Original Research Article: 23 to 38 (2024)
ISSN: 2583-7419
biologyforum.actabotanica.org

Characterization of Soil and Growth Response of Rice on Different Positions Along the Toposequence in Awka, Anambra State

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Citation: IGWESI, Sandra Ogechi, NNABUDE, Peter Chinedu, MADUEKE, Chike Onyeka, OJEH, Vincent Nduka (2024). Characterization of Soil and Growth Response of Rice on Different Positions Along the Toposequence in Awka, Anambra State. *Acta Biology Forum*. **DOI: https://doi.org/10.51470/ABF.2024.4.2.23**

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Received 14 May 2024 | Revised 15 June 2024 | Accepted 14 July 2024 | Available Online 10 August 2024

ABSTRACT

This study examined soil characteristics and the growth response of Rice along different positions of a toposequence in Awka, Anambra State, Nigeria. The soils were delineated using the Geomorphon algorithm in the Geographic Resources Analysis Support System (GRASS) Geographic Information System (GIS) environments. This was then readapted to reflect the Uplands, midslopes, and Lowlands. The results show that in the uplands, bulk density increased down the profile, silt decreased down the profile, and clay fluctuated with increasing soil depth. In the lowlands, sand and silt content decreased down the profile, while clay content increased down the profile. The clay content had an inverse relationship with saturated hydraulic conductivity, decreasing the profile. In the midslope, sand content increased, and silt content decreased, while clay content was high in the topsoil, fluctuating with increasing depth. This result shows that physiographic positions critically influence the nature, properties, and variation of soils across the landscape. The soil properties, in turn, influenced the growth response of the rice plants, with particular reference to varietal variations (FARO 44, 52, 58, 59). Due to its high sand content, high runoff rate, and saturated hydraulic conductivity, the upland yielded rice plants with a lower number of tillers and height, while the reverse was the case in the lowlands. This may be attributed to Rice thriving best under swampy conditions, which are prevalent in lowland areas. The relatively low hydraulic conductivity, and higher organic matter, clay content, and water accumulation in the lowlands consequently ensure a higher yield. Generally, the swamp rice varieties (FARO 44 and 52) performed best in the lowlands, while the upland varieties (FARO 58 and 59) performed best in the midslopes.

Keywords: *Geomorphons, Hillslope Delineation, Soil Characterization, Growth Response of Rice, Rice and Topography*

1. INTRODUCTION

Soils are unrenewable natural resources that vary in their properties and composition spatially across the landscape and vertically down the soil profile (Brady & Weil., 2010., Brubaker *et al*., 1993). However, soil variation is a function of various factors, including climate, living organisms, parent materials, topography, and time. Within a locality, the topography may play a more prominent role in determining soil variability (Madueke *et al*., 2020). According to Odgers *et al*. (2008), toposequence can be described as a transect (not necessarily a straight line) that begins at a hilltop and ends at a lowland (lower slope) or a stream. As a key factor in soil formation, the topography may speed up or delay the work of climatic factors. Topography significantly impacts soil morphological, physical, and chemical properties and likewise affects the pattern of soil distribution in an environment (Esu*et al*., 2008; Madueke *et al*., 2020), even when the parent material is of a similar source. Consequently, soils on slopes exhibit remarkable differences in properties from those on the crest because of the infiltration of water, which tends to move laterally across a profile instead of vertically (Akinbola*et al*., 2009).

Soil often occurs in a well-defined and relatively regular sequence (Smyth &Montogomery, 1962). This sequence has been referred to as the toposequence or soil catena by Moorman (1981) and Okusami*et al.* (1985). Landscape position influences runoff, drainage, soil temperature, soil erosion, soil depth, and soil formation. Different soil properties encountered along landscapes will affect the patterns of plant production, litter production, and decomposition, which will affect the soil's carbon (C) and nitrogen (N) content. Soil properties such as clay content and its distribution with depth, sand content, and pH are highly correlated with landscape position (Wang *et al*., 2000), while organic matter varies with slope position (Miller *et al*., 1998).

Soil properties (morphological, physical, and chemical) and the potential for crop production often vary from the crest to the lowlands due to differences in soil types. In Southern-eastern Nigeria, Eshett (1985) observed that the valleys are continuously used for rice (*Oryza sativa*) cultivation. Stoop (1978) observed a high degree of variability in crop stands and low average productivity on the West African landscape and noted that crop fields tend to decrease from fertile lowland soils to generally infertile uplands.

Rice is an important arable crop in Nigeria whose productivity differs relative to variations along the toposequence. In terms of production, it is the second most important cereal in the world after wheat (Udemezue, 2018). Though West Africa is the leading producer of Rice in sub-Saharan Africa, a large chunk of its consumption still has to be imported from Southeast Asia.

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Given the importance of Rice as a major staple crop, farmers now seem enthusiastic about growing it on every available piece of land, irrespective of the drainage conditions dictated by topography and soil texture. This necessitated the development of several varieties, some designated as upland varieties and others as swamp varieties.

Irrespective of the vast importance of Rice as a staple food crop and the extensive knowledge of its soil requirements, few studies have focused on delineating the various topographic units of the landscape and assessing the relative potential of different rice varieties to thrive under such prevailing conditions. Therefore, this study's primary objective was to characterize rice soils and yield responses along a toposequence at the NnamdiAzikiwe University, Awka, Anambra State. The specific objectives are todelineate the different physiographic / landscape positions in the study area, characterize the soils in each delineated unit,andassess the yield response of different rice varieties in the delineated soil/landscape units.

2. CONCEPTUAL ISSUES ANDLITERATURE REVIEW

2.1 Concept of Toposequence

Soils commonly occur in groups, each group member occupying a characteristic and different sequential topographical position from top to bottom of a slope, termed toposequence. The two top sequences are called a catena when the same sequence occurs as a mirror image on a similar parent material (Buol *et al.,* 2003). Soil properties such as clay, sand, pH, and organic matter correlate highly with landscape position (Agbugba, 2018). In a given geographic location where diverse physiographic features like steep slopes, hilly lands, and mountainous surfaces are prevalent, topographic features (slope steepness and elevation differences) play an immense role in influencing and characterizing soil properties (Ahmed, 2002). Soil conditions tend to vary with topography because the orientation of the hilly surfaces on which soils form can significantly affect the microclimate and the adjacent vegetation distribution, eventually resulting in soil properties' variation (Agbugba, 2018). Within specific geographic regions, topography affects many morphological, physical, chemical, and biological properties of soils.

2.2. Variability of Soils of the Toposequence

Several researchers have assessed the variability of soils along a toposequence in southeastern Nigeria (Asongwe*et al.,* 2016; Madueke *et al.*, 2020; Osinuga*et al.*, 2020).

2.3. Soil physical properties

The physical properties of soils determine their adaptability to cultivation and the level of biological activity the soil can support. Soil physical properties also largely determine the soil's water and air supply capacity to plants. Some soil physical properties change with changes in land use system and management, such as the intensity of cultivation, the instrument used, and the nature of the land under cultivation. Some of these land use/management options can make the soil less permeable and more susceptible to runoff and erosion losses (Naseli, 2016).On this note, Arthur&Okae-Anti (2022)reiterated that it isprudent to investigate and understand the dynamism of soil properties to inform proper management.

2.3.1. Soil texture

Soil texture determines a number of physical and chemical properties of soils. It is the distribution of the different sizes of mineral particles in the soil. Textures range from clay, sand, and silt at the extremes to loam with all three-sized fractions present. Soil texture is an intrinsic property of the soil that does not change with agricultural activities. The primary influence of texture is on permeability, which decreases with decreasing particle size. It affects the infiltration and retention of water, soil aeration, absorption of nutrients, microbial activities, tillage, and irrigation practices (Naseli, 2016). It is also an indicator of some other related soil features such as the type of parent material, homogeneity and heterogeneity within the profile, clay migration, and intensity of weathering of soil material or the soil age (Naseli, 2016).

Soil texture is one of the natural soil physical properties less affected by management. The rate of increase in stickiness or ability to mold as the moisture content increases and the degree to which the clay particles are bound together into stable granules depends on silt and clay content (Naseli, 2016). Over a very long period, pedogenic processes such as erosion, deposition, eluviations, and weathering over a very long period can change the textures of various soil horizons (Brady & Weil, 2002).

During a study on the characterization of soils along a toposequence in Makurdi for rice cultivation, Abegyeh et al. (2018) observed that the soil texture ranged from sandy loam to clay. Thus, the toposequence presents soils with different degrees of limitations to rice cultivation. The clayey soils on the lowlands or plains are more amenable to swamp rice cultivation. In contrast, the coarser textured soils on higher elevations may only be suitable for upland rice cultivation, and even then, the yield may be relatively lower.

Abdulwahab et al. (2020) reported that the trend of distribution of clay along a toposequence was in the following order, lowland> upper slope> crest > middle slope. This may not be universal, but the higher clay content in the valleys could be attributed to the erosion of finer sediments from a higher elevation and their subsequent deposition in the valleys. Indeed, topography influences the pattern of soil distribution over the landscape (Esu*et al.,* 2008).

