



# **Pluvial Flooding Impacts on Soil Properties under Oil Palm (*Elaeis guineensis*) Plantation in a Lowland Humid Tropical Environment of Southern Nigeria**

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## **Abstract**

Flooding has been a major threat not only to the socioeconomic growth and development of tropical countries but also on their agricultural farmlands. Therefore, this study assessed the impact of pluvial flooding on the morphological, physical, chemical and biological properties of soils under oil palm (*Elaeis guineensis*) plantation in a lowland humid tropical environment of southern Nigeria. A total of eighteen (18) soil samples were collected from flooded and non-flooded sites at three respective soil depths (0-15, 15-30 and 30-45 cm). Soil samples were analyzed in-situ for their key morphological features while the selected physical, chemical and biological properties were determined following standard laboratory methods. Results indicated the dominance of sand fractions in all the test soils and they were slightly acidic. Pluvial flooding had increasing effects on iron - Fe (47.20, 51.26 and 54.50 mg kg<sup>-1</sup>) and manganese - Mn (2.66, 2.63 and 2.16 mg kg<sup>-1</sup>) across the three soil depths. However, the poorly drained soils were deficient in copper (Cu) concentrations and inhibited the proliferation of bacteria and fungi. Organic carbon (OC), total nitrogen (TN) and available phosphorous (Avl P), as well as the exchangeable cations (calcium - Ca, sodium - Na, potassium - K and magnesium - Mg) were rated adequate. The study concluded that the deficiency of Cu element in all the test soils may inhibit oil palm plant and root growth.

**Keywords:** NIFOR, Oil palm plantation, Pluvial flooding, Soil properties, Tropical environment

## **Introduction**

The current climate change phenomenon has necessitated scientific investigations into the effects of hydroclimatic variations on soils (De Jager et al., 2012). Flooding which may be caused by natural and/or anthropogenic events has been described as the accumulation of water beyond its normal limit and rise to overflow land areas that are not usually submerged (European Union Floods Directive, 2007; Umar & Gray, 2022). Since the late 20th century, increased rainfall-driven flood occurrences in many parts of the world have been observed (Kundzewicz et al., 2014). Floods have posed a great threat not only to the socioeconomic

growth and development of various countries but on agricultural farmlands. Pluvial floods are triggered by heavy precipitation and are independent of an overflowing water body (Kundzewicz & Pinskiwar, 2022). Urban land expansion due to increasing human population have made farmers to cultivate marginal lands which are susceptible to flooding and may adversely affect the accumulation of ground biomass and alter the soil morphological, physical, chemical and biological properties (Ubuoh et al., 2016). Soil morphological characteristics are studied from in-situ evaluation of the soils while the physical, chemical and biological properties are

determined using standard laboratory techniques (Ugwa et al., 2017).

Flood is the most common and widespread of all natural disasters, although it may have positive or negative effects on the soil (Clement, 2012). Flooding, although destructive, can be considered an important factor for enhancing soil quality due to long term alluvial depositions. During flooding, the saturated soil combined with microbial activities depletes soil oxygen and cause a decline in soil nutrients altering the nutrient cycle (Unger et al., 2009). Soil microbes are not very effective at decomposing plant residues when in saturated soils therefore slowing the denitrification process and uptake of phosphorous. Visser et al. (2003) asserted that oxygen shortage is the most important environmental factor that inhibits plant growth in flooded areas. If persistent, it may result in plant dieback and decline, attack by root rot organisms and declining photosynthetic capability (Lee et al., 2014). Oxygen shortage affects soil aeration but releases readily available nutrients in the soil that were left-over from the previous flood event and those that result from the rapid decomposition of plant litter that has accumulated over time. Njoku and Okoro (2015) reported increase in pH and organic carbon in soils after flooding.

The Centre for Research on the Epidemiology of Disasters (CRED, 2023) reported that floods have affected approximately 80 million people in sub-Saharan Africa in the last four decades. In Nigeria, during the rainy season and especially in the lowland humid tropical environment, pluvial flooding has remained a dominant ecological threat and is sometimes deleterious to soil properties particularly in poorly drained rural areas. Orimoloye (2011) reported that most soils of southern Nigeria are inherently low in fertility, susceptible to erosion and acidic with poor physical structure. Studies such as the physicochemical characteristics of seasonally flooded soils in Bangladesh and their management implications (Akter et al., 2011); impact of Nigerian flood disaster on the soil quality of farmlands in Oshimili south local government area of Delta State, Nigeria (Osakwe et al., 2014); assessment and control measures of flood risk in Ajibode area of Ibadan, Oyo State, Nigeria (Adetunji & Oyeleye, 2018); assessment of soil properties for flood vulnerability

zones in parts of Obio/Akpor local government area, Rivers State, Nigeria (Nwankwoala & Jibril, 2019); causes and effects of flooding in Nigeria (Mfon et al., 2022); participatory risk assessment of pluvial floods in four towns of Niger (Tiepolo et al., 2023) have revealed diverse incidences and impacts of flooding on the soil environment.

