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Spatial Variation in Soil Chemical Properties Associated with Agrochemical Use in Farming Communities of Oju Local Government Area, Benue State, Nigeria

[1]Mercy Ogeyi Ikape; [2]Jonathan Ali Ogwuche; [3]Patricia Ali
Department of Geography,
Rev. Fr. Moses Orshio Adasu University, Makurdi, Nigeria

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Abstract: *This study examined the spatial variation in selected soil chemical properties associated with agrochemical use in farming communities of Oju Local Government Area (LGA), Benue State, Nigeria. A comparative field-based design was adopted across seven farming communities—Ibilla, Ukpa, Iyeche, Owo, Oboru, Uwokwu and Oju. Twenty-eight soil samples comprising 14 agrochemical-treated and 14 control samples were collected at depths of 0–15 cm and 15–30 cm and analysed for selected chemical properties using standard laboratory procedures. The results revealed considerable spatial and depth-related variation. Soil pH ranged from* ***6.08 to 6.52****, indicating slightly acidic to near-neutral conditions. Soil organic carbon (SOC) was consistently higher in control soils, with values of* ***14.0% and 12.6%*** *at 0–15 cm and 15–30 cm, respectively, in Owo, compared with* ***10.3% and 10.1%*** *in treated soils. In Uwokwu, control SOC values of* ***14.3% and 13.88%*** *exceeded treated values of* ***10.6% and 10.4%****. Organic matter ranged from approximately* ***1.7% to 4.5%****, while total nitrogen ranged from* ***0.01% to 0.12%****. Available phosphorus reached* ***2.49 mg/kg*** *in treated surface soil at Owo. Exchangeable potassium and calcium reached maximum surface values of* ***0.38 and 4.30 cmol(+)/kg****, respectively, at Uwokwu. The study concludes that, active agrochemical use was most consistently associated with lower SOC, whereas other properties exhibited variable spatial and depth-related patterns. The study therefore recommends integrated soil fertility management, appropriate agrochemical application, soil testing and regular monitoring.*

Keywords: agrochemicals, soil chemical properties, spatial variation, soil fertility, Oju LGA

INTRODUCTION

Soil is a fundamental natural resource that supports agricultural production, nutrient cycling, water regulation and terrestrial ecosystem functioning. Its chemical condition is particularly important because the availability and balance of essential nutrients influence plant growth, soil fertility and the long-term productivity of agricultural systems. Soil quality refers broadly to the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and support plant and animal health (Bünemann et al., 2018). Because soil functions and properties vary according to environmental conditions, land use and management history, assessment of soil quality requires the use of appropriate indicators that reflect the specific objectives and conditions of a study (Bünemann et al., 2018; Karlen et al., 2017). In agricultural landscapes, chemical indicators such as soil pH, organic carbon, total nitrogen, available phosphorus and exchangeable cations are particularly important because they provide information on nutrient availability, soil fertility and the effects of management practices. Recent evidence from farming communities in different ecological regions of Nigeria has also demonstrated substantial spatial variation in soil pH, organic carbon, total nitrogen, available phosphorus and exchangeable cations, reinforcing the importance of location-specific soil assessment and management (Oyun, et al., 2025).

Agrochemicals, including inorganic fertilisers, herbicides, pesticides, fungicides and related agricultural inputs, are widely used to improve crop production by supplying nutrients and controlling weeds, pests and diseases. Appropriate application can enhance crop growth and productivity; however, continuous or inappropriate use may alter soil chemical characteristics and contribute to nutrient imbalance and environmental contamination. The effects may include changes in soil pH, organic matter, organic carbon, nitrogen, phosphorus and exchangeable cations, depending on the type and composition of the agrochemical, application rate and frequency, soil characteristics and other management practices. Evidence from Nigeria indicates that persistent pesticide residues have been detected in environmental media, including agricultural soils, while inappropriate application and inadequate management can increase the potential for environmental contamination (Mazlan et al., 2017). More recent evidence has similarly shown that prolonged agrochemical application can influence soil quality indicators and contribute to the accumulation of trace elements in agricultural soils (Osinuga et al., 2023). These concerns make the assessment of soil chemical properties under different agrochemical-use conditions important for sustainable soil and agricultural management.