2.3.2. bulk density

Measuring soil bulk density (the mass of a unit volume of dry soil) is required to determine compactness, as a measure of soil structure, for calculating soil pore space, and as an indicator of aeration status and water content (Naseli, 2016). Bulk density also provides information on the environment available to soil microorganisms. Naseli (2016) stated that values of bulk density range from < 1 g/cm^3 for soils high in organic matter to1.4g/cm^3 for well-aggregated loamy soils and 1.2 to 1.8 g/cm^3 for sands and compacted horizons in clay soils. Bulk density decreases typically as mineral soils become finer in texture. Soils with low and high bulk density exhibit favorable and poor physical conditions. Bulk densities of soil horizons are inversely related to the amount of pore space and soil organic matter (Brady & Weil, 2002). Any factor that influences soil pore space will also affect bulk density. For instance, intensive cultivation increases bulk density, reducing total porosity (Naseli, 2016). Plants perform best in bulk densities below 1.4 g/cm^3 and 1.6 g/cm^3 for clayey and sandy soil, respectively (Abdulwahab*et al.,* 2020). The soil along a toposequence characterized for rice production showed that the bulk density of the soil ranged from 1.18-1.53 g/cm^3 and increased with depth (Osinuga*et al.,* 2020).

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2.3.3. Total porosity

In soils with the same particle density, the lower the bulk density, the higher the percent total porosity. As soil particles vary in size and shape, pore spaces vary in size, shape, and direction (Naseli, 2016). Coarse textured soils tend to be less porous than fine texture soils, although the mean size of individual pores is more significant in the former than in the latter. There is a close relationship between relative compaction and the larger (macro-pores) of soils (Naseli, 2016). Intensive cultivation causes soil compaction and degradation of soil properties, including porosity. Macro-pores can occur as the spaces between individual sand grains in coarse textural soils. Thus, although sand soil has relatively low total porosity, the movement of air and water through such soil is surprisingly rapid because of macropores' dominance. Fertile soils with ideal conditions for most crops have sufficient pore space, more or less equally divided between large (macro) and small (micro) pores. The decreasing organic matter and increase in clay that occurs with depth in many soil profiles are associated with a shift from macro-pores to micro-pores (Brady & Weil, 2002).

2.4. Soil Colour

Soil colour is often the first impression one has when viewing soil. Striking colours and contrasting patterns are especially noticeable. In general, colour is determined by the organic matter content, drainage conditions, and degree of oxidation. While easily discerned, soil colour must be used more in predicting soil characteristics. It is of use in distinguishing boundaries within a soil profile/horizons, determining the origin of a soil's parent material, as an indication of wetness and waterlogged conditions, and as a qualitative means of measuring organic, salt, and carbonate contents of soils (Johnson *et al.,* 2005).

The development and distribution of colour in a soil profile result from chemical and biological weathering, especially redox reactions. As the primary minerals in soil parent material weather, the elements combine into new and colorful compounds. Iron forms secondary minerals of a yellow or red colour. Organic matter decomposes into black and brown compounds, and manganese, sulphur, and nitrogen can form black mineral deposits (Naseli, 2016). These pigments can produce various colour patterns within the soil. Aerobic conditions produce uniform or gradual colour changes, while reducing environments (anaerobic) result in rapid colour flow with complex, mottled patterns and points of colour concentration (Johnson *et al.,* 2005).

2.4. Soil Chemical Properties

Soil chemical properties are the most important factor determining soil's nutrient-supplying power to plants. The chemical reactions in the soil affect processes leading to soil development and soil fertility build-up.

2.4.1. Soil Reaction (pH)

Soil reaction (usually expressed as pH value) is the degree of soil acidity or alkalinity. Soil reaction affects nutrient availability, toxicity, microbial activity, and root growth. Thus, it is one of the most critical chemical characteristics of the soil because higher plants and microorganisms respond so markedly to changes in soil pH. Descriptive terms commonly associated with specific ranges in pH are: extremely acidic (pH <4.5), very strongly acidic (pH 4.5-5.0), strongly acidic (pH 5.1-5.5), moderately acidic (pH 5.6-6.0), slightly acid (pH 6.1-6.5), neutral (pH 6.6-7.3), slightly alkaline (pH 7.4-7.8), moderately alkaline (pH 7.9-8.4), strongly alkaline (pH 8.5-9.0), and very strongly alkaline (pH > 9.1) (Naseli, 2016). The degree and nature of soil reactions are influenced by different anthropogenic and natural activities, including leaching of exchangeable bases, acid rains, decomposition of organic materials, application of organic and inorganic fertilizers, and farming practices (Naseli, 2016). In strongly acidic soils, Al^{3+} becomes soluble and increases soil acidity, while in alkaline soils; exchangeable basic cations tend to occupy the exchange sites of the soils by replacing exchangeable H^+ and Al^{3+} (Naseli, 2016). A study that characterized the soil along a toposequence for rice production recorded that the soil was acidic (Osinuga*et al.,* 2020). Acidification or lowering of soil pH hurts most crop growth (Horneck *et al.,* 2011), of which Rice is inclusive.

According to (Abegyeh et al. (2018), the soil chemical properties that could affect soil suitability for the cultivation of Rice include acidity, salinity, and fertility. According to the results of a study that was done in Zaria to determine the impact of toposequence on soil quality, Abdulwahab et al. (2020) observed that pH value decreases down the toposequence, and there was no significant difference in the soil reaction of all the geomorphic units.

2.4.2. Soil Organic Matter

Soil organic matter is defined as any living or dead plant and animal materials in the soil, and it comprises a wide range of organic species such as humic substances, carbohydrates, proteins, and plant residues (Naseli, 2016). Humus is the substance left after soil organisms have modified original organic materials to a rather stable group of decay products, as is the colloidal remains of organic matter (Naseli, 2016). Naseli (2016) has indicated that the distribution of organic matter, expressed as organic carbon, is 38% in trees and ground cover, 9% on the forest floor, and 53% in the soil, including the roots plus the organic matter associated with soil particles.

Biological degradation is frequently equated with the depletion of vegetation cover in the soil but also denotes the reduction of beneficial soil organisms, which is an important indicator of soil fertility (Naseli, 2016). Uncultivated soils have higher soil organic matter (both on the surface and in the soil) than those cultivated in years (Naseli, 2016). In the forest, there is a continuous growth of plants and additions to the three pools of standing crops, forest floor, and soil. In grassland ecosystems, much more organic matter is in the soil, and much less occurs in the standing plants and grassland floor. Although approximately 50% of the total organic matter in the forest ecosystems may be in the soil, over 95% may be in the soil where grasses are the dominant vegetation (Naseli, 2016). This means unsustainable land management practices, reduces soil fertility, and severely decreases its chemical activity and ability to hold plant nutrients (Naseli, 2016). Soluble and exchangeable aluminum in acid soils is substantially reduced by organic amendments (Naseli, 2016).

Naseli (2016) reported that some of the functions of organic matter are:

(a) Aids in water management as residues or plants protect the soil surface from raindrop impacts, resist wind action, and thus, greatly aid in erosion control. Decomposing organic matter causes soil aggregation, which helps infiltration and increases pore space in clay soils. Thus, water and oxygen holding capacity is increased, even beyond the absorptive capacity of organic matter.

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(b) Increases exchange and buffering capacity since well-decomposed organic matter or humus have a very high CEC that adds to the soil's buffering capacity.

(c) Minimizes leaching loss because organic substances can hold substances, including cations, against leaching.

(d) Sources of nutrients (N, P, S, and most micronutrients) and growth-promoting substances. Hormones or growth-promoting and regulating substances valuable to plants may be produced by organisms that decompose soil organic matter.

(e) Stabilizes soil structure, and Provides energy for microbial activity.

The surface layer is most relevant to assess the impact of management practices on soil organic matter because surface soils are easily modified directly by cultivation. The organic carbon from a study conducted to characterize the soil along a toposequence for rice production was low as it was below 45g/kg, which is the value regarded for productive soils (Osinuga*et al.,* 2020).

More clayey soils generally tend to contain higher levels of organic matter mainly because of the tendency of clay to slow down microbial degradation of organic matter as clay forms clay-humus complexes with organic matter (Brady & Weil, 2002).

Most humid tropical soils have relatively low organic matter content that may not be able to support sustainable crop production. Therefore, the organic matter content has to be substantially increased through effective crop residue management and using mineral and organic fertilizers.

2.4.3. Total Nitrogen

Nitrogen (N) is the fourth plant nutrient taken up by plants in the most significant quantity next to carbon, oxygen, and hydrogen. However, it is one of the most deficient elements in the tropics for crop production (Naseli, 2016). The total N content of a soil is directly associated with its organic carbon content, and its amount on cultivated soils is between 0.03% and 0.04% by weight (Naseli, 2016). DUE TO LOW ORGANIC MATTER CONTENT, the N content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub-humid tropics due to leaching and in highly saline and sodic soils of semi-arid and arid regions (Naseli, 2016). Osinuga*et al.* (2020) reported low total nitrogen content for soils along a toposequence assessed for rice production. This could result from leaching and crop removal, which could cause nitrate loss (Aiboni*et al.,* 2007). Also, as organic matter, which is a main nitrogen source, was low, it explains the low nitrogen content (Osinuga*et al.,* 2020). Generally, the total nitrogen value decreases down the profile.

2.4.4. Available Phosphorus

Phosphorus (P) is known as the master key to agriculture because the lack of available P in the soils limits the growth of both cultivated and uncultivated plants (Fothan&llis, 1997). N and P have a more widespread influence on natural and agricultural ecosystems than any other essential elements. In most natural ecosystems, such as forests and grasslands, P uptake by plants is constrained by the low total quantity of the element in the soil and by the very low solubility of the scarce quantity present (Brady & Weil, 2002). It is the most common plant growth-limiting nutrient in tropical soils beside the water and N (Naseli, 2016). Erosion tends to transport predominantly the soil's clay and organic matter fractions, which are relatively rich in P fractions. Thus, compared to the original soil, eroded sediments are often enriched in P by a ratio of two or more (Brady & Weil, 2002). According to Foth and Ellis (1997), natural soil will contain from 50 to over 1,000 mg of total P per kilogram of the soil' this quantity; ut 30 to 50%, maybe in the inorganic form in mineral soils (Foth and El&, 1997). The main sources of plant available P are the weathering of soil minerals, the decomposition and mineralization of soil organic matter, and commercial/inorganic fertilizers.