However, scholarly literature aimed at evaluating the impacts of pluvial flooding on the morphological, physical, chemical and biological properties of soil under oil palm (*Elaeis guineensis*) plantation in the lowland humid tropical environment of southern Nigeria remains undocumented. Contemporary enquiries (Ekpenkhio & Ugwa, 2023, Balogun et al., 2023; Ugwa et al., 2022) in the geographic region of interest are mainly soil quality studies based on land use change. They did not examine pluvial flooding effects on soil properties in an oil palm agroecosystem. The effects of pluvial flooding on agricultural soils which may lead to a decline or increase in soil properties necessitated this investigation. Specifically, the objectives of this study were to: (a) characterize the morphological properties of soils impacted by pluvial flooding in an oil palm environment, and (b) assess the impact of pluvial flooding on the physical, chemical and biological properties of soil in an oil palm environment in lowland humid tropical region of southern Nigeria.

## **Materials and Methods**

### *Study area*

This study was carried out on the inland-valley and upland soils of the Nigerian Institute for Oil Palm Research (NIFOR) main station in Ovia North-East Local Government Area of Edo State, Nigeria (Figure 1). The study area lies between Latitude 6° 33' to 7° 25' N and Longitude 5° 15' to 5° 37' E. It is located in the lowland humid tropical climate zone of southern Nigeria with mean annual temperature of 26°C and average annual rainfall of between 1500 mm and 3500 mm (Ojanuga, 2006; Odjugo, 2012). The soils of NIFOR developed on coastal plain sand parent materials. The soils are highly weathered acidic sandy soils, well drained with low to moderate fertility (Osayande et al., 2013). Soil leaching is high especially during the rainy season when rainfall exceeds

evapotranspiration. Four soil series of acid sands have been classified at NIFOR main station. They are Ahiara, Kulfo, Orlu and Alagba soil series (NIFOR, 1982). Soils of the inland-valley are mainly Ahiara series while those of the upland soils are Orlu series. The natural vegetation consists of dense forest of mostly perennial trees with tropical hard woods which have been replaced by oil palm

plantations. The main permanent crop, oil palm, occupies prominent positions in the land use of the study area.

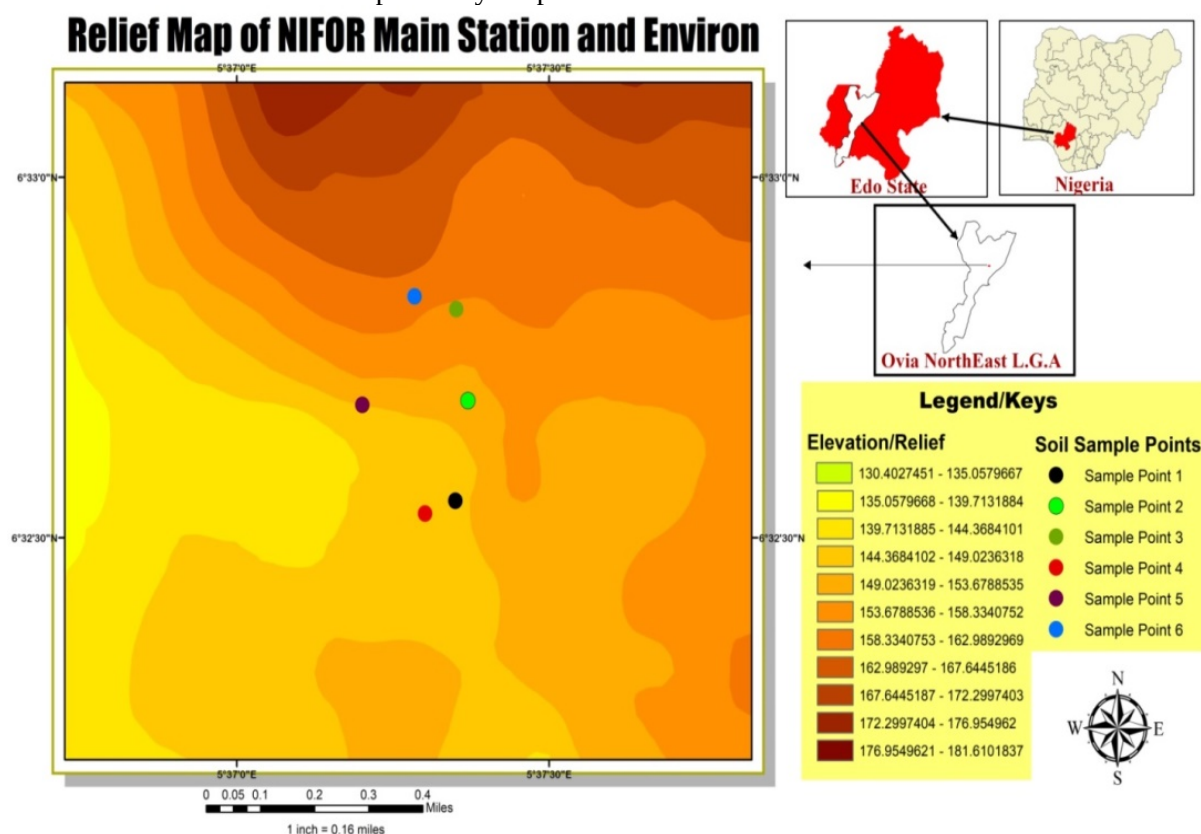


Figure 1: Nigerian Institute for Oil Palm Research (NIFOR) in Ovia North-East Local Government Area of Edo State, Nigeria