In Nigeria, agricultural intensification has increased farmers' dependence on fertilisers, herbicides and pesticides to maintain crop production and manage weeds, pests and diseases. The implications of such inputs for soil quality, however, may vary considerably according to soil type, cropping system, input type, application history and local environmental conditions. For example, Ogundijo et al. (2015) found that the application of organic and inorganic fertilisers influenced soil organic carbon, total nitrogen, available nutrients and pH in soils from southwestern Nigeria, with combined organic and inorganic inputs producing different soil responses from inorganic fertiliser alone. Similarly, Osinuga et al. (2023), in a study of wetlands under different agricultural uses in Abeokuta, reported lower soil pH, organic matter, total nitrogen and potassium in agrochemical-applied fields than in the control site, whereas available phosphorus was higher in the agrochemical-applied fields. These findings demonstrate that the response of soil chemical properties to agricultural inputs is not necessarily uniform and should be evaluated under specific local conditions.

The importance of spatial assessment is particularly relevant because soil properties can vary considerably over relatively short distances as a result of differences in topography, parent material, drainage, land use and management history. In Ipinu-Oju, Benue State, Ogbu et al.

(2023) reported significant variations in soil pH, total nitrogen, organic carbon, organic matter, available phosphorus, potassium, cation exchange capacity and other soil properties along different topographic positions. The study demonstrates that spatial variability is an important consideration in understanding soil conditions within agricultural landscapes. Similarly, Ayeni et al. (2025), using soil samples from farming communities across southern and northern Nigeria, reported marked spatial variation in soil organic carbon, total nitrogen, available phosphorus, exchangeable cations and other physicochemical properties. Such evidence suggests that the effects of agricultural management practices should not be interpreted solely from aggregate values but should also be examined according to location and soil depth.

Benue State is one of Nigeria's important agricultural regions, with extensive cultivation of crops such as yam, cassava, maize, rice and vegetables. Agricultural production is an important component of rural livelihoods in the state, and the use of chemical inputs forms part of contemporary crop-management practices. In Oju Local Government Area (LGA), agriculture constitutes a major land-use activity, with farmers using fertilisers, herbicides and pesticides to support crop production and control weeds and pests. The increasing dependence on these inputs raises concerns about possible changes in soil chemical conditions, particularly where application is frequent and soil testing and complementary soil-management practices are limited. Localised assessment is therefore necessary to establish the condition of agricultural soils and determine whether differences exist between areas under active agrochemical use and areas with little or no recent agrochemical application.

Evidence from studies conducted within Oju LGA provides an important basis for understanding the variability of local soils but does not adequately address the specific influence of agrochemical use. For instance, Dachung et al. (2022) investigated the effects of sawdust disposal on soil nutrient status and microbial characteristics in Ichakobe, Ibilla, Oju LGA, and found differences between soils from sawdust dumpsites and adjacent normal sites. However, the study focused on sawdust disposal rather than agrochemical application. Similarly, Ogbu et al. (2023) examined the effects of topography on soil properties in Ipinu-Oju and reported significant variations in pH, total nitrogen, organic carbon, organic matter, available phosphorus, potassium and other soil properties across slope positions. While the findings demonstrate the existence of spatial variability in the soils of Oju, they did not specifically examine differences associated with agrochemical application.

Other Nigerian studies provide further empirical support for examining agrochemical-related differences in soil chemical properties. Okafor et al. (2023), for example, compared agrochemical-applied and control rice-field soils at depths of 0–15 cm and 15–30 cm in Ifite-Ogwari, Anambra State, and reported differences in soil pH, organic carbon, total nitrogen, available phosphorus and exchangeable bases between the two categories of soil. The study therefore provides a useful empirical basis for comparing treated and control soils at different depths. More recently, Hassan et al. (2025) examined the effects of agrochemical use on soil quality in the Sudan Savannah zone of northwestern Nigeria using soil indicators including organic carbon, phosphorus, nitrogen, cation exchange capacity and exchangeable cations. Their findings further demonstrate the relevance of evaluating agrochemical effects through measurable soil-quality indicators. Collectively, these studies indicate that agricultural chemical inputs may be associated with changes in soil chemical properties, although the magnitude and direction of such changes may differ among locations and management environments.

Despite the growing body of evidence, there remains limited empirical information specifically comparing soil chemical properties between actively agrochemical-treated soils and soils without recent agrochemical application across farming communities in Oju LGA. Existing studies in the area have largely focused on general soil characteristics, topographic variation and other forms of land or environmental management rather than directly assessing differences associated with active agrochemical use. Consequently, there is inadequate local evidence on how key soil chemical properties vary between actively treated soils and soils that have not received agrochemicals or where agrochemical application ceased in 2021. This represents an important research gap because such a comparison can provide empirical evidence on whether measurable differences exist in soil chemical conditions under contrasting agrochemical-use histories.