Available P. decreases with depth in the crest and the upper slope but increases with depth in the middle and lowland; it was also significantly higher in the lowland than in the other geomorphic units (Abdulwahab et al., 2020). The higher P content in the valley may be attributed to the higher moisture conditions of the units, which slows the rate of organic matter decomposition, as well as the erosion of P-rich upland topsoil and its deposition in the valleys.

2.4.5. Cation Exchange Capacity (CEC)

The Cation exchange capacity (CEC) of soils is defined as the capacity of soils to adsorb and exchange cations (Brady and We& 2002). Cation exchange capacity is an important parameter of soil because it indicates the type of clay minerals present in the soil, its capacity to retain nutrients against leaching, and assessing their fertility and environmental behavior. The chemical activity of the soil depends on its CEC. The CEC of soil is strongly affected by the amount and type of clay and the amount of organic matter in the soil (Naseli, 2016). Both clay and colloidal organic matter are negatively charged and, therefore, can act as anions (Naseli, 2016). As a result, these two materials, individually or combined as a clay-humus complex, can adsorb and hold cations. In surface horizons of mineral soils, higher organic matter and clay contents significantly contribute to the CEC. In contrast, in the subsoil, particularly where the Bt horizon exists, more CEC is given by the clay fractions than by organic matter due to the decline of organic matter with profile depth (Brady and We& 2002).

Soil solutions contain dissolved chemicals, and many of these chemicals carry positive charges (cations) or negative charges (anions) (Naseli, 2016). Cation exchange is considered more important to soil fertility than anion exchange because plants absorb essential minerals as cations (Naseli, 2016).

Malgwi (2007) rated CEC values as follows <6 low, 6-12 medium, and >12 high. According to a study that determined the impact of toposequence on soil quality, Abdulwahab et al. (2020), cation exchange capacity (CEC) was rated medium. The medium value of CEC suggests a dominance of sesquioxides and kaolinite clays. Abdulwahab et al. (2020) recorded that the crest and lowland CEC value increase with depth which could be attributed to leaching, while upper slope and middle slope CEC values decrease with depth. Generally, the CEC value decreases from the crest down to the lowland except for the middle slope, which also recorded a higher value. However, there was no significant difference in CEC value along the toposequence (Abdulwahab et al., 2020).

2.4.6. Exchangeable Acidity

Exchangeable hydrogen (H^+) and exchangeable aluminium (Al^{3+}) are soil exchangeable acidity.

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Soil acidity occurs when acidic H^+ ion occurs in the soil solution to a greater extent and when an acid-soluble Al^{3+} reacts with water (hydrolysis) and results in the release of H^+ and hydroxyl Al^{3+} into the soil solution (Brady & Weil, 2002). As soils become strongly acidic, they may develop sufficient Al^{3+} in the root zone and decrease the amount of exchangeable basic cations. Solubility and availability of some toxic plant nutrients increase, and the activities,s of many soil microorganisms are reduced, resulting in the accumulation of organic matter, reduced mineralization and lower availability of some macronutrients like N, S and P and limitation of growth of most crop plants and ultimately decline in crop yields and productivity (Naseli, 2016). Foth& Ellis (1997) stated that during soil acidification, protonation increases the mobilization of Al^{3+} and Al^{3+} forms serve as a sink for the accumulation of H^+. The concentration of H^+ in soils to cause acidity is pronounced at pH values below four (4), while the excess concentration of Al^{3+} is observed at a pH below 5.5 (Naseli, 2016).

In strongly acidic conditions of humid regions where rainfall is sufficient to leach exchangeable basic cations, exchangeable Al^{3+} occupies more than approximately 60% of the adequate cation exchange capacity, resulting in a toxic level of aluminum in the soil solution (Naseli, 2016; Maduekе*et al.*, 2021). Generally, more than one part per million of Al^{3+} in the soil solution can significantly bring toxicity to plants. Hence, the management of exchangeable Al^{3+} is a primary concern in acid soils. According to a study that was done to determine the impact of toposequence on soil quality, Abdulwahab et al. (2020) recorded that the exchangeable acidity values were classified as generally low (<1.0 cmolkg-1) and suggested that the soils have little or no acidity problems.

2.4.7. Exchangeable Potassium and Sodium

Soil parent materials contain potassium (K) mainly in feldspars and micas. As these minerals weather, the K ions released become either exchangeable or exist as adsorbed or soluble in the solution (Foth& Ellis, 1997). Potassium is the third most important essential element that limits plant productivity next to N and P. Its behaviour in the soil is influenced primarily by soil cation exchange properties and mineral weathering rather than microbiological processes. Unlike N and P, K causes no off-site environmental problems when it leaves the soil system. It is not toxic and does not cause eutrophication in aquatic systems (Brady & Weil, 2002).

Naseli (2016) reported that the variation in the distribution of K depends on the mineral present, particle size distribution, degree of weathering, soil management practices, climatic conditions, degree of soil development, intensity of cultivation, and the parent material from which the soil is formed. The more significant the proportion of clay minerals high in K, the greater the potential K availability in soils (Naseli, 2016). Soil K is mostly a mineral form, and the daily K needs of plants are little affected by organic associated K, except for exchangeable K adsorbed on organic matter. Naseli (2016) reported a low concentration of exchangeable K under acidic soils and soils under intensive cultivation.

Exchangeable sodium (Na) alters soil physical and chemical properties mainly by inducing swelling and dispersion of clay and organic particles resulting in restricting water permeability and air movement and crust formation and nutritional disorders (decreased solubility and availability of calcium (Ca) and magnesium (Mg) ions) (Naseli, 2016). Moreover, it also adversely affects the population, composition and activity of beneficial soil microorganisms directly through its toxicity effects and indirectly by adversely affecting soil's physical and chemical properties. In general, high exchangeable Na in soils causes soil toxicity, affecting soil fertility and productivity.

According to a study that determined the impact of toposequence on soil quality, Abdulwahab et al. (2020) observed that the crest, middle slope, and lowland Na content decrease with depth while the upper slope Na content value increases with depth. Generally, exchangeable Na content increases down the toposequence, though there was no significant difference in exchangeable Na in the toposequence and between the surface and subsoils.

2.4.8. Exchangeable Calcium and Magnesium

Soils in areas of moisture scarcity (such as in arid and semi-arid regions) have less potential to be affected by the leaching of cations than soils in humid regions (Naseli, 2016). Soils under continuous cultivation, application of acid-forming inorganic fertilizers, high exchangeable and extractable Al, and low pH are characterized by low Ca and Mg mineral nutrient contents resulting in Ca and Mg deficiency due to excessive leaching (Naseli, 2016). Exchangeable Mg commonly saturates 5 to 20 % of the effective CEC compared to the 60 to 90 % typical for Ca in neutral to somewhat acid soils (Brady & Weil, 2002). Different crops have different optimum ranges of nutrient requirements. The response to calcium fertilizer is expected from most crops when the exchangeable Ca is less than 0.2 cmol/kg of soil, while 0.5 cmol/kg soil is reported to be the deficiency threshold level for Mg in the tropics (Naseli, 2016).

2.4.9. Percentage Base Saturation (PBS)

The per cent base saturation (PBS) is as much a measure of the actual percentage of cation exchange sites occupied by exchangeable bases (Teferi, 2008). The pH influences it. Since neither the content of exchangeable Al nor exchangeable H is appreciable above pH 5.5, the effective CEC of the soil above this pH should be essentially 100 % base saturated (Bohn *et al.,* 2001). However, soils in the pH range of 5.5 to 7.0 or 8.2 generally have measured base saturations well below 100%. Such base saturation values are particularly low for minerals with a high proportion of pH-dependent charges, such as kaolinite clays. A soil with a percent base saturation of less than 20 % is considered low, 20–60 % medium, and greater than 60 % high fertility (Agbugba, 2018). Similarly, Abdulwahab et al. (2020) reported that soils with a base saturation of >50 % are fertile soils, while soils with less than 50 % are regarded as non-fertile soils.

Generally, BS increases down the toposequence, with the lowland recording the highest value, which could be attributed to the downward movement of material deposited on the lowland, which enriches the unit (Nahusenay&Kibebew, 2016).

2.5 Soil

Soil is a mixture of minerals, organic matter, gases, liquids, and many organisms that can support plant life. It performs four important functions: it is a medium for plant growth; it is a means of water storage, supply, and purification; it is a modifier of the atmosphere; and it is a habitat for organisms that take part in the decomposition of organic materials (Naseli, 2016). Soil is said to form when the organic matter has accumulated, and colloids are washed downward, leaving clay, humus, iron oxide, carbonate, and gypsum deposits. Soil consists of a solid phase (minerals & organic matter) and a porous phase that holds gases

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2.6.1. Upland rice

Upland rice is grown on free-draining soils where the water table is permanently below the roots of the rice plant. The ecological conditions under which upland rice grows in Nigeria are diverse. However, to obtain a successful crop, adequate and assured soil moisture reserves and fertility during key periods of plant growth are essential. The upland rice environments are defined based on soils, climate, water resources, water regime at the micro level (Longtau, 2003) and topography. Two types of Upland Rice Systems (URS) are found in Nigeria. These are Rainfed Upland and Irrigated Upland.