Sources: Esri, Garmin, USGS and Geospatial Links Company (2023)

### Field work

Soil samples were collected during the rainy season from both flooded and non-flooded sites within the study area using a soil auger. The inland-valley area served as the sample area for flooded soils while the upland area served as the sample area for non-flooded (control) soils. Nine soil samples each were randomly collected from three different sampling points at a minimum of 15 m apart and at three depth levels; 0-15 cm (topsoil), 15-30 cm (subsoil) and 30-45 cm (deep subsoil) from the

flooded and non-flooded sites respectively. This will help to compare the spatial effects of pluvial flooding on soils as depth increased. Also, the boundary of 45 cm soil depth was chosen because it is the rooting depth for most tropical tree crops. Thus, a total of 18 soil samples were collected for the purpose of this study. The key morphological features of each soil sample were evaluated in-situ using a Munsell soil colour chart and by hand-felt technique. In order to track where the soil samples were collected, each of the soil sampling points

was geo-referenced using a handheld global positioning system (GPS).

#### *Soil laboratory analysis*

The homogenized soil samples were air dried and sieved through 2 mm sieve before soil laboratory analyses were carried out using standard laboratory procedures. Soil texture (sand, silt and clay) was determined using hydrometer method (Gee & Or, 2002). Bulk density (BD) was determined using Grossman and Riensah (2002) method. Total porosity (TP) was calculated from the values of bulk density (BD) and particle density (PD) using the formula:  $TP = [1 - (BD / PD)] \times 100$  (Equation 1). The average particle density of mineral soils which is  $2.65 \text{ g cm}^{-3}$  was used for the computation (Brady & Weil, 2007). Water holding capacity (WHC) and electrical conductivity (EC) was carried out following the method adopted by Chopra and Kanzar (1988). Soil pH was determined by McLean (1982) method. Organic carbon was determined by the dichromate wet oxidation method of Walkley and Black (Jackson, 1969). Total nitrogen was determined using micro-kjeldahl method (Bremner & Mulvaney, 1982). Available phosphorus was determined calorimetrically by molybdenum blue method (Bray & Kurtz, 1945). For the exchangeable cations, calcium (Ca) and magnesium (Mg) were determined by ammonium acetate method while sodium (Na) and potassium (K) were by flame photometer. 0.005 diethylenetriaminepentaacetic (DTPA) acid was used to extract available micronutrients (copper - Cu, iron - Fe, zinc - Zn and manganese - Mn) from the soils and their concentrations were measured with Perkin-Elmer Analyst 300 atomic absorption spectrophotometer (AAS) with flame atomization (Lindsay & Norvell, 1978). Enumeration of total heterotrophic bacteria counts (THB) and total heterotrophic fungi counts (THF) was by pour-plating of 0.1 ml of the appropriate soil dilution ( $10^{-6}$ ) on nutrient agar plates. The microbial load was determined as a colony forming unit (cfu  $\text{g}^{-1}$ ) in each sample after inoculated plates were incubated for 24 hours at  $30^\circ\text{C}$  (Phil-Eze, 2010).

#### *Data analysis*

The soil data were analyzed in Microsoft Excel, version 2010 for descriptive and inferential statistics. Range, mean, standard deviation and coefficient of variation were tabulated for all the soil physical, chemical and biological properties in both the flooded and non-flooded sites and across the three soil depths. Student t-test was used to test for significant differences in soil properties between the two study sites and for each soil depth.

### **Results and Discussion**

#### *Morphological features*

The morphological properties of flooded and non-flooded soils of NIFOR main station are shown in Table 1. Under moist conditions floodplain soils are characterized by dark grey, very dark reddish grey, dark brown, reddish yellow and brown with dominant hue of 7.5 YR (Nsor & Akamigbo, 2009). Table 1 reveals that soils of the two study sites do not have identical colours under moist condition. Although the soils in both flooded and non-flooded sites had different hue and chroma values, they were predominantly dark reddish brown. The dominance of dark reddish brown-coloured soils suggests high organic matter contents in the study sites. The dominant soil texture from in-situ evaluation of the soil samples ranged between sandy loam and loamy sand in both the flooded and non-flooded sites. These soil textures are usually loose, excessively drained and retain little moisture and nutrient for plant growth. The structure of the flooded soils were weak, medium, coarse or angular blocky. This structural observation agrees with the findings of Troeh and Thompson (1993) who observed that floodplain soils that are seasonally dry possess similar structures. The firm consistency (when moist) of majority of soil samples suggests that the soils anchor plants properly. In both flooded and non-flooded sites, the roots were generally fine and few. This maybe as a result of the centrosema grasses and shrubs found in the study sites. Mottles although absent in some soil samples were few, fine and faint in the study sites. Soil mottling could arise as a result of redox condition in the soil matrix (Ugwa et al., 2017).