In the present study, agrochemical-treated soils represent areas where farmers are actively applying agrochemicals, whereas control soils represent areas with no current agrochemical application or where application ceased in 2021. Comparing these two categories at 0–15 cm and 15–30 cm provides a basis for examining both spatial and depth-related variations in soil pH, organic carbon, organic matter, total nitrogen, available phosphorus and exchangeable potassium. The comparison is particularly relevant because changes in these properties can provide important evidence of differences in soil fertility and chemical condition associated with contrasting agricultural management practices. The study therefore focuses on measurable differences rather than assuming that all observed variations are attributable exclusively to agrochemical use, recognising that soil properties may also be influenced by inherent spatial and environmental factors.

Against this background, the present study investigates the spatial variation in soil chemical properties associated with agrochemical use in farming communities of Oju Local Government Area, Benue State, Nigeria**.** Specifically, the study compares selected soil chemical properties of actively agrochemical-treated soils with control soils and examines their variation across the 0–15 cm and 15–30 cm soil depths. The findings are expected to provide localised empirical evidence to support improved soil management, responsible agrochemical use and sustainable agricultural production in Oju Local Government Area.

MATERIALS AND METHODS

Study Area

Oju LGA is located in the southern part of Benue State in North-Central Nigeria.It lies between latitudes 6°40ʹ00ʹʹ N to 7°50ʹ00ʹʹ N and longitude 8°05′00’’E to 8°40′00’’E, occupying a transitional terrain between the southern Guinea savanna and the Cross River plains. It shares boundaries with several other LGAs and states: To the north: Obi LGA and Gwer East LGA, To the east: Konshisha LGA to the south: Izzi LGA of Ebonyi State. To the west: Ado LGA and parts of Cross River State as shown (Figure 1).

The topography of Oju is moderately undulating, with elevations ranging from 150 meters to over 350 meters above sea level, forming part of the Benue trough hinterlands and extending eastward toward the Obudu-Cameroon Highlands. The terrain is generally gently rolling, particularly in the central and western parts of the LGA (around Idekpa, Owo, and Uwokwu), interspersed with low inselbergs and isolated hillocks in the east (in Oboru, Okudu, and Itogo), which are residual features of basement complex rocks that resisted weathering (Ofomata, 1975; Iloeje, 1981). The topographic gradient becomes more rugged as one approaches the border areas with Cross River State, reflecting a shift from sedimentary plains to crystalline basement highlands. Its geology comprises Precambrian Basement Complex rocks and Cretaceous sedimentary formations, which influence topography, drainage, soil development and erosion. Oju experiences a tropical wet-and-dry climate, with annual rainfall of about 1,200–1,800 mm and mean temperatures of 26–32°C. The vegetation is predominantly Southern Guinea Savanna, although extensive human activities have transformed parts of the natural vegetation into derived savanna and fragmented landscapes. Soils include Ferralsols, Luvisols, Lixisols, Vertisols and Lithosols/Regosols, with considerable variation in fertility, drainage and susceptibility to erosion.

Agriculture is the dominant economic activity in Oju and is largely based on smallholder, rain-fed and mixed subsistence farming. Major crops include cassava, yam, maize, soybean, groundnut, cowpea and vegetables, with cassava increasingly becoming dominant because of its tolerance to poor soils and variable rainfall. Traditional practices such as fallowing, crop rotation, residue retention and ash application are increasingly being replaced or supplemented by continuous cultivation and mineral fertiliser use, resulting in declining soil organic matter and nutrient depletion. Livestock production exists but is weakly integrated with crop production, limiting the recycling of manure and nutrients. Consequently, the combination of intensive smallholder farming, soil fertility decline, climatic variability and increasing reliance on agrochemicals makes Oju LGA an appropriate setting for investigating the effects of agrochemical use on soil quality.