According to Longtau (2003), rain-fed upland rice is Nigeria's dominant upland rice system. It is found in all agroecological zones and depends entirely on rainfall for survival. In certain dry years or regions, it may be susceptible to drought. In some places where the growing period (LGP) is short, some form of supplementary irrigation may be required to ameliorate drought conditions during critical stages of growth in the rice crop (Longtau, 2003). It is predominant in areas with rainfall between 150-500mm, and the soils are generally sandy and have low water-holding capacities.

2.6.2. Hydromorphic Rice

According to Longtau (2003), hydromorphic conditions occur when water is supplied to the rice crop by a shallow ground water table within the rooting zone of the plants. Hydromorphic Rice is found either on lower slopes in the toposequence or when an impermeable soil layer reduces water percolation. Another situation that can give rise to hydromorphic conditions is the slow flow of water in a grassedwaterway or even a simple ditch by a highway. It is common to see Rice in this environment all over Northern and Southern Guinea Savannah. Hydromorphic land occurs as a transition zone or fringe on a continuum of the toposequence from the bottom of an inland valley to upland or a mere depression on a flat plain or topography whose soils have good water-holding capacities (Longtau, 2003). Fringes of streams or rivulets are areas for this system of rice production. Wet uplands will also be an appropriate terminology for this system. The area sown to hydromorphic Rice fluctuates from season to season depending on the amount and distribution of rainfall. Hydromorphic Rice generally gives higher and more stable yields than upland rice (Longtau, 2003).

2.6.3. Rainfed Lowland Rice

An estimated 25 per cent of Nigeria's rice area is under rainfed lowland rice cultivation. This ecology contributes between 43 and 45 percent of national rice production (Imolehin& Wada, 2000). However, hydromorphic Rice might have been included in that category. Two sub-types are set up here for lowland ecologies: shallow fadama and deep fadama or deep inland valleys or wetlands. A distinguishing feature of this system and hydromorphic Rice is that the soil must be entirely covered by water at some stage in the growth cycle. In deep fadamas, the land is always flooded or during a significant part of the cropping season. Farmers generally adjust their date of planting or transplanting in order to avoid flooding during the early stage of growth (Longtau, 2003). This is the dominant system in the floodplains of Niger, Benue, Katsina-Ala, Kaduna, Yobe and their tributaries. Shallow fadamas are seldom flooded.

In the Abakaliki area, excessive flooding, iron toxicity, and lack of water control structures have been the bane of lowland swamp rice production. Farmers in that area have an exciting farming system. Giant mounds are made at the end of rain or the onset of rain. Yam is planted at the top of the mound. With early rains, groundnut is planted lower down the mound. By May, Rice is raised in a nursery for four weeks. The yams and groundnuts are harvested, the mound is broken down and puddled by hand, and the crop residues are incorporated into the soil. At this stage, the fields are flooded, and Rice is transplanted. The giant mounds prevent the yams and groundnuts from waterlogging (Longtau, 2003).

2.6.4 Irrigated Lowland Rice

The establishment of River Basin Development Authorities (RBDAs) in the 1980s boosted Rice Schemes and irrigated lowland rice. Irrigation is supplied from rivers, dams, wells, boreholes, and other sources to supplement rainfall for total rice crop growth (Imolehin& Wada, 2000). This system accounts for 18 percent of cultivated rice land and 10-12 percent of the national rice supply. In parts of Ogoja, irrigation is done by gravity. It is a system developed entirely by the farmers. They have incorporated rice bran as an organic fertilizer in the farming system. Apart from the Adani Scheme in Enugu state and Bida Scheme in Niger state, most irrigated Rice is in the Northern Guinea Savannah, Sudan Savannah and Sahel (Longtau, 2003).

2.6.5. Deep Inland Water Rice

This is the floating rice system (Longtau, 2003). Just before rain sets in, much of the water in the river course has receded. The land is prepared and planted with Rice by directly seeding or transplanting seedlings raised in a nursery. The plants grow in not-too-moist conditions for four weeks, and the river's water level begins to rise and overflow its banks. The rice fields become flooded, but the plants send down deep roots, and the vegetative parts float on the water. The plant has the ability not to be submerged. It matures in this flooded condition and may be harvested from a canoe, as seen in Sokoto. This system has been known there for hundreds of years. Imolehin and Wada (2000) state that it constitutes 5 to 12 percent of the national rice production area and 10 to 14 percent of the national rice output. The problem of low yield plagues this system because of the use of unimproved varieties of the traditional rice *Oryzaglaberrima*.

2.6.6. Mangrove Swamp Rice

This is also called a tidal wetland rice system (Longtau, 2003). The coastal swamp areas in Delta, Ondo, Lagos, Rivers, Bayelsa, Akwa-Ibom, and Cross River states are suitable for mangrove swamp rice production. This covers a potential 1 million ha of land, but not up to 1000 ha is cultivated (Imolehin& Wada, 2000). This vast potential lies in waste due to neglect, given the cheap harvest of petro-dollar in these oil-producing states. Mangrove rice is produced only in Warri and on Shell Company farms in Bayelsa state (Longtau, 2003).

Table 1: Summary of rice systems in Nigeria

Type	Characteristics	Geographical spread
Upland	Rainfed Rice grown on free-draining fertile soils. This is also called dry uplands.	Widespread except on coasts, high rain forests and the Sahel.
Hydromorphic	Rainfed Rice is grown on soils with shallow ground water table or an impermeable layer.	Very widespread at the fringes of streams and the intermediate zone between upland and swamps of rivers in the Savannah.
Lowland	Rainfed or irrigated Rice in aquatic conditions or medium ground water table. Water covers the soil completely at some stages during the cropping season. These are called shallow swamps or Madama.	Very widespread from high rain forest to the Sahel.
Deep Inland water	Rainfed Rice is grown on soils with deep water tables. The rice crop floats at some stage, and harvesting may be done from a canoe. These are also called deep Madama or floodplains.	Found in the Sokoto-Rima and Chad Basin, floodplains of the Niger, Benue, Kaduna, Gbako, Hadejia and Komadugu-Yobe.
Mangrove swamps	Rice is grown on the coast or swamps of the high rain forest.	Coastal areas and Warri area in Delta state.

Source: Longtau (2003)

2.6.7. Rice Varieties Conducive for Different Positions of the Toposequence

Though the toposequence can be divided into five classes, namely summit, upper slope, back slope, foot slope and toe slope(Miller &Schaetzl, 2015), for this study, three elevation classes (upper slope, mid-slope and foot slope/valley) as reported by Madueke et al. (2020) will be reviewed for their suitability for different rice varieties. Some rice varieties thrive under swampy conditions (FARO 44 and 52), some thrive under both swampy and upland conditions (FARO 44), while other varieties thrive under upland conditions (FARO 58 and 59) (Longtau, 2003; Philip et al., 2018).

Table 2: Rice Varieties and Their Adapted Habitat

S/N	Variety	Adaptation	Elevation Class	Remark
1.	FARO 44	Lowland / Swamp	Foot Slope / Valley	Also grown on uplands
2.	FARO 52	Lowland / Swamp	Foot Slope / Valley	
3.	FARO 58	Upland	Mid Slope / Upper Slope	Also called NERICA 7
4.	FARO 59	Upland	Mid Slope / Upper Slope	Also called NERICA 8
Adapted from Longtau (2003) and Philip et al. (2018)				

3 MATERIALS AND METHODS

3.1 Description of Experimental Site

The study was carried out in the Soil Science Departmental Fields of the Faculty of Agriculture Teaching and Research Farms, NnamdiAzikiwe University, Awka, Anambra state, Nigeria. (Figure 1). The campus is located within Latitudes 06°14.0'N – 06°15.95'N and Longitudes07°6.0'E – 07°7.8'E. It covers an area of approximately 500 hectares, ranging from 57 to 83 m above sea level (Figure 2). The landscape is predominantly an undulating terrain. The predominant parent material is the Imo Shale Group. It is located in the tropical rainforest belt of Nigeria. The rainy season lasts from March to October, with rainfall ranging from 1,500 to 2,000mm annually. The temperature ranges from 20°C to 35°C, while the relative humidity ranges from an average value of 63% in December to 88% in July (Madueke *et al.*, 2020).

The study site (the Soil Science Departmental Fields) was delineated and found to have seven (7) geomorphic units, which included a Ridge having an area of 0.0156 ha, Flat 0.0156 ha, Valley 0.1557 ha, Midslope 0.3269 ha and Spur 0.2646 ha. The total area of the study site was 1.2143 ha, but for my work, I focused on the slope (0.3269 ha) and midslope (0.3269 ha), so the total area I worked on amounted to 0.8095 ha. The geographic coordinates are shown in Table 3.

Table 3: Site Geographical Coordinates values

Profile No	Geomorphone	Longitude (°E)	Latitude (°N)
Profile 108	Slope	7.1128724	6.243395
Profile 104	Midslope	7.1129375	6.2590097
Profile 105	Lowland	7.1207228	6.2496702

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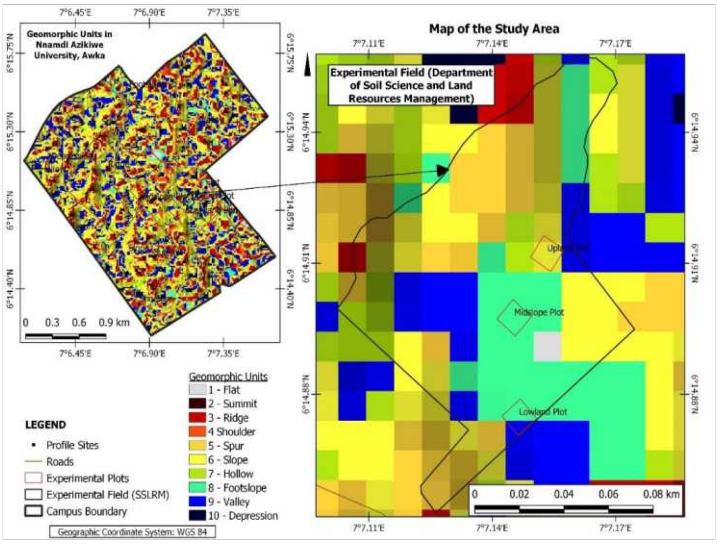

Figure 1: Map of the study area

The map shows the different geomorphic units identified within the study area. Seven geomorphic units were identified, but the study focused only on three geomorphic units, including upland, midslope and lowlands.

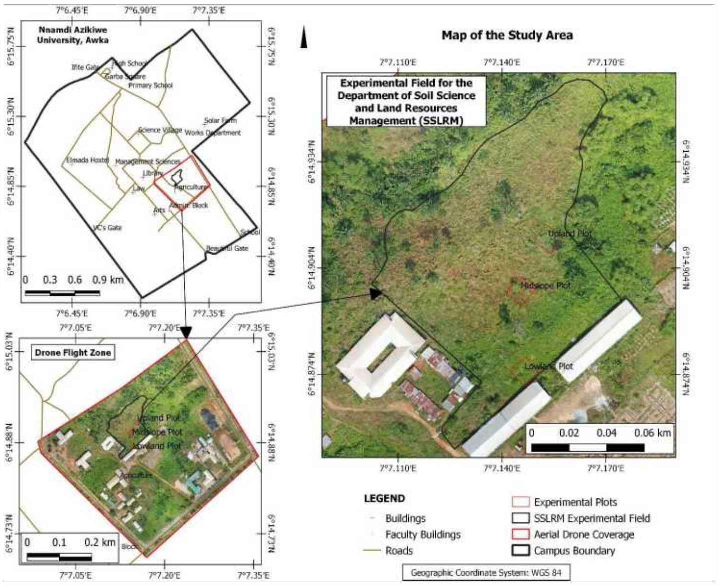

Figure 2: Aerial photo map of the Study Area generated with an unmanned aerial vehicle

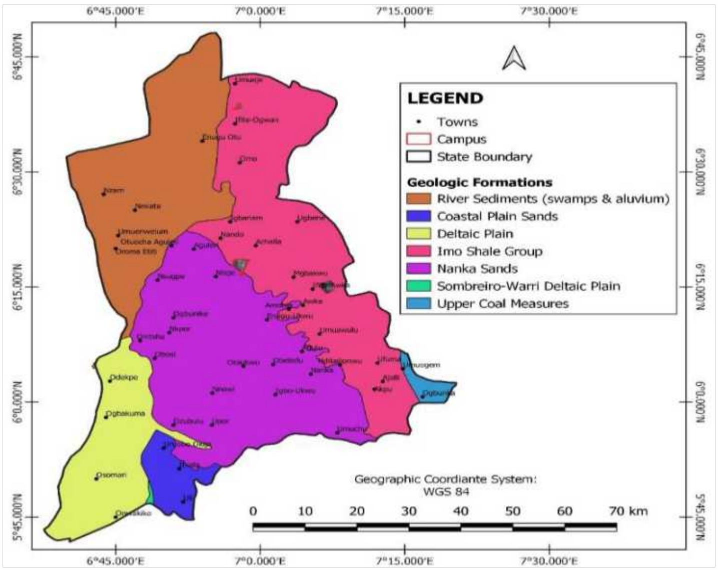

Figure 3: Geologic Map of Anambra State

3.1.1. Required Tools and Software

Some of the tools and equipment that were used in this study include the GPS receiver, data sheets, soil auger, soil sample rings, field knife, hammer, measuring tape, squeezing bottle, shear vane apparatus, unmanned aerial vehicle (UAV) and digital elevation models (DEMs). The software used in this study includes QGIS, GRASS GIS, SPAW, GenStat, Microsoft Excel and Microsoft Word.

3.2 Acquisition of Elevation Data

Data on altitude was based on remotely sensed AlosPalsar digital elevation models (DEM) with 12.5-meter resolution. The data is available for free download at the Alaska Satellite Facility online directory (https://search.earthdata.nasa.gov/search?m=5.763427734375!5.142476954368504 5!7!1!0!0%2C2). Using the bounding box of the Awka campus of Nnamdi Azikiwe University, a section of the downloaded DEM was clipped out in QGIS. Using the r.reclass algorithm, the DEM data was delineated into three elevation classes, namely:

57 thru 65 m = 1
66 thru 71 m = 2
72 thru 83 m = 3

Where 1 represents lowlands, 2 equals midslope, and 3 represents uplands. Notably, 57 m is the minimum elevation within the campus, while 83 m is the maximum elevation recorded. Figure 2 shows the DEM, the reclassified data and the focus area for this study.

3.3 Digital Soil Mapping

3.3.1. Delineation of the Geomorphic Units

The r.geomorphon in GRASS GIS, which classifies hillslopes using pattern recognition (Jasiewicz & Stepinski, 2013) by creating patterns through the comparison of a target pixel with the pixel values of the eight neighbouring pixels along the line of sight of the eight principal directions were assessed. This classifies the land into ten landform units: flat, summit, ridge, shoulder, spur, slope, hollow, midslope, valley and depression (Figure 4).

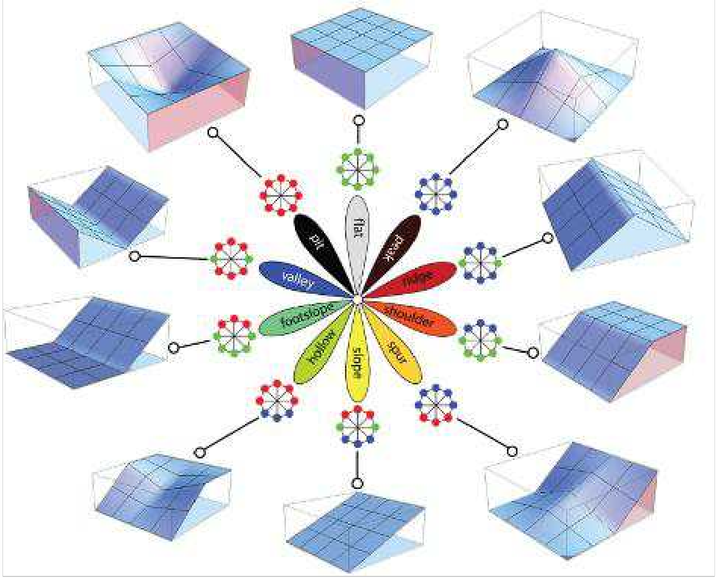

Figure 4: The different landform units captured by the eomorphic algorithm

3.4 Delineation of the Geomorphic-Geologic Units

The geomorphic and geologic maps of the study area were overlaid to produce the geomorphic-geologic map of the site.

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This enabled the delineation of soil boundaries. This was based on the assertion of Foth (1990) that, locally, the predominant factors of soil formation are topography and geology.

3.4.1. Definition of Sample Sites

Representative soil profile sites were defined for each of the mapped geomorphic units. The sampling points were defined in QGIS and converted from ESRI shapefiles to kml vector format. The XML files were then loaded onto the google maps application associated with the authors' Gmail account. The stored map was subsequently accessed via the Google Maps application on our Ipad.

3.4.2. Location of the Predefined Profile Sites

The soil profiles were located using the tracking system in our Ipad, which uses the Global Navigation Satellite System (GNSS), particularly the global positioning system (GPS). Once the map of the sample sites was opened on Google Maps, a dot on the screen showed where we were located and the direction towards which we were facing. We subsequently reorient ourselves and move towards the location of a soil profile site of interest.

3.4.3. Site Description and Soil Profiling

Soil profiles were dug in each of the defined soil units. The sites and soil profiles were described in accordance with the specifications of the guidelines for soil description (FAO, 2006). The site characteristics assessed include physiographic position, geomorphic unit, slope form, rock outcrops, boulders, surface stoniness, soil depth, erosion, deposition, depth to the water table, site drainage, land use/land cover and dominant plant species. The soil horizon characteristics assessed and recorded include horizon type and depth, thickness and form of horizon boundaries, mottle features, soil structure, induration, cementation, shear strength, soil stoniness, root size, kind and frequency. The location of the study area was recorded using the Garmin Oregon GPS receiver; soil colour was determined using the Munsell colour chart, while shear strength was measured using the pocket shear vane apparatus. Subsequently, soil samples were taken from each horizon.

3.5. Laboratory Soil Analysis

The physical and chemical properties of the soil samples were determined using routine analytical methods. Particle size distribution was analyzed using the hydrometer method (Gee &Bauder, 1986). Soil texture was subsequently determined from the relative proportion of sand, silt and clay using the textural triangle. Bulk density, porosity, saturated hydraulic conductivity, and moisture content at field capacity and permanent wilting point were estimated using the pedotransfer functions developed by Saxton et al. (1986) and eventually transformed into the SPAW software by Saxton & Rawls (2006). The input data used in the model were sand, clay and organic matter content.

Soil pH (in water) was measured electrometrically by a glass electrode in a pH meter using a soil: liquid ratio of 1: 2.5 (International Institute for Tropical Agriculture, 1979). Exchangeable basic cations were extracted with neutral ammonium acetate ($1NH_4OAC$). The ethylene diamine-tetraacetic acid (EDTA) titration method determined exchangeable calcium and magnesium, while flame photometry estimated exchangeable potassium and sodium (Jackson, 1962).

Exchangeable acidity was extracted with KCl (1 N) and measured titrimetrically according to the procedure of Mclean (1982). Effective Cation Exchange Capacity (ECEC) was the sum of the exchangeable bases and the exchange acidity. Base saturation and Aluminum saturation were computed as the percentage of the ratios of exchangeable Aluminum to ECEC. Soil Organic carbon (SOC) was determined by Walkley and Black digestion method (Nelson & Sommers, 1982). Total nitrogen was estimated by the micro-Kjeldahl digestion method (Bremner& Mulvaney, 1982), while the Bray II Method determined available phosphorus (Olsen & Sommers, 1982).

3.6. Field Experiment

This part of the study was conducted from September to December 2019. A reconnaissance of the site and its environs, including an aerial survey with a drone, was conducted before establishing the experimental plots. The site and its environment were subsequently surveyed, mapped and characterized using the protocols outlined in the preceding section of this chapter.

3.7. Experimental Design

The experiment was laid out as a 4 X 3 factorial (with three replicates) in a randomized complete block design (RCBD). The factors were rice varieties and site physiography/topography. The rice varieties were FARO 44, 52, 58 and 59, while the physiographic positions were upland, middle slope and lowland. 12 plots of 2 by 3 m each were delineated on each physiographic position. All the rice varieties were planted on each of the predefined blocks (rows) of each physiographic position, amounting to a total of 36 rice plots. The rice grains were planted by direct drilling method at a spacing of 25 cm by 25 cm at the rate of 10 seeds per hole.

3.8. Plant Sampling and Statistical Analysis

Several parameters were recorded ten weeks after planting. These included the Number of tillers, plant height, wet weight and dry weight. To determine whether there is a significant difference in yield as a result of variation in topography, rice varieties and possible interaction between both factors, the data collected was analyzed as a 4 X 3 factorial experiment with three replicates using GenStat statistical software.

4 RESULTS AND DISCUSSION

4.1. Physical Properties of the Soils

For profile 108 (Upland), the soil particles showed an irregular distribution with depth in the profile. The sand and clay particles showed the highest percentage in the A2 horizon of the topsoil.

The sand percentage in profile 104 (midslope) was increasing down the horizons. The silt decreased down the profile while the clay per cent fluctuated (increased and decreased) down the profile. The sand and silt fraction of the lowland (profile 105) decreased down the horizons while the clay increased down the profile; this has a relationship with Ksat (saturated hydraulic conductivity), which decreased down the horizon.

The textural class for upland (profile 108) was predominantly loam. For profile 104 (midslope), the textural class ranged from clay to loam, to sandy clay loam and then to sandy loam.For profile 105 (Lowland), the topsoil was predominantly sandy loam, loam, sandy clay loam and then loam.

In profile 108 (Upland), bulk density increased down the profile, ranging from 1.36 g/cm^3 in the Ap (0-32 cm) to 1.63 g/cm^3 in the

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B4 (147-200 cm). In profile (104) midslope, there was a negligible increase down the profile (A1, 0-14 cm) to (B5, 166-200 cm). In comparison, the lowland (profile 105) experienced some sort of irregular increase and decrease in the subsoil horizons. Naseli (2016) stated that values of bulk density range from < 1 g/cm^3 for soils high in organic matter to1.4g/cm^3 for well-aggregated loamy soils and 1.2 to 1.8 g/cm^3 for sands and compacted horizons in clay soils. This result agrees with the findings of Osinuga*et al.* (2020) that soil along a toposequence which was characterized for rice production, showed that the bulk density of the soil ranged from 1.18-1.53 g/cm^3 and increased with depth.

Saturated hydraulic conductivity (Ksat) in profile (108) in the upland decreased down the profile, Ap (0-32 cm) to B4 (147- 200 cm), and this is equally in agreement with the clay %. From the table, clay % in profile 108 had the highest in the B4 profile while the Ksat at the same B4 horizon with a value of 19.83 mm/hr; while profile 104 (midslope) had an irregular pattern of increase and decrease down the horizon, although it had the highest value at B5 horizon (166-200 cm) 24.53 mm/hr which can be traced to the high sand per cent (%) in the B5 horizon (68.4 %) as well as low clay % of 15.6% at the same B5 horizon. This irregularity was observed in both the upland and midslope as soils with high sand% are known to have high Ksat while soils with high clay% are known to have low Ksat. For the lowland (profile 105), there was a decrease down the profile A1 (0 – 10 cm) to B6 (143-200 cm). This can be seen to have a relationship with the clay %, which was high at (23.6 %) at the same B6 horizon. 41.53mm/hr of Ap horizon of the topsoil (0-32 cm) to 19.83mm/hr B4 horizon (147-200 cm) of the subsoil. As reported by Oguike and Mbagwu (2009). This may be attributed to the negative correlation existing between hydraulic conductivity and clay content. This negative correlation is due mainly to the preponderance of micropores, which, relative to macropores, reduces the ease of flow of fluids. As such, the greater hydraulic conductivity of the topsoil is due mainly to its greater macro-porosity.

Table 4: Physical Properties of Selected Geomorphic Units in Unizik, Awka.

				Particle Size Distribution						
Site No.	Horizon	Depth(cm)		Sand (%)	Silt (%)	Clay (%)	Texture	B.D. (g/cm³)	Porosity (%)	Ksat (mm/hr)
						Upland				
Profile 108	Ap	0-32		43.60	46.00	10.40	L	1.36	48.60	41.53
	A2	32-58		47.60	40.00	12.40	L	1.42	46.50	34.46
	B1	58-89		44.00	48.00	8.00	L	1.59	40.00	28.08
	B2	89-126		44.00	48.00	8.00	L	1.60	39.70	27.46
	B3	126-147		46.00	44.00	10.00	L	1.64	38.20	22.02
	B4	147-200		47.60	40.00	12.40	L	1.63	38.40	19.83
						Midslope				
Profile 104	A1	0-14		26.8	40	33.2	CL	1.21	54.2	12.2
	A2	14-42		42.4	34	23.6	L	1.48	44.3	9.82
	B1	42-92		46.4	28	25.6	L	1.55	41.7	6.64
	B2	92-105		52	26	22	SCL	1.57	40.6	10.54
	B3	105-125		52.8	26	21.2	SCL	1.58	40.5	11.8
	B4	125-166		56	22	22	SCL	1.59	40.2	11.17
	B5	166-200		68.4	16	15.6	SL	1.61	39.2	24.53
						Lowland				
Profile 105	A1	0 - 10		52.4	36	11.6	SL	1.43	46.2	36.6
	A2	10 - 32		54	34	12	SL	1.55	41.5	28.83
	B1	32 - 56		51.6	30	18.4	SL	1.57	40.9	15.72
	B2	56 - 72		51.6	30	18.4	SL	1.57	40.6	15.42
	B3	72 - 96		50.4	30	19.6	L	1.57	40.6	12.15
	B4	96 - 107		60.3	20	19.7	SL	1.59	39.9	14.64
	B5	107 - 143		49.6	26	24.4	SCL	1.57	40.9	8.41
	B6	143 - 200		42.4	34	23.6	L	1.56	41.3	7.23

SL= Sandy loam, L= Loam, SCL= Sandy clay loam, Sie= Site, B.D.= Bulk Density, Ksat= Saturated Hydraulic Conductivity.

4.2. Chemical Properties of the Soils

The Effective Cation Exchange Capacity (ECEC) of the soil was observed to be highest in the topsoil horizons of the three different profiles. Ap horizon(0-32 cm) 14.33 cmol/kg and A2 (32-58 cm) 5.96 cmol/kg, it fluctuated in the various subsoil horizons; for the midslope (profile 104) it was equally highest in the topsoil horizons A1 horizon (0-14 cm) 11.73 cmol/kg and 9.00 cmol/kg in the A2 horizon (14-42 cm) and decreased down the various subsoil horizon and was least in the B5 horizon (166-200 cm) 4.15cmol/kg and also in profile 105 (lowland), it was highest in the first topsoil horizon A1 (0-10 cm) 6.35cmol/kg and fluctuated in the subsoil but was least at the last horizon B6 (143-200 cm) 2.53cmol/kg these was in correspondence to the result of the clay content of the upland. For the topsoil of the midslope, a high rate of organic matter content favours the ECEC of the soil. It ranged from 11.73-4.15cmol/kg of the A1-B5 horizons of the midslope with a depth range of 0-14 to 166-200 cm. The ECEC ranged between 14.33 – 3.68cmol/kg of the Ap to B4 horizons with a depth range of 0-32 to 147-200 cm. The result showed that a decrease of organic matter down the profile leads to a decrease in ECEC as well as the clay content. The general result of the entire study site showed a high ECEC of all the topsoils, which was a result of the interaction and decomposition of organic matter by microorganisms and a decrease down the horizon as a result of illuviation of material down the various soil horizons.

The pH of the soils of the three different profiles (108, 104, 105) showed to be acidic, which ranged from 6.34 in the Ap horizon (0-32 cm) to 5.20 in the B4 horizon (147-200 cm), then for the profile 104 (midslope), the pH ranged from 5.71 in the A1 horizon (0-14 cm) to 5.21in the B5 horizon (166-200 cm), and also in profile 105 (lowland), the pH ranged from 6.17 in the A1 horizon (0-10 cm) to 5.12 in the B6 horizon (143-200 cm). Generally, pH values are relatively higher in the surface horizons and decrease with an increase in depth in all pedons, which could be attributed to a decrease in organic carbon content (Jimoh et al., 2016). pH values decreased down the toposequence, and there was no significant difference in the soil reaction of all the geomorphic units.

Soil organic carbon (O.C.) was generally rated low, being lower than 10 g kg-1 (Malgwi, 2007). Organic carbon content decreased with depth and could be attributed to a decrease in plant materials with depth; this confirms the report of Nahusenay and Kibebew (2016), who also reported a decrease in Organic matter with soil depth. The midslope recorded higher organic carbon, which could be attributed to the stable state of the unit, which allows the accumulation of organic materials, while the upper slope that recorded a lower value could be attributed to erosion as a result of the steep slope in the unit. More clayey soils generally tend to contain higher levels of organic matter mainly because of the tendency of clay to slow down microbial degradation of organic matter as clay forms clay-humus complexes with organic matter (Brady & Weil, 1999), unlike the upper slope and lowland positions which are interrupted by constant erosion and deposition of materials. The low organic matter content recorded on most of the soils cannot sustain crop production on long time bases.

Available Phosphorus (Ava. P) was noticed from the result to decrease down the horizon from 24.45 mg/kg in the Ap horizon (0-32 cm) to 0.45 mg/kg in the B4 horizon (147-200 cm). These followed the same pattern of decrease in the three profiles (108, 104,105). Profile 104 (midslope) A1 (0-14 cm) 12.73 mg/kg to 0.45 in the B4 horizon (147-200 cm) and in profile 105, lowland, A1 (0-10 cm) 12.73 mg/kg to 0.31 mg/kg in the B6 horizon (143-200 cm).

Organic matter (O.M.) generally decreased down the profile for the three geomorphic sample units. It ranged from 3.26 in the Ap horizon of depth (0-32 cm) to 0.13 in the B4 horizon of depth (147-200 cm) in the upland, it ranged from 5.74 in the A1 horizon of depth (0-14 cm) to 0.44 in the B5 horizons with a depth of (166-200 cm) on the midslope, it equally ranged from 2.82 in the A1 horizon of depth (0-10 cm) to 0.55 in the B6 horizon with a depth of (143-200 cm) on the lowland. The organic matter on the midslope tended to be highest. This was attributed to the accumulation of plant litter, leaves, stems and erosion deposits from the upland; therefore, there was a relationship between bulk density and organic matter cause as the organic matter was decreasing down the horizon of each geomorphic unit, bulk density had a corresponding increase. For the lowland, since organic matter is highest on the topsoil, which enhances infiltration, this also agrees with the high Ksat rate at the topsoil.

Total nitrogen (T.N.) ranged from 0.163 on Ap horizons (0-32 cm) to 0.005 on B4 horizons (147-200 cm) on the upland, it ranged from 0.280 on the A1 horizons (0-14 cm) to 0.022 of B5 horizons (166-200 cm) on the midslope and further ranged from 0.140 of the A1 horizons (0-10 cm) to 0.020 of B6 horizons (143-200 cm). The result showed that the T.N. values were low. The low content could be ascribed to rapid microbial activities and crop removal, leading to nitrate loss in the soil environment (Aiboni et al., 2007). This was an obvious reason for the expected decrease in the level of nitrogen content of the soil, as O.M. is essentially the main source of nitrogen.

Base saturation (B.S.) from the result was observed to increase and decrease down the profile in each of the geomorphic units. Although irregular in the increase and decrease pattern, each of the geomorphic units was observed to be fertile, which might be in accordance with the findings that soils with cent base saturation of less than 20 % are considered to be low, 20–60 % medium and greater than 60 % high fertility (Agbugba, 2018). Similarly, Abdulwahab et al. (2020) reported that soils with a base saturation of >50 % are regarded as fertile soils, while soils with less than 50 % are regarded as non-fertile soils.

Table 5: Chemical Properties of Selected Geomorphic Units.

Site No.	Horizon	Depth (cm)	pH	O.C. (%)	O.M. (%)	T.N. (%)	Ava. P (mg/kg)
			Upland				
Profile 108	Ap	0-32	6.34	1.89	3.26	0.163	25.45
	A2	32-58	6.27	1.63	2.82	0.140	7.55
	B1	58-89	5.56	0.41	0.72	0.036	3.74
	B2	89-126	5.47	0.35	0.61	0.031	1.71
	B3	126-147	5.25	0.07	0.13	0.006	0.47
	B4	147-200	5.20	0.06	0.13	0.005	0.45
			Midslope				
Profile 104	A1	0- 14	5.71	3.33	5.74	0.280	12.73
	A2	14 -42	5.66	1.12	1.92	0.080	3.73
	B1	42 -92	5.75	0.45	0.79	0.039	1.41
	B2	92 - 105	5.37	0.4	0.69	0.034	1.55
	B3	105 - 125	5.33	0.39	0.68	0.034	1.36
	B4	125 - 166	5.18	0.34	0.55	0.029	0.45
	B5	166 - 200	5.21	0.25	0.44	0.022	0.33
			Lowland				
Profile 105	A1	0 - 10	6.17	1.63	2.82	0.140	12.73
	A2	10 - 32	6.03	0.69	1.2	0.060	7.55
	B1	32 - 56	5.79	0.49	0.85	0.043	1.86
	B2	56 - 72	5.74	0.45	0.79	0.039	1.07
	B3	72 - 96	5.81	0.39	0.67	0.033	0.8
	B4	96 - 107	5.33	0.35	0.6	0.030	0.42
	B5	107 - 143	5.1	0.37	0.65	0.030	0.3
	B6	143 - 200	5.12	0.31	0.55	0.020	0.31

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pH= Soil reaction, OC= Organic carbon, OM= Organic matter, TN= Total nitrogen, Ava.P= Available phosphorus

Table 6: Chemical Properties of Selected Geomorphic Units.

Site No.	Hor.	Depth (cm)	Exch. Acidity (cmol/kg)			Exch. Bases (cmol/kg)					ECEC (cmol / kg)	B.S. (%)	Al Sat. (%)
			Al^{3+}	H^+	T.E.A.	Ca^{++}	Mg^{++}	K^+	Na^+	T.E.B.			
	Upland												
Profile 108	Ap	0-32	1.00	1.10	2.10	7.20	4.80	0.11	0.11	12.23	14.33	85.34	6.98
	A2	32-58	0.70	0.60	1.30	3.20	1.20	0.12	0.14	4.66	5.96	78.19	11.74
	B1	58-89	0.40	0.40	0.80	2.00	0.80	0.10	0.09	2.99	3.79	78.89	10.55
	B2	89-126	0.80	0.40	1.20	1.20	0.80	0.12	0.10	2.22	3.42	64.91	23.39
	B3	126-147	0.70	0.10	0.80	1.20	0.60	0.15	0.09	2.04	2.84	71.83	24.65
	B4	147-200	0.60	0.50	1.10	1.60	0.80	0.11	0.07	2.58	3.68	70.11	16.30
	Midslope												
Profile 104	A1	0- 14	1.10	0.80	1.90	6.80	2.40	0.42	0.21	9.83	11.73	83.80	9.38
	A2	14 -42	1.10	0.60	1.70	4.80	2.00	0.33	0.17	7.30	9.00	81.11	12.22
	B1	42 -92	0.60	0.20	0.80	2.40	1.60	0.24	0.13	4.37	5.17	84.53	11.61
	B2	92 - 105	0.70	0.50	1.20	2.00	1.60	0.26	0.22	4.08	5.28	77.27	13.26
	B3	105 - 125	0.90	0.40	1.30	2.20	1.80	0.20	0.10	4.30	5.60	76.79	16.07
	B4	125 - 166	0.40	0.20	0.60	2.00	1.40	0.22	0.14	3.76	4.36	86.24	9.17
	B5	166 - 200	0.60	0.20	0.80	1.80	1.20	0.25	0.10	3.35	4.15	80.72	14.46
	Lowland												
Profile 105	A1	0 - 10	0.70	0.60	1.30	2.80	2.00	0.07	0.18	5.05	6.35	79.53	11.02
	A2	10 - 32	0.80	0.50	1.30	2.40	1.20	0.06	0.21	3.87	5.17	74.85	15.47
	B1	32 - 56	0.90	0.46	1.36	2.20	1.60	0.22	0.16	4.18	5.54	75.45	16.25
	B2	56 - 72	0.40	0.46	0.86	2.00	0.80	0.09	0.04	2.93	3.79	77.31	10.55
	B3	72 - 96	0.30	0.20	0.50	1.80	1.20	0.33	0.24	3.57	4.07	87.71	7.37
	B4	96 - 107	0.70	0.10	0.80	1.20	0.60	0.11	0.05	1.96	2.76	71.01	25.36
	B5	107 - 143	0.40	0.20	0.60	1.60	0.80	0.13	0.14	2.67	3.27	81.65	12.23
	B6	143 - 200	0.60	0.10	0.70	1.20	0.40	0.17	0.06	1.83	2.53	72.33	23.72

Exch. Bases= Exchangeable Bases, Exch. Acid= Exchangeable Acid, ECEC=Effective Cation Exchange Capacity, Al.Sat= Aluminum Saturation, B.Sat= Base Saturation.

4.3. Soil Classification

The soils were classified according to Soil Taxonomy and the World Reference Base for Soil Resources (WRB). The different soil classes are shown in Table 7.

Table 7: Summary of Selected Geomorphic Units Land Use Recommendation

Geomorphic Unit	Soil Taxonomy (Order-level)	Land Use Recommendation
Upland	Inceptisols	Land use varies considerably with Inceptisols. If erosion and drainage problems are managed effectively, they can be quite productive. Inceptisols support approximately 20 per cent of the world's population, the largest percentage of any of the soil orders (Department of Soil and Water Systems, 2021).
Midslope	Inceptisols	Land use varies considerably with Inceptisols. If erosion and drainage problems are managed effectively, they can be quite productive. Inceptisols support approximately 20 per cent of the world's population, the largest percentage of any of the soil orders (Department of Soil and Water Systems, 2021).
Lowland	Alfisols	Alfisols are moderately leached soils that have relatively high native fertility. The combination of a generally favourable climate and high native fertility allows Alfisols to be very productive soils for both agricultural and silvicultural use. They support about 17 per cent of the world's population (Department of Soil and Water Systems, 2021).

4.3.1. Soil Taxonomy

Order: Profile 105 (lowland) may have been classified as Alfisols or Ultisols because of the existence of a Kandic horizon as well as evidence of increasing clay content with increasing depth. It was, however, classified as Alfisols due to a base saturation that was higher than 35% at all depths.

Profile 108 (upland) and Profile 104 (Midslope) were classified as Inceptisols due to evidence of irregular clay distribution with increasing soil depth, which is diagnostic of the absence of argillic or kandic horizons.

Table 8: Summary of Selected Geomorphic Units Diagnostic Features and their Soil Order.

Geomor phic Unit	Diagnostic Features	Soil Order
Lowland	Evidence of increasing clay content with depth is diagnostic of the presence of argillic or Candice horizons; base saturation was generally higher than 35 % at all depths.	Alfisols
Upland	Evidence of irregular clay content with depth, which is diagnostic of the absence of argillic or kandic horizons.	Inceptis ols
Midslope	Evidence of irregular clay content with depth, which is diagnostic of the absence of argillic or kandic horizons.	Inceptis ols

4.4. Growth Response of Rice

The experimental site, after delineation, had seven geomorphic units, which included Ridge, Flat, Valley, Midslope and Spur. For my work, I focused on the upland, midslope and lowland. The various units focused on were used for rice cultivation to determine the effect of toposequence on the various varieties of Rice (FARO 44, 52, 58, 59) and their adaptations, as some varieties were known to be upland varieties (FARO 44 and 52) while others upland varieties (FARO 58 and 59) according to Longtau(2003). The slope depicted the Uplands; the midslope depicted the middle slope, and the valley depicted the lowlands.

Table 9: Effect of Variety and Toposequence on Height and Number of Rice Tillers.

Treatments	Plant Height	Number of tillers
Variety(V)		
FARO 44	48.92	2.97
FARO 52	55.56	3.22
FARO 58	71.47	2.69
FARO 59	66.25	2.42
LSD (0.05)	4.45*	0.58*
Toposequence(T)		
Lowland	64.92	3.67
Middle slope	62.65	2.58
Crest	54.08	2.23
LSD(0.05)	3.86	0.51
Interaction		
V X T	7.715*	1.009*

4.4.1. Plant height:

There existed a significant difference in plant height (P > 0.05), which was a result of the characteristics of the various varieties used due to the different physiographic positions of the plots. Also, there existed a clear-cut difference in the height of the plants in relation to the position of the plots; from the table, the heights of all the varieties grown on the lowland were more in height ranging from FARO 58, FARO 59, FARO 52 and FARO 44. This may be attributed to the high clay content of the lowland, which has a significant role in the Ksat of the plot. More so, there is perceived to be a runoff of sediments and organic matter from the upland to the midslope and to the lowlands.

4.4.2. Number of tillers:

The lowland supported significantly more tillers from the rice plant than the middle slope and upland (P > 0.05) for all four varieties (Table 7). Comparing the heights of the different varieties to the Number of tillers produced, it was seen that FARO 52 and FARO 44 which were the least in height, recorded to have more tillers ranging from the lowland to upland.

4.4.3. Interaction Effect of Variety and Toposequence on Rice Height and Number of Tillers

From the analyzed soil results, it was observed that the lowlands produced rice plants with many numbers of tillers when compared to the midslope and uplands. This is a result of its highwater-holding capacity, which may be attributed to high clay content and saturated hydraulic conductivity (Ksat) in the lowlands. The above-mentioned parameters (Ksat, high clay content, and also high organic matter content) supports the growth of rice plant. The above-mentioned parameters were predominantly high in the lowlands, which were a result of the runoff of sediments and mineral matter from the upland down to the lowlands of the plots. Table 9. Shows that the interaction between rice varieties and toposequence position had a significant effect on the variations in the Number of tillers and plant height.

It was seen that all the rice varieties (FARO 44, 52, 58, and 59) cultivated in the lowland were more in the Number of tillers as well as in plant height when compared to those cultivated in the midslope and uplands. This interaction is depicted in Figures 5 and 6. According to Dytham (2011), an interaction plot that shows a convergence of factors is indicative of the fact that the observations assigned to factor 1 do not respond in the same way to the observations assigned to factor 2. This is reflected in the results as the plant height and tiller number did not respond in the same way to variation in rice varieties and toposequence position. This may be attributed to the fact that the rice varieties were bred specifically for either uplands (middle slope or upland) or swamps (lowland). As such, while some varieties will have higher outputs in the lowlands, the output in the middle slope and uplands will be depressed, and vice versa. The breeding of the varieties to be adapted to specific toposequence positions and soil (water) conditions was effective.

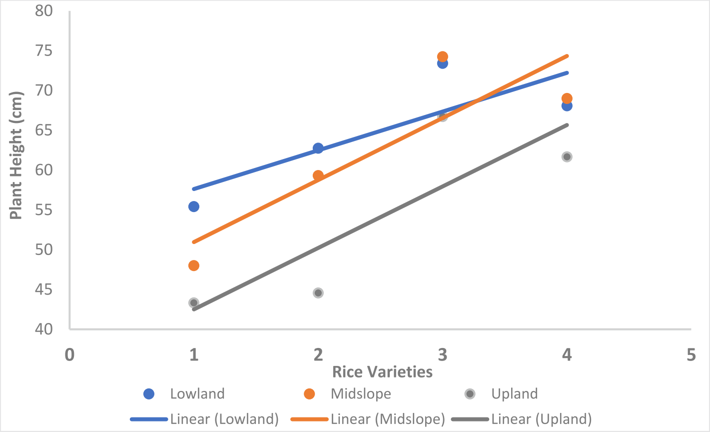

Figure 5: Interaction of Rice Varieties and Toposequence Position on Plant Height

KEY

1 = FARO44
2 = FARO52
3 = FARO58
4 = FARO59
FARO: Federal Agricultural Research Oryza

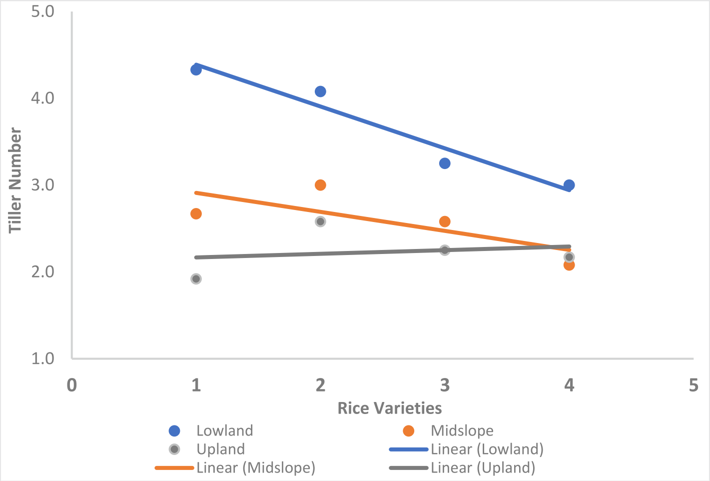

Figure 6: Interaction of Rice Varieties and Toposequence Position on Tiller Number.

KEY

1 = FARO44
2 = FARO52
3 = FARO58
4 = FARO59

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Table 10: Effect of Variety and Toposequence on growth characteristics of Rice.

Treatments	Fresh Biomass Weight	Dry Biomass (Dry matter)
Variety(V)		
FARO 44	5.29	4.09
FARO 52	6.43	5.19
FARO 58	7.44	5.72
FARO 59	7.97	6.32
LSD(0.05)	1.742	0.066^{NS}
Toposequence (T)		
Lowland	6.41	5.28
Middle slope	7.06	5.62
Crest	6.88	5.08
LSD (0.05)	3.016^{NS}	2.899^{NS}
Interaction		
V X T	0.085^{NS}	0.062^{NS}

NS: Non-significant.

4.4.4. Fresh Biomass and Dry Biomass (Dry Matter)

The fresh biomass of the rice tillers was a function of the height and Number of tillers as well as the moisture content percentage. From (Table 9) $p < 0.05$ implied that there was no significant difference between toposequence and varieties on rice dry matter, while $p > 0.05$ implied that there was a significant difference between varieties on fresh biomass.

5 CONCLUSION AND RECOMMENDATION

Physiographic influenced the different soil physical and chemical properties such as the Clay content, Ksat, bulk density, organic matter, available phosphorus, and base saturation; all these properties in tune played a role in the growth response of the rice plant.

The research work showed that the upland varieties of Rice (FARO 58 and FARO 59), as well as the lowland varieties (FARO 52 and FARO 44), showed considerable adaptation to the different toposequence positions. Proper delineation of any given site for rice cultivation should always be done to ascertain the most favorable position for the cultivation of Rice as well as the necessary soil tests should equally be done to derive the maximum yield.

From the results of the soil tests, the soils of all the delineated plots were generally acidic. The soils on the upland had the least Ksat followed by the midslope, while the lowland had the highest Ksat. The bulk density, as well as the organic matter content, showed a relationship as the organic matter reduced down the various horizons while bulk density had an appreciable increase. The ECEC of the soils generally was moderate for the production of rice plants.

It is therefore recommended that there should be more cultivation of rice plants within the lowlands and midslope; these can be supported by the results conducted on the soil tests and analysis. Other land management and amendment practices can be practised in order to maximize the output from the use of the upland for rice cultivation which can be due to its poor Ksat, organic matter, as seen in the result.

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