egg at maturity. Significant increase in K_{sat} was consistent in Garden egg plots during the growth periods.

3.2 Effects on Chemical Properties

The pH value was significantly higher ($p<0.05$) at 5.9, 5.6 and 5.7 in Okra, Pepper and Garden egg, respectively during establishment growth periods (Table 3). Available P, total N and organic matter (OM) were consistently higher ($p<0.05$) under Maize plots. At harvesting, available P was in the order of Maize > Okra > Garden egg > Pepper (Table 3) However, low mobility of P is revealed in their very marginal changes during the growing periods. Organic matter was significantly higher in Maize plot at 21.5 g kg^{-1} during flowering period and reduced by about 25% at harvesting for the same crop. Total N was generally not significantly different across the crop development stages. Exchangeable Ca^{2+} was significant ($p<0.05$) under pepper at 4.5 C mol kg^{-1} during the establishment growth period, whereas, exchangeable K^{+} was generally not significant across the four crops and growth stages. Exchangeable acidity was significantly higher at 1.90 C mol kg^{-1} in Maize plots, followed by Pepper and Okra, while garden egg plots had the lowest exchangeable acidity value of 1.48 C mol kg^{-1} (Table 3). Percent base saturation indicating the proportion of the exchangeable bases significantly higher ($p<0.05$) at 80.3, 81.4 and 80.4 in maize, Okra, and Pepper plots, respectively, during the establishment growth period. Ay harvesting, percent base saturation were in the order of Okra > Maize > Garden egg > Pepper.

4. DISCUSSION

The non-significant different in the particle-size distribution of the soil across the different crops and growth periods was not surprising. This further confirmed that soil texture is usually a reflection of the parent materials from which the soil was formed. The crop type and growth stages did not influence the soil texture. The soil pH further confirmed that the soil is acidic; and highly weathered due to high rainfall usually obtained in this area as earlier reported [28]. The highest pH value found at the establishment stage of Okra could be due to the composition of the exudates released by the root at this physiological development. It is possible that this plant roots can exude organics which have positive effect in reducing rhizosphere acidity, and stabilize P bound in soil mineral matric [12]. The significant reduction in soil bulk density found Garden egg plots at flowering and harvesting periods could be attributed to the root characteristics of the plant with accompanying organic matter which opened up the soil and allowed for aggregation of the soil [29]. Saturated hydraulic conductivity was rapid in Garden egg soils and further collaborate the works of [30] who found significant influence of root characteristics and density on water movement into and within the soil. The effect of the biological exudates secreted by plant root on soil physical and chemical properties may depend on their physico-chemical characteristics and the quantity of the exudates [4].

Available P, total nitrogen and organic matter were higher in pre-planting plots than at the various growth stages of the crops. The decreased may be attributed to loss of soil materials during cropping and removal by the cultivated crops [30]. The variations in the levels of exchangeable Ca^{2+}, $Mg^{2+,}$ Na^{+} and K^{+} across the different growth stages could be as a result of the exudates by each plant roots which enhanced the available nutrients for plant uptake. This assertion is in agreement with [15] who reported that organic exudates such as organic acids can affect nutrient availability in the rhizosphere and assist in nutrient uptake by plants.

Table 1. Some physical and chemical properties of experimental soil before application of treatments

Soil properties	Crops			
	Maize	**Okra**	**Pepper**	**Garden egg**
Sand (g kg^{-1})	564	552	582	582
Silt (g kg^{-1})	310	320	310	320
Clay (g kg^{-1})	126	128	108	98
Texture	SCL	SCL	SCL	SCL
Total Nitrogen (g kg^{-1})	2.2	2.1	2.1	2.1
Organic matter (g kg^{-1})	24.8	25.8	24.6	25.6
pH (H_2O)	4.3	4.0	4.2	4.0
Available P (m kg^{-1})	51.2	55.2	41.8	55.2
Ca^{2+}(C mol kg^{-1})	4.0	4.0	4.1	4.1
Mg^{+}(C mol kg^{-1})	2.81	2.80	2.80	2.81
K^{+} (C mol kg^{-1})	0.26	0.28	0.27	0.21
Base saturation (%)	85.56	85.88	85.33	85.85
Bulk density (g cm^{-3})	1.53	1.52	1.53	1.53
Total porosity (%)	42.3	42.1	42.1	42.3
Ksat (cm h^{-1})	9.61	10.10	9.68	9.77

Ksat- saturated hydraulic conductivity, SCL- sandy clay loam

Table 2. Some physical properties of the soil at different growth stages of the crops after the application of treatments