Table 1: Morphological features of flooded and non-flooded soils in an oil palm (*Elaeis guineensis*) environment

| Sampling points   | Depth (cm) | Major colour (moist) | Texture (field) | Structure | Consistency (moist) | Roots    | Mottles    |
|-------------------|------------|----------------------|-----------------|-----------|---------------------|----------|------------|
| Flooded soils     |            |                      |                 |           |                     |          |            |
| A <sub>1</sub>    | 0 - 15     | 7.5YR 3/4; Db        | LS              | 1, 2, Gr  | F                   | Fi, Fe   | -          |
| A <sub>2</sub>    | 15 - 30    | 5YR 3/3; Drb         | SL              | 2, C, Abl | F                   | Fi, Fe   | Fa, Fe, Fi |
| A <sub>3</sub>    | 30 - 45    | 5YR 3/2; Drb         | SL              | 2, C, Abl | F                   | Fi, Fe   | -          |
| B <sub>1</sub>    | 0 - 15     | 7.5YR 2.5/3; vdb     | SL              | 1, C, Abl | F                   | C, M     | -          |
| B <sub>2</sub>    | 15 - 30    | 5YR 3/3; Drb         | SL              | 1, C, Bl  | L                   | Fi, Fe   | Fa, Fe, Fi |
| B <sub>3</sub>    | 30 - 45    | 10R 3/4; dr          | SL              | 2, F, Abl | Fr                  | Fi, Fe   | C, Di, Fe  |
| C <sub>1</sub>    | 0 - 15     | 2.5YR 3/4; Drb       | SL              | 2, F, Gr  | F                   | C, M     | -          |
| C <sub>2</sub>    | 15 - 30    | 2.5YR 2.5/4; Drb     | SL              | 2, F, Gr  | Fr                  | Fi, M    | -          |
| C <sub>3</sub>    | 30 - 45    | 2.5R 3/6; Dr         | SL              | 2, Me, Bl | F                   | Fi, F    | Di, Me     |
| Non-flooded soils |            |                      |                 |           |                     |          |            |
| D <sub>1</sub>    | 0 - 15     | 2.5YR 3/3; Drb       | LS              | 1, 2, Gr  | Fr                  | Fi, Fe   | -          |
| D <sub>2</sub>    | 15 - 30    | 5YR 3/4; Drb         | SL              | 1, 2, Gr  | F                   | Fi, Fe   | -          |
| D <sub>3</sub>    | 30 - 45    | 5YR 3/3; Drb         | SL              | 1, 2, Abl | F                   | Fi, Fe   | -          |
| E <sub>1</sub>    | 0 - 15     | 5YR 3/2; Drb         | LS              | 1, 2, Gr  | F                   | Fi, M    | -          |
| E <sub>2</sub>    | 15 - 30    | 2.5YR 3/4; Drb       | SL              | 1, 2, Gr  | F                   | Fi, Fe   | -          |
| E <sub>3</sub>    | 30 - 45    | 2.5YR 2.5/3; Drb     | SL              | 2, C, Gr  | F                   | Fi, Fe   | -          |
| F <sub>1</sub>    | 0 - 15     | 7.5 YR 3/3; Db       | LS              | 1, C, Abl | L                   | C, M     | Co, Fa, Fe |
| F <sub>2</sub>    | 15 - 30    | 5YR 3/4; Drb         | SL              | 1, C, Abl | L                   | C, Fi, M | -          |
| F <sub>3</sub>    | 30 - 45    | 10R 3/2; dr          | SL              | 1, C, Bl  | F                   | C, M     | -          |

Key:

Major colour (moist): Db - Dark brown, Drb - Dark reddish brown, vdr - very dark brown, Dr - dark red, dr - dusky red

Texture (field): LS - loamy sand, SL - sandy loam

Structure: 1 - weak, 2 - medium, Abl - angular blocky, Bl - blocky, C - coarse, F - firm, Gr - granular

Consistency (moist): F - firm, Fr - friable, L - loose

Roots: Fi - fine, C - coarse, Fe - few, M - many

Mottles: C - coarse, Co - common, Di - distinct, Fa - faint, Fe - few, F - fine, Me - medium

### Physical properties

Results of the physical properties of flooded and non-flooded soils as displayed in Table 2 revealed the preponderance of sand in all the soil samples as their mean values varied between 683.33 and 850.00 g kg<sup>-1</sup>. Since the study area is located within the tropical rainforest which is characteristic of heavy rainfall, silt and clay contents may have been eroded below the investigated soil depths thereby leaving sand fractions dominant in the soils. Also, the generally sandy soils may indicate the

dominance of quartz in the parent material of the study area. Silt and clay values increased with soil depth in both top and sub soils of the study locations but declined in the deep subsoil layers. Clay migration below the deep subsoil due to intermittent flooding events may have accounted for the lower clay values found in the three soil depths of the flooded and non- flooded sites. This finding is in agreement with the works of Ubuoh et al. (2016) and Ugwa et al. (2017).

