Physico-chemical properties in rhizosphere of field crop covers during growth stages in a sandy loam soil

ABSTRACT

The effects of different cultivated plants 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 was studied. The objective was to understand the behavior of soil properties near the plant environment during the growing period for optimum management, especially of fragile soils. Four (4) plants: Maize, Okra, Pepper, and Garden egg 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. Maximum activities at the rhizospheres of the plants were found during the flowering stage. Bulk density of 1.36 and 1.34 g cm^{-3} were significantly ($p<0.05$) low at during the 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. 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 both nutrient soil management and possible expected changes in soil physical and chemical properties.

Key words: soil texture; bulk density; saturated hydraulic conductivity; exchangeable bases; soil acidity

Comment [AAS1]: Write Scientific/botanical name of all four test crops as appear first in the text. Soil textural class is permanent/ Stable fundamental soil property; hence there will be no any change in it by plant induced root rhizophric modification.

Concluding sentence is not clear (Last sentence of abstract…..” Therefore …………….properties”. .

Comment [AAS2]: Maximum activity of ??

1. INTRODUCTION

Introduction of plants to the soil affects physicochemical properties and biological features of the soil environment close to the growing roots [1]. Deposition of nutrients 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, 3]. 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

Comment [AAS3]: The description of changes in rhizospheric soil properties need to for selected crops. Cite some crop specific references for such changes (Four selected crops).
Avoid writing of info. For those properties which were not described in result and discussion section.

Comment [AAS4]: Not clear??
Are authors trying to say root exudates by plant root?

exudates on soil physical properties might depend on their physicochemical characteristics and age of the plant [4, 5]

According to [6, 7], the quantity and physicochemical characteristics of root exudates are determined by the plant species, the age of an individual plant and external factors such as soil structure, presence of microorganisms and nutritional status. The mucilage secreted by plant root, a viscous, high molecular weight, and insoluble polysaccharide-rich material helps in binding of soil particles together to form aggregates which maintain hydraulic conductivity in the soil system [8, 9], thus improving soil quality by increasing water infiltration and aeration. [10] also observed significant increase in the aggregate stability of soil with different substrates such as polygalacturonic acid, modelled soluble exudates and maize root exudate.

Comment [AAS5]: Rewrite the sentence once again. Don't start sentence with reference number. For example: "Significant increase in the aggregate stability of soil with different substrates such as polygalacturonic acid, modelled soluble exudates and maize root exudates was also reported [10]."

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 [11]. –Root networks enhance soil porosity as well as soil aggregation through direct binding of particles and/or secretion of mucilages that help accolade soil particles together [12]. 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 [13, 14]. 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 [15]. 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 [15].

Plant secrets 10-30% of photosynthates through the root system into the rhizosphere soil [16], 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 [17]. Polysaccharides contribute to mineral particle adhesion, resulting in large transiently stable aggregates [18]. 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 [19, 20]. However, very few studies have investigated the effect of plant growth stages on properties of soil within the rhizosphere [21]. 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 under four different plants development phases viz., ~~at~~ seedling, flowering and maturity growth stages. This will improve our knowledge on the effective management of certain crops in order to sustain soil productivity.

Comment [AAS6]: Is it three or four? Please check.

2. MATERIALS AND METHODS

Comment [AAS7]: Information on crop growing practices and input addition is lacking and essential to write herewith (As these practices affect the soil properties and plant growth).
Plant growth duration and timing of sampling need to mention herewith (As the selected crops may having different duration).
Is there any reason of selecting these four crop plants. Provide some info. For this.
Study is conducted for one growing season or repeated for multiple years (2, 3 or 4 years)- Need to mention herewith.

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 [22]. Mean annual minimum

Comment [AAS8]: Is it correct? Please confirm and do needful.

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 [23]. The dry bulk density is about 1.53 g cm^{-3}. Some physical and chemical properties of the site are shown in Table 1.

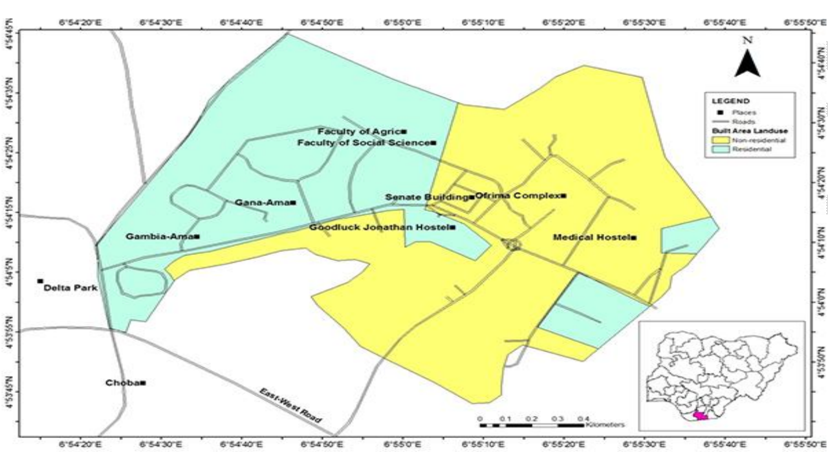

Fig. 1. Map of University Park showing the sampling location

Comment [AAS9]: Reference/Source of map need to cite herewith.