Soil properties	Maize	Okra	Pepper	Garden egg	LSD (0.05)
Establishment					
Sand (g kg^{-1})	567	582	582	570	NS
Silt (g kg^{-1})	305	290	290	300	NS
Clay (g kg^{-1})	128	118	128	128	NS
Bulk density (g cm^{-3})	1.52	1.50	1.54	1.54	NS
Total porosity (%)	43.7	43,1	44.2	43.6	NS
K_{sat} (cm h^{-1})	10.08	9.94	10.11	11.2	NS
Flowering at 80%					
Sand (g kg^{-1})	592	592	575	582	NS
Silt (g kg^{-1})	280	280	310	300	NS
Clay (g kg^{-1})	128	128	113	118	NS
Bulk density (g cm^{-3})	1.49	1.49	1.50	1.36	0.13*
Total porosity	41.6	50.2	49.2	42.5	4.29*
K_{sat} (cm h^{-1})	20.4	18.1	18.3	22.9	3.18*
Maturity/Harvesting					
Sand (g kg^{-1})	592	562	542	564	NS
Silt (g kg^{-1})	290	310	340	310	4.12*
Clay (g kg^{-1})	118	128	118	126	NS
Bulk density (g cm^{-3})	1.41	1.42	1.45	1.34	0.11*
Total porosity	41.2	51.7	51.4.5	43.6	6.21*
K_{sat} (cm h^{-1})	26.9	20.4	20.2	27.0	3.11*

*NS- non-significant at p > 0.05, *Significant at p < 0.05, Ksat- saturated hydraulic conductivity*

Table 3. Chemical properties of the soil at different growth stages of the crops after the application of treatments

Soil properties	Maize	Okra	Pepper	Garden egg	LSD(0.05)
Establishment					
pH (H_2O)	4.9	5.9	5.6	5.7	0.84*
Available P (mg kg^{-1})	48.9	31.5	34.1	35.5	9.8*
Total N (g kg^{-1})	1.7	1.5	1.3	1.2	NS
Organic matter (g kg^{-1})	21.9	17.8	15.4	18.5	4.1
Ca^{2+} (C mol kg^{-1})	3.61	3.72	4.00	3.80	NS
Mg^{2+} (C mol kg^{-1})	2.47	1.86	1.80	1.81	0.35*
K^{+} (C mol kg^{-1})	0.22	0.20	0.20	0.20	NS
Na^{+} (C mol kg^{-1})	0.18	0.18	0.17	0.18	NS
EA (C mol kg^{-1})	1.60	1.36	1.52	1.56	NS
Base saturation (%)	80.3	81.4	80.4	77.3	3.51*
Flowering at 80%					
pH (H_2O)	4.7	5.6	5.7	5.2	0.45*
Available P (mg kg^{-1})	30.52	37.65	37.70	33.85	2.11*
Total N (g kg^{-1})	1.5	1.4	1.5	1.5	NS
Organic matter (g kg^{-1})	21.5	17.5	19.2	18.7	3.1*
Ca^{2+} (C mol kg^{-1})	4.05	3.80	4.50	4.40	0.57*
Mg^{2+} (C mol kg^{-1})	2.20	2.55	2.22	2.22	NS
K^{+} (C mol kg^{-1})	0.17	0.18	0.45	0.18	NS
Na^{+} (C mol kg^{-1})	1,17	0.17	0.17	0.17	0.90*
EA (C mol kg^{-1})	1.90	1.80	1.87	1.48	0.41*
Base saturation (%)	77.65	78.93	79.50	82.38	NS
Maturity/Harvesting					
pH (H_2O)	5.7	5.9	5.7	5.8	NS
Available P (mg kg^{-1})	36.75	41.00	36.90	39.70	2.75*
Total N (g kg^{-1})	1.6	1.6	1.6	1.5	NS
Organic matter (g kg^{-1})	17.2	18.0	16.7	17.4	NS
Ca^{2+} (C mol kg^{-1})	3.50	3.70	3.40	3.35	NS
Mg^{2+} (C mol kg^{-1})	2.45	2.85	1.80	2.85	1.08*
K^{+} (C mol kg^{-1})	0.18	0.20	0.20	0.45	NS
Na^{+} (C mol kg^{-1})	0.20	0.17	0.19	0.17	NS
EA (C mol kg^{-1})	1.61	1,54	1.88	1.64	0.25*
Base saturation (%)	78.17	81.23	74.87	77.71	4.25*

*NS- non-significant at $p > 0.05$, *significant at $p < 0.05$, EA- exchangeable acidity*

5. CONCLUSSION

Conclusions drawn from this study are that: 1.The crops exhibited different modifications of the rhizospere soils at specific growth stages. 2. Saturated hydraulic conductivity, as well as the total porosity was also influenced by the type of plant and at specific growth stages 3. Garden egg significantly reduced the soil bulk density, increased saturated hydraulic conductivity and total porosity at the flowering and harvesting periods. 4. Maize crop depleted greater soil nutrients at the flowering stage. Therefore, significant changes in soil physical and chemical properties should be expected for maize and garden egg crops during the flowering growth period.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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