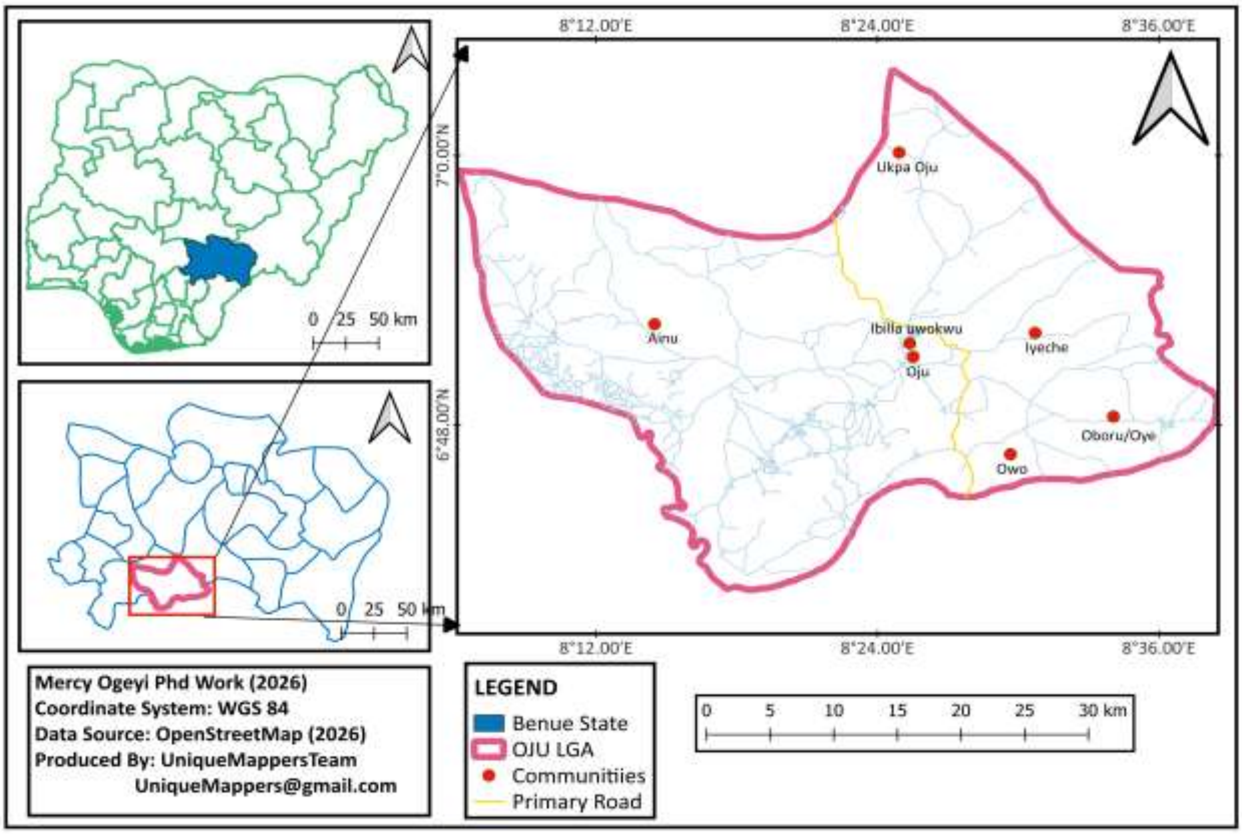

Figure 2: Study Communities in Oju Local Government Area of Benue State.

METHODS

The study adopted a comparative and field-based research design, with seven (7) farming communities, namely Ibilla, Ukpa, Iyeche, Owo, Oboru, Uwokwu and Oju, selected for the study. Soil samples were collected from both agrochemical-treated plots (areas with active agrochemical application) and non-treated control plots (areas with no agrochemical application or where agrochemical application had ceased since 2021) in the selected communities, giving a total of 28 soil samples comprising 14 treated and 14 control samples. Soil sampling was conducted at depths of 0–15 cm and 15–30 cm using standard soil augers. The samples were properly labelled, transported to the laboratory, air-dried, gently crushed and passed through a 2-mm sieve prior to analysis. Laboratory analyses focused on selected soil chemical properties relevant to soil quality and agrochemical effects, including soil pH, organic carbon, organic matter content, total nitrogen, available phosphorus and exchangeable potassium.

Standard laboratory analytical procedures were employed to determine the selected soil chemical properties. Soil pH was determined using the soil–water suspension method; organic carbon was determined using the Walkley–Black method; total nitrogen using the Kjeldahl method; available phosphorus using the Bray-1 method; and exchangeable potassium using the ammonium acetate extraction method. The laboratory results obtained from the treated and control soils were subjected to descriptive analysis and presented using bar graphs to facilitate

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comparison of the selected soil chemical properties across the sampled farming communities and between agrochemical-treated and control soils.

RESULTS AND DISCUSSION

Results

The results of the laboratory analysis of soil samples from the selected farming communities in Oju Local Government Area are presented in Figures 1–7. For the purpose of interpretation, treated soils refer to areas where agrochemicals are actively applied, whereas control soils refer to areas with no history of agrochemical application or where agrochemical use ceased since 2021.