2.2 Experiment Layout, Planting and Sampling

The experiment was laid out in a Randomized Complete Block Design (RCBD) consisting of 4 treatments in three (3) replications giving a total of twelve (12) plots on a 0.225 ha farm. Four (4) crops (maize, okra, pepper and garden egg each) were planted as sole crops during the early rains. 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.

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 cm ×x 5 cm were used to collect undisturbed soil samples for physical determinations of some physical properties.

Comment [AAS10]: Dimensions are not clear.

2.3 Laboratory Analyses

Particle size distribution was determined by hydrometer method [24] after the removal of gravel from the fine earth material (< 2 mm diameter). 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 [25], 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 [26]. 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 [27]. Total porosity was calculated with core samples using the method [28]. Saturated hydraulic conductivity was measured using the constant head soil core method [29], and calculated by rearranging the Darcy's equation for constant head condition as:

$$Ksat = \frac{V}{AT} \text{ x } \frac{L}{\Delta H} \quad (1)$$

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 ΔH is the hydraulic head difference (cm).

2.4 Data Analysis

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

Table 1. Some physical and chemical properties of the soil of the study area

Soil properties	Plots			
	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

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 textural class during the growing periods. The marginal changes in sand, silt and clay contents did not influence the soil texture (Table 2).

Comment [AAS11]: Changes in soil textural class due to plant rhizospheric phenomenon is not expected.
The results were non-significant for most of the soil properties indicating the inferior selection of properties for studying the changes in soil properties. The MS might have concentrated on soil biological properties which are most dynamic with respect to crop growth and management aspect.

The sand content ranged between 567 and 582, 575 and 592, and 542 and 592 g kg^{-1} at establishment, flowering, and maturity growth periods, respectively. Clay content ranged between 118-128 g kg^{-1}. Bulk densities were not significantly different at the establishment growth stage of the crop, but was significantly low ($p<0.05$) at 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} for 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 ($p<0.05$) in 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 crops. Exchangeable Ca^{2+} was significantly higher ($p<0.05$) in pepper plots at 4.5 C mol kg^{-1} soil 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.

Table 2 Some physical properties of the soil at different growth stages of the crops

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

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

4.0 DISCUSSION

Comment [AAS12]:

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 [30]. The crop type and growth stages did not influence the soil texture, despite minor contributions to clay content by organic matter from the crop residues [31]. The soil is generally acidic; due to possible leaching of the highly weathered soils as a result of high rainfall associated with the environment as earlier reported [32]. 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 [15]. The significant reduction in soil bulk density found Garden egg plots at flowering and harvesting periods could be adduced to the root characteristics of the plant with accompanying organic matter which opened up the soil and allowed for aggregation of the soil [33]. Saturated hydraulic conductivity was rapid in Garden egg soils and further collaborate the works of [34] 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].

Comment [AAS13]: Is it for selected soil/location? Write clearly please.

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 [35]. 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.

5. CONCLUSSIONS

Comment [AAS14]: Write result in concise and objective addressing sentences;
1. Indicate the crops showing maximum changes in the soil properties and also give percent changes in any 1 or 2 significant properties.
2. Indicate stage of crop growth showing maximum changes in selected soil properties and percent changes over initial soil.
3. No need to write about all changes in conclusion as these changes was already written in result and discussion.

Conclusions drawn from this study are that: different plants exhibit different pattern of nutrient removal from the rhizospere at specific growth stages. Soil bulk density was not significantly reduced until at the flowering and harvesting periods, when the plant roots especially the Garden egg sufficiently modified the plant environment. Saturated hydraulic conductivity, as well as the total porosity were also influenced by the plant and specific growth stages. In this study, the maize plant specifically removed greater soil nutrients at the flowering stage while exchangeable acidy was lowered at harvesting. Garden egg improved bulk density and saturated hydraulic conductivity of the soil. Therefore, for crop and soil management in highly weather soils of the tropics such as the one used in this study, greater activities should be expected at the plant rhizosphere during the flowering stage of the crop, especially maize and garden egg.

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