Table 2: Results of the impact of pluvial flooding on soil physical properties in an oil palm (*Elaeis guineensis*) environment

| Soil properties               | Depth (cm) | Flooded soils   |        |       |        | Non-flooded soils |        |        |        | p-value |
|-------------------------------|------------|-----------------|--------|-------|--------|-------------------|--------|--------|--------|---------|
|                               |            | Range           | Mean   | SD    | CV (%) | Range             | Mean   | SD     | CV (%) |         |
| Sand<br>(g kg <sup>-1</sup> ) | 0 - 15     | 700.00 - 850.00 | 783.33 | 76.37 | 9.75   | 800.00 - 900.00   | 850.00 | 50.00  | 5.88   | 0.21    |
|                               | 15 - 30    | 650.00 - 700.00 | 683.33 | 28.86 | 4.22   | 700.00 - 750.00   | 716.66 | 28.86  | 4.02   | 0.09    |
|                               | 30 - 45    | 700.00 - 750.00 | 716.66 | 28.86 | 4.02   | 650.00 - 850.00   | 740.00 | 101.48 | 13.71  | 0.38    |
| Silt<br>(g kg <sup>-1</sup> ) | 0 - 15     | 100.00 - 250.00 | 150.00 | 86.60 | 57.73  | 100.00 - 150.00   | 116.66 | 28.86  | 24.74  | 0.31    |
|                               | 15 - 30    | 200.00 - 250.00 | 233.33 | 28.86 | 12.37  | 100.00 - 200.00   | 166.66 | 57.73  | 34.64  | 0.13    |
|                               | 30 - 45    | 100.00 - 200.00 | 166.66 | 57.73 | 34.64  | 50.00 - 250.00    | 133.33 | 104.08 | 78.06  | 0.37    |
| Clay<br>(g kg <sup>-1</sup> ) | 0 - 15     | 50.00 - 100.00  | 66.66  | 28.86 | 43.30  | 50.00 - 100.00    | 66.66  | 28.86  | 43.30  | 0.50    |
|                               | 15 - 30    | 50.00 - 150.00  | 83.33  | 57.73 | 69.28  | 100.00 - 150.00   | 116.66 | 28.86  | 24.74  | 0.26    |
|                               | 30 - 45    | 100.00 - 150.00 | 116.66 | 28.86 | 24.74  | 100.00 - 180.00   | 126.66 | 46.18  | 36.46  | 0.40    |
| BD<br>(mg cm <sup>-3</sup> )  | 0 - 15     | 1.38 - 1.56     | 1.47   | 0.09  | 6.12   | 1.42 - 1.42       | 1.42   | 0.00   | 0.00   | 0.21    |
|                               | 15 - 30    | 1.42 - 1.61     | 1.51   | 0.09  | 6.28   | 1.42 - 1.47       | 1.45   | 0.02   | 1.98   | 0.20    |
|                               | 30 - 45    | 1.42 - 1.42     | 1.42   | 0.00  | 0.00   | 1.38 - 1.42       | 1.40   | 0.02   | 1.64   | 0.21    |
| TP<br>(%)                     | 0 - 15     | 41.13 - 47.92   | 44.52  | 3.39  | 7.62   | 46.41 - 46.41     | 46.41  | 0.00   | 0.00   | 0.21    |
|                               | 15 - 30    | 39.24 - 46.41   | 42.88  | 3.58  | 8.36   | 44.52 - 46.41     | 45.15  | 1.09   | 2.41   | 0.20    |
|                               | 30 - 45    | 46.41 - 46.41   | 46.41  | 0.00  | 0.00   | 46.41 - 47.92     | 46.91  | 0.87   | 1.85   | 0.21    |
| WHC<br>(%)                    | 0 - 15     | 32.00 - 36.00   | 34.00  | 2.00  | 5.88   | 32.00 - 36.00     | 34.66  | 2.30   | 6.66   | 0.40    |
|                               | 15 - 30    | 32.00 - 36.00   | 34.66  | 2.30  | 6.66   | 32.00 - 32.00     | 32.00  | 0.00   | 0.00   | 0.09    |
|                               | 30 - 45    | 34.00 - 36.00   | 35.33  | 1.15  | 3.26   | 30.00 - 36.00     | 32.66  | 3.05   | 9.35   | 0.09    |
| EC<br>(dS/m)                  | 0 - 15     | 5.80 - 7.20     | 6.66   | 0.75  | 11.35  | 5.80 - 6.00       | 5.86   | 0.11   | 1.96   | 0.09    |
|                               | 15 - 30    | 6.90 - 7.00     | 6.96   | 0.05  | 0.82   | 7.00 - 7.20       | 7.13   | 0.11   | 1.61   | 0.09    |
|                               | 30 - 45    | 7.00 - 7.20     | 7.06   | 0.11  | 1.63   | 7.00 - 7.20       | 7.13   | 0.11   | 1.61   | 0.21    |

BD - bulk density, TP - total porosity, WHC - water holding capacity, EC - electrical conductivity, SD - standard deviation, CV - coefficient of variation,

\* - significant at 0.05 level

The higher mean BD values in soils of the flooded site than non-flooded site could be attributed to the constant waterlogged state of the soil that has made the soil pore spaces compact (Biswas & Murkherjee, 1994). Using the FAO (2006) total porosity classification scheme, TP values of all the soil samples which varied between 42.88 and 46.91% were classified as either high or very high. The moisture content of this area is neither frozen nor completely dry all year round. It is mostly moist or saturated with water within the depth of the root zone. The higher WHC mean values obtained from the floodplain soils suggest the ability of soils in the in-land valley area to hold more water than the upland area. Electrical conductivity gives an estimate of ionic concentrations in soils. It is a measure of soil salinity. Mean EC values of all the soil samples insignificantly increased ( $p > 0.05$ ) with increasing soil depth in the study sites. The EC values varied between 5.86 and 7.13 dS/m. This range of values infers slightly and strongly saline soils. The higher clay TP values found in the deep subsoils of both

study sites may have caused higher EC values at that soil depth.

It is generally argued that higher soil TP connote greater ability of soils to conduct electrical currents.

#### Chemical and microbial properties

The chemical and microbial properties of soils in the flooded and non-flooded sites are presented in Table 3. The results revealed that all the soils were slightly acidic as their pH values varied between 6.00 and 6.40 (Foth & Ellis, 1997). Non-significant higher pH values ( $p > 0.05$ ) were observed in soils of the flooded area than non-flooded area across the three depth levels. This might be due to regular leaching of bases in the flooded site. However, the slightly acidic nature of the soils may not pose any danger to tree crop production. Esekhide et al. (2003) argued that tree crops in tropical environments thrive on soils with such range of pH. Organic carbon (OC) gives an estimate of organic matter in soils (Buol et al., 1973). Values of OC were observed to be higher in the flooded area than

the non-flooded area with a significant difference ( $p \leq 0.05$ ) observed in the subsoil. Periodic flooding may have caused rapid plant litter

decomposition thereby increasing OC in the floodplain soils.

Table 3: Results of the impact of pluvial flooding on soil chemical and microbial properties in an oil palm (*Elaeis guineensis*) environment

| Soil properties                              | Depth (cm) | Flooded soils |       |       |        | Non-flooded soils |       |       |        | p-value |
|----------------------------------------------|------------|---------------|-------|-------|--------|-------------------|-------|-------|--------|---------|
|                                              |            | Range         | Mean  | SD    | CV (%) | Range             | Mean  | SD    | CV (%) |         |
| pH                                           | 0 - 15     | 6.20 - 6.60   | 6.40  | 0.20  | 3.12   | 6.00 - 6.30       | 6.10  | 0.17  | 2.83   | 0.09    |
|                                              | 15 - 30    | 6.20 - 6.60   | 6.40  | 0.20  | 3.12   | 5.80 - 6.20       | 6.00  | 0.20  | 3.33   | 0.09    |
|                                              | 30 - 45    | 5.90 - 6.50   | 6.26  | 0.32  | 5.12   | 5.80 - 6.20       | 6.00  | 0.20  | 3.33   | 0.18    |
| OC<br>(g kg <sup>-1</sup> )                  | 0 - 15     | 0.16 - 0.29   | 0.21  | 0.06  | 31.90  | 0.17 - 0.21       | 0.19  | 0.02  | 10.76  | 0.36    |
|                                              | 15 - 30    | 0.16 - 0.19   | 0.17  | 0.01  | 8.64   | 0.13 - 0.16       | 0.14  | 0.01  | 10.65  | 0.00*   |
|                                              | 30 - 45    | 0.17 - 0.21   | 0.18  | 0.02  | 11.15  | 0.16 - 0.21       | 0.18  | 0.01  | 6.92   | 0.18    |
| TN<br>(g kg <sup>-1</sup> )                  | 0 - 15     | 0.02 - 0.04   | 0.03  | 0.01  | 33.33  | 0.02 - 0.04       | 0.03  | 0.01  | 33.33  | 0.50    |
|                                              | 15 - 30    | 0.02 - 0.03   | 0.02  | 0.00  | 24.74  | 0.01 - 0.02       | 0.01  | 0.00  | 43.30  | 0.40    |
|                                              | 30 - 45    | 0.02 - 0.04   | 0.02  | 0.01  | 43.30  | 0.02 - 0.02       | 0.02  | 0.00  | 0.00   | 0.21    |
| Avl P<br>(mg kg <sup>-1</sup> )              | 0 - 15     | 0.52 - 1.10   | 0.82  | 0.29  | 35.42  | 0.60 - 0.94       | 0.78  | 0.17  | 21.90  | 0.44    |
|                                              | 15 - 30    | 0.48 - 0.49   | 0.48  | 0.00  | 1.18   | 0.48 - 0.49       | 0.48  | 0.00  | 1.18   | 0.06    |
|                                              | 30 - 45    | 0.58 - 0.96   | 0.75  | 0.19  | 25.75  | 0.50 - 0.71       | 0.57  | 0.12  | 21.27  | 0.20    |
| Ca<br>(cmol kg <sup>-1</sup> )               | 0 - 15     | 20.04 - 24.04 | 22.70 | 2.30  | 10.17  | 18.03 - 32.06     | 22.70 | 8.10  | 35.67  | 0.50    |
|                                              | 15 - 30    | 16.03 - 32.06 | 22.71 | 8.34  | 36.73  | 16.03 - 24.04     | 19.36 | 4.16  | 21.52  | 0.32    |
|                                              | 30 - 45    | 20.04 - 24.04 | 22.04 | 2.00  | 9.07   | 20.04 - 28.05     | 22.71 | 4.62  | 20.36  | 0.41    |
| Na<br>(cmol kg <sup>-1</sup> )               | 0 - 15     | 1.71 - 2.35   | 2.10  | 0.34  | 16.29  | 1.92 - 3.00       | 2.29  | 0.61  | 26.85  | 0.28    |
|                                              | 15 - 30    | 1.72 - 2.94   | 2.13  | 0.69  | 32.74  | 1.65 - 2.20       | 1.95  | 0.27  | 14.27  | 0.38    |
|                                              | 30 - 45    | 1.94 - 2.42   | 2.12  | 0.26  | 12.33  | 1.94 - 2.8        | 2.28  | 0.45  | 20.06  | 0.34    |
| K<br>(cmol kg <sup>-1</sup> )                | 0 - 15     | 2.34 - 2.90   | 2.70  | 0.31  | 11.57  | 2.20 - 3.60       | 2.66  | 0.80  | 30.31  | 0.47    |
|                                              | 15 - 30    | 2.00 - 3.50   | 2.62  | 0.78  | 29.88  | 1.90 - 2.95       | 2.45  | 0.52  | 21.50  | 0.42    |
|                                              | 30 - 45    | 2.61 - 2.83   | 2.74  | 0.11  | 4.34   | 20.04 - 24.04     | 2.70  | 2.30  | 10.17  | 0.45    |
| Mg<br>(cmol kg <sup>-1</sup> )               | 0 - 15     | 4.86 - 5.84   | 5.51  | 0.56  | 10.26  | 4.38 - 7.79       | 5.51  | 1.96  | 35.68  | 0.49    |
|                                              | 15 - 30    | 3.89 - 7.79   | 5.51  | 2.03  | 36.82  | 3.89 - 5.84       | 4.86  | 0.97  | 20.04  | 0.36    |
|                                              | 30 - 45    | 5.35 - 5.84   | 5.67  | 0.28  | 4.98   | 4.86 - 6.81       | 5.51  | 1.12  | 20.43  | 0.42    |
| Cu<br>(mg kg <sup>-1</sup> )                 | 0 - 15     | 0.60 - 0.92   | 0.79  | 0.16  | 21.29  | 0.80 - 0.86       | 0.83  | 0.03  | 3.66   | 0.36    |
|                                              | 15 - 30    | 0.70 - 0.90   | 0.80  | 0.10  | 12.50  | 0.90 - 1.20       | 1.01  | 0.16  | 16.07  | 0.13    |
|                                              | 30 - 45    | 0.74 - 0.94   | 0.82  | 0.10  | 12.41  | 0.80 - 1.20       | 0.96  | 0.20  | 21.53  | 0.25    |
| Fe<br>(mg kg <sup>-1</sup> )                 | 0 - 15     | 35.80 - 69.3  | 47.20 | 19.14 | 40.55  | 30.50 - 54.20     | 41.66 | 11.90 | 28.58  | 0.38    |
|                                              | 15 - 30    | 36.10 - 62.80 | 51.26 | 13.71 | 26.75  | 38.60 - 56.20     | 47.90 | 8.84  | 18.46  | 0.39    |
|                                              | 30 - 45    | 44.60 - 68.40 | 54.50 | 12.39 | 22.74  | 40.80 - 72.60     | 54.50 | 16.35 | 30.00  | 0.50    |
| Zn<br>(mg kg <sup>-1</sup> )                 | 0 - 15     | 12.20 - 14.40 | 13.53 | 1.17  | 8.65   | 12.20 - 14.80     | 13.83 | 1.42  | 10.28  | 0.42    |
|                                              | 15 - 30    | 12.40 - 14.00 | 13.40 | 0.87  | 6.50   | 10.50 - 14.90     | 13.16 | 2.34  | 17.80  | 0.40    |
|                                              | 30 - 45    | 13.60 - 15.10 | 14.40 | 0.75  | 5.24   | 12.20 - 15.00     | 13.90 | 1.49  | 10.74  | 0.19    |
| Mn<br>(mg kg <sup>-1</sup> )                 | 0 - 15     | 2.40 - 2.80   | 2.66  | 0.23  | 8.66   | 2.20 - 2.80       | 2.56  | 0.32  | 12.52  | 0.37    |
|                                              | 15 - 30    | 2.40 - 2.80   | 2.63  | 0.20  | 7.90   | 1.48 - 2.80       | 2.02  | 0.68  | 33.97  | 0.17    |
|                                              | 30 - 45    | 1.50 - 2.60   | 2.16  | 0.58  | 27.04  | 1.50 - 2.80       | 2.10  | 0.65  | 31.22  | 0.46    |
| THB<br>( $\times 10^6$ cfu g <sup>-1</sup> ) | 0 - 15     | 1.12 - 1.54   | 1.35  | 0.21  | 15.80  | 1.25 - 1.40       | 1.31  | 0.07  | 5.80   | 0.40    |
|                                              | 15 - 30    | 1.06 - 1.30   | 1.20  | 0.12  | 10.40  | 1.02 - 4.80       | 2.40  | 2.08  | 86.48  | 0.22    |
|                                              | 30 - 45    | 1.05 - 1.38   | 1.20  | 0.16  | 13.81  | 7.60 - 9.80       | 8.70  | 1.10  | 12.64  | 0.00*   |
| THF<br>( $\times 10^4$ cfu g <sup>-1</sup> ) | 0 - 15     | 1.10 - 3.10   | 2.26  | 1.04  | 45.91  | 1.20 - 2.40       | 1.60  | 0.69  | 43.30  | 0.19    |
|                                              | 15 - 30    | 1.90 - 9.00   | 4.43  | 3.96  | 89.38  | 5.00 - 8.00       | 6.00  | 1.73  | 28.86  | 0.32    |
|                                              | 30 - 45    | 1.60 - 7.00   | 3.56  | 2.98  | 83.65  | 6.00 - 8.00       | 7.00  | 1.00  | 14.28  | 0.10    |

OC - organic carbon, TN - total nitrogen, Avl P - available phosphorous, Ca - calcium, Na - sodium, K - potassium, Mg - magnesium, Fe - iron, Cu - copper, Mn - manganese, Zn - zinc, THB - total heterotrophic bacteria counts, THF - total heterotrophic fungi counts, \* - significant at 0.05 level

Brady (2002) opined that the relationship between organic carbon and total nitrogen is reciprocal. Total nitrogen (TN) in the current study was insignificantly higher in the topsoil (0.03 g kg<sup>-1</sup>, 0.03 g kg<sup>-1</sup>) than subsoil (0.02 g kg<sup>-1</sup>, 0.01 g kg<sup>-1</sup>) and deep subsoil (0.02 g kg<sup>-1</sup>, 0.02 g kg<sup>-1</sup>) of both examined sites. The trend of TN concentrations follows that of OC. Similar values for both OC and TN have been reported (Oviasogie & Omoruyi, 2007).

Available phosphorus (Avl P) in all the soil samples was low as the values were less than 8 mg kg<sup>-1</sup> (Ekpenkhio, 2022). However, higher Avl P values were recorded in soils of the flooded area than the non-flooded area. This can partly be attributed to the slight increase in OC concentrations in the flooded soils. The values of exchangeable cations (Ca, Mg, K and Na) across soil depths of both sites were in no particular order (Table 3). However, K and Mg concentrations were insignificantly ( $p > 0.05$ ) higher in the flooded soils than non-flooded soils. Intermittent flooding is expected to cause anoxic conditions because of prolonged waterlogging which could lead to mobilization of K and Mg resulting in their increase. The marginally low Na values recorded in flooded soils could be as a result of leaching and dilution as flooding increases the solubility of mineral nutrients (Conklin, 2005).

Similar to the exchangeable cations, available micronutrients (Cu, Fe, Zn and Mn) in both study locations were in no specific sequence (Table 3). But, the concentrations of Cu and Fe were insignificantly lowest in the topsoil (0.79 mg kg<sup>-1</sup> and 47.20 mg kg<sup>-1</sup>) than subsoil (0.80 mg kg<sup>-1</sup> and 51.26 mg kg<sup>-1</sup>) and deep subsoil (0.82 mg kg<sup>-1</sup> and 54.50 mg kg<sup>-1</sup>) of the flooded area. This infers an antagonistic effect of pluvial flooding on topsoil Cu and Fe concentration. Copper in the pluvial flooded soils fell well below the reported critical levels of between 1.00 and 3.00 mg kg<sup>-1</sup> (Deb & Sakal, 2002) and suggests Cu deficiency in the floodplain soils. This finding is consistent with Orhue et al. (2015) who reported Cu deficiencies in basement complex soils of Edo State. It was

observed too that the deep subsoil of the two study sites served as reservoir for Fe as the highest mean values (54.50 mg kg<sup>-1</sup> and 54.50 mg kg<sup>-1</sup>) were recorded there. The values of Fe reported in this study are higher than the values reported by Osakwe et al. (2014). This is not a surprising outcome because natural soils contain substantial amount of Fe (Aluko & Oluwande, 2003). Zinc values at the three soil layers of both locations were above the critical level of 3.0 mg kg<sup>-1</sup> (Pam, 1990). Also, Zn values were observed to be highest in the deep subsoil layer (14.40 mg kg<sup>-1</sup> and 13.90 mg kg<sup>-1</sup>) of the sites whereas for Mn, it was highest in the topsoil (2.66 mg kg<sup>-1</sup>, 2.56 mg kg<sup>-1</sup>).

Brady (2002) is of the opinion that available micronutrients are more available in soils under acid conditions. This may have accounted for higher values of Cu, Fe and Zn in the deep subsoil as the pH values indicated that the soils were slightly acidic especially in that depth. Table 3 shows that bacteria and fungi counts were higher in the subsoil and deep subsoil of non-flooded site ( $8.70$  and  $7.00 \times 10^4$  cfu g<sup>-1</sup>) than flooded site ( $1.20$  and  $3.56 \times 10^4$  cfu g<sup>-1</sup>). Soil microbial activities are controlled mainly by adequate levels of oxygen which will result in maximum activities of soil microbes. Since the soils of the flooded area became too wet and oxygen diffusion was hindered, overall microbial activities will slow down since oxygen is needed by most microbes. This reason may be attributed to the generally lower values of THB and THF in the flooded areas than the non-flooded area.

### **Conclusion**

This study has revealed higher pH values due to the effect of pluvial flooding. Non-detrimental effects of pluvial flooding on Fe, Zn and Mn were observed as the values did not significantly differ. The contents of Fe and Mn were higher in the poorly drained inland-valley soils than in the upland soils. Copper was deficient in the floodplain soils as their values were below the critical limit of between 1.00 and 3.00 mg kg<sup>-1</sup>. The poorly drained soils were not suitable for the proliferation of bacteria and fungi but OC, TN and Avl P and the

exchangeable cations (Ca, Na, K and Mg) were adequate. The study concluded that the deficiency of micronutrients especially Cu in this study may

result in increased susceptibility of the oil palm to diseases such as Ganoderma species.

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