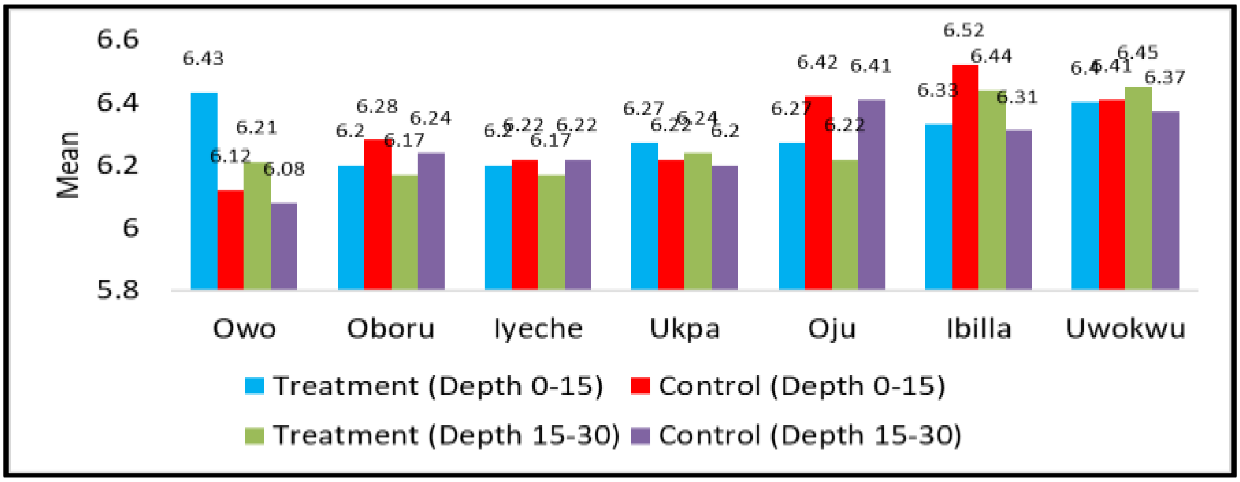

Figure 1: Soil pH

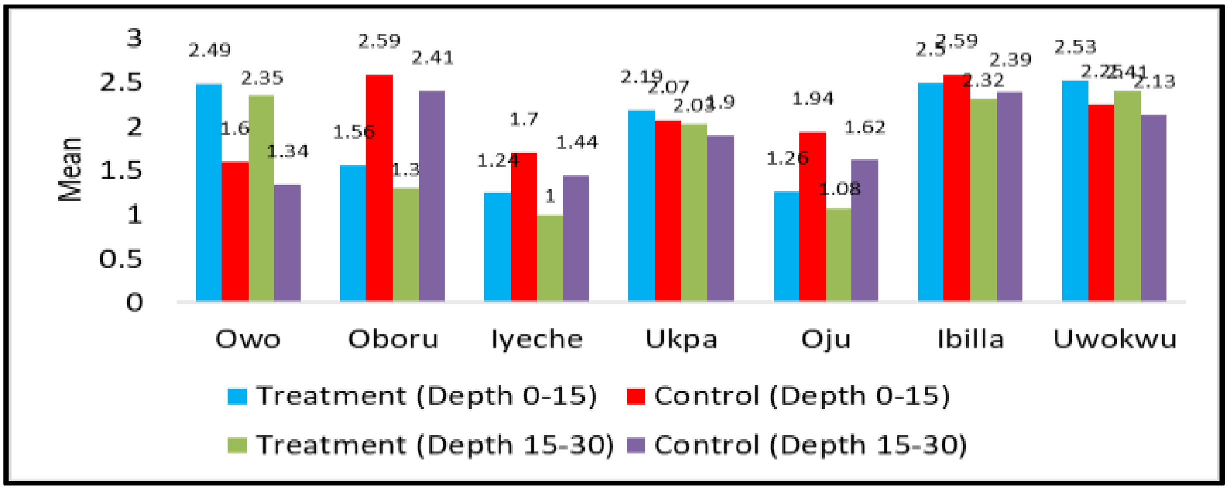

Figure 2: Soil organic carbon (SOC)

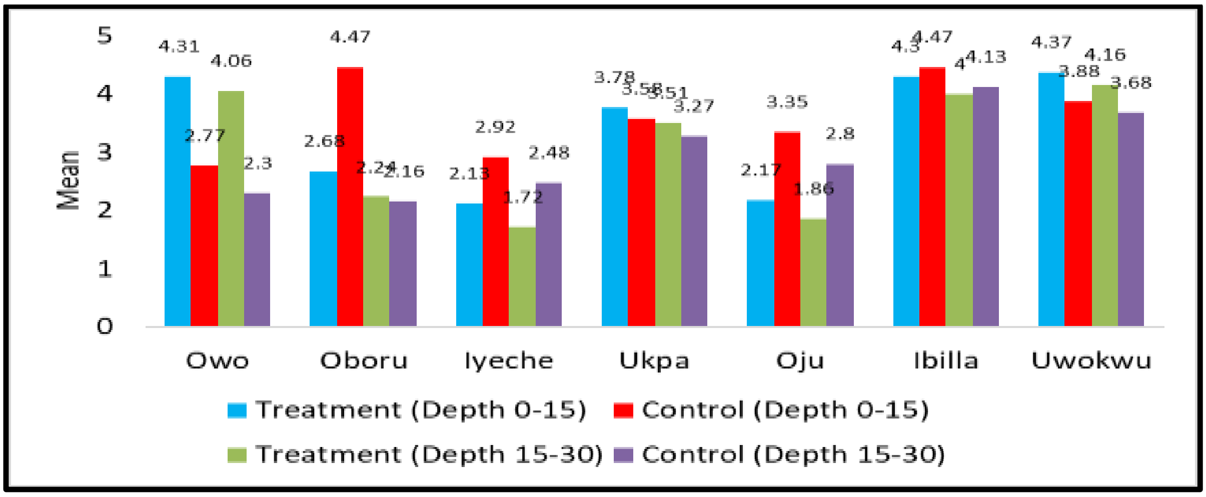

Figure 3: Soil Organic Matter Content

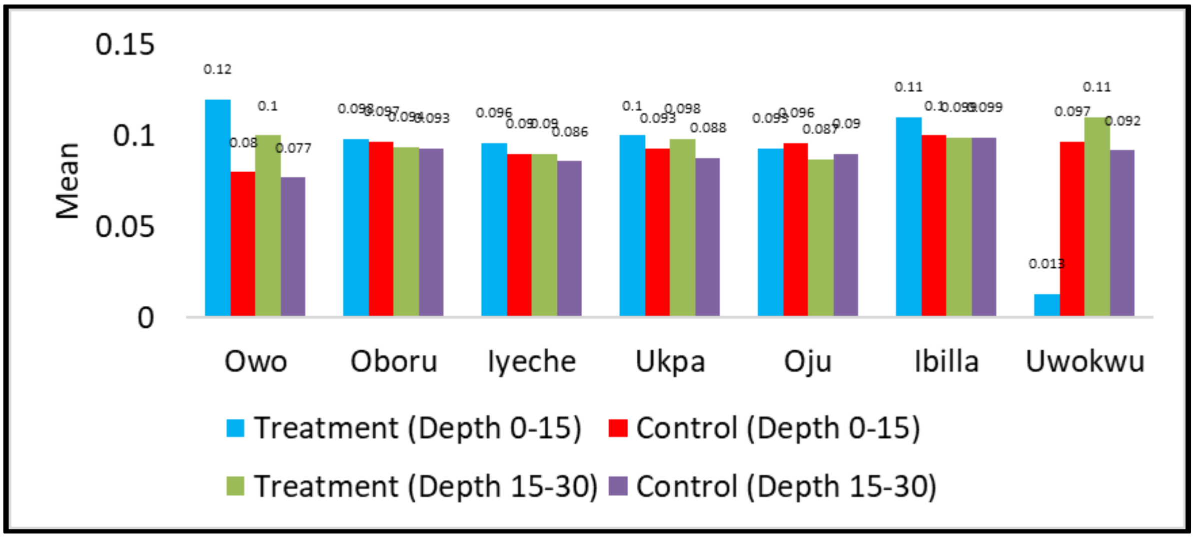

Figure 4: Total Nitrogen (N) Content in the Soil.

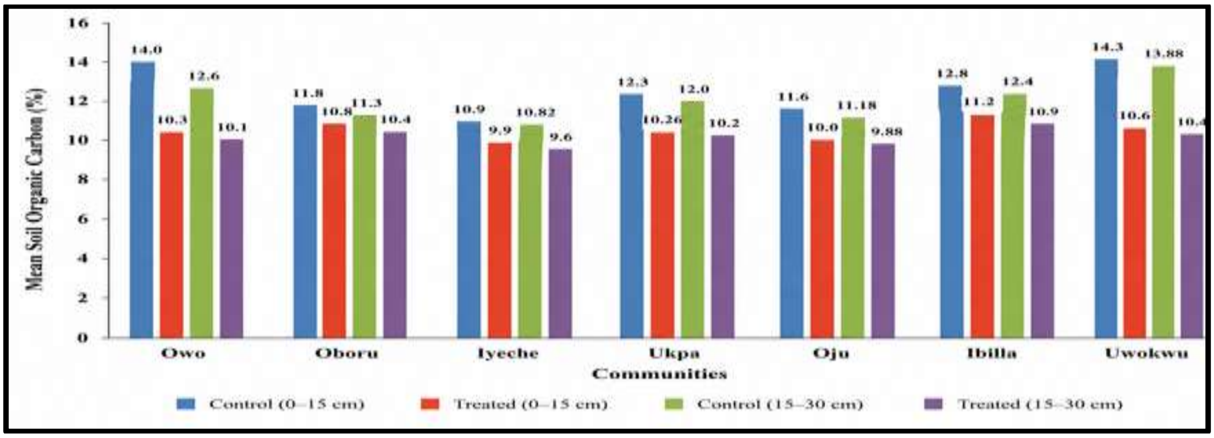

Figure 5: Available Phosphorus (P) in **Soil**.

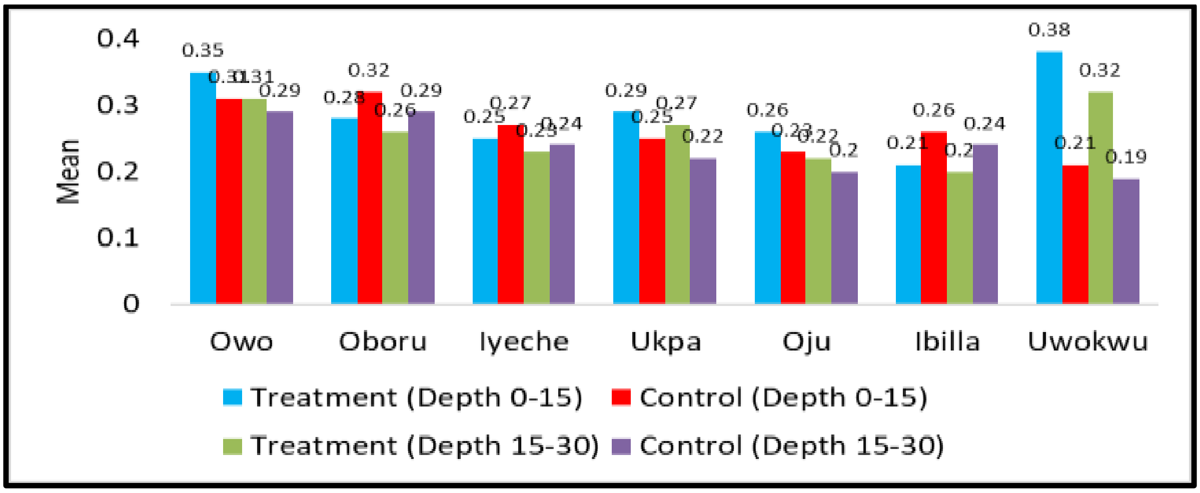

Figure 6: Available potassium

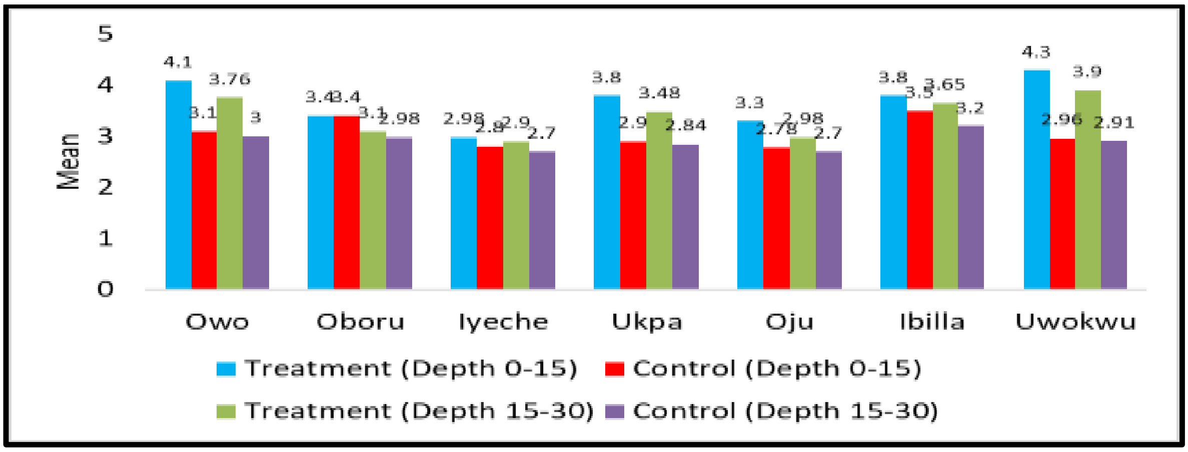

Figure 7: Available Calcium in the soil

Soil pH (Figure 1) remained slightly acidic to near-neutral across all communities, with values ranging from 6.08 to 6.52 (pH units). In Owo, the 0–15 cm treated soil recorded a pH of 6.43, compared with 6.12 in the control soil, while at 15–30 cm, the corresponding values were 6.21 and 6.08, respectively. Similarly, Ibilla recorded values between 6.33 and 6.52, while Uwokwu ranged from 6.37 to 6.45. The relatively narrow pH range suggests that agrochemical application was associated with only modest variation in soil acidity across the sampled communities and depths.

Soil organic carbon (SOC) (Figure 2), expressed as percentage (%), showed a more pronounced difference between treated and control soils. In general, SOC concentrations were higher in the control soils than in the actively treated soils at both sampling depths. In Owo, the control soil recorded 14.0% SOC at 0–15 cm and 12.6% at 15–30 cm, compared with 10.3% and 10.1%, respectively, in the treated soils. A similar pattern occurred in Uwokwu, where control soils recorded 14.3% and 13.88%, compared with 10.6% and 10.4% in treated soils at 0–15 cm and 15–30 cm, respectively. Other communities also showed lower SOC in treated soils, including Oboru (11.8% control versus 10.8% treated) and Ukpa (12.3% control versus 10.26% treated).

These results indicate a consistent spatial association between active agrochemical use and lower soil organic carbon content, although the observed differences may also reflect variations in land management and other site-specific factors.

Organic matter (OM) content (Figure 3), expressed as percentage (%), varied considerably among the communities and sampling depths, with values generally ranging from approximately 1.7% to 4.5%. Unlike SOC, the results did not show a consistent difference between treated and control soils across all locations. This spatial variability suggests that organic matter content was influenced by several factors in addition to agrochemical application, including vegetation cover, residue incorporation, soil management practices and local environmental conditions.

Total nitrogen (TN) (Figure 4), expressed as percentage (%), was generally low across the sampled soils, with values ranging from 0.01% to 0.12%. The lowest value of 0.01% was recorded in the 0–15 cm treated soil at Uwokwu, whereas the highest value of 0.12% occurred in the 0–15 cm treated soil at Owo. The generally low TN concentrations indicate limited nitrogen availability in several of the sampled soils. The variation between treated and control soils was not uniform across the communities, suggesting that the relationship between active agrochemical use and total soil nitrogen was spatially variable.

Available phosphorus (Figure 5), expressed in mg/kg, also varied among communities, depths and treatment categories. The highest observed value was approximately 2.49 mg/kg in the 0–15 cm treated soil at Owo, whereas Iyeche recorded values below 1.70 mg/kg across the sampled depths and treatment categories. The relatively higher phosphorus concentration in some surface treated soils may be associated with the application of phosphorus-containing fertilisers or other agrochemical inputs. However, the absence of a consistent pattern across all communities indicates that phosphorus availability was also influenced by local soil properties and management practices.

Exchangeable potassium (Figure 6), measured in cmol(+)/kg, was generally higher in the 0–15 cm surface soils than in the 15–30 cm subsoil. The highest concentration was recorded in the 0–15 cm treated soil at Uwokwu (0.38 cmol(+)/kg), followed by Owo (0.35 cmol(+)/kg). At the 15–30 cm depth, potassium values generally declined to approximately 0.19–0.29 cmol(+)/kg. The higher surface concentrations may reflect the accumulation of nutrients in the upper soil layer through fertiliser application, crop residues and other surface-based management practices.

Exchangeable calcium (Figure 7), also expressed in cmol(+)/kg, exhibited a pattern broadly similar to potassium, with relatively higher concentrations in the 0–15 cm layer. Uwokwu recorded the highest surface treated-soil calcium concentration of 4.30 cmol(+)/kg, while Owo recorded 4.10 cmol(+)/kg. At the subsoil depth, calcium concentrations generally decreased to approximately 2.70–3.20 cmol(+)/kg, particularly in the control soils. The higher surface concentrations of calcium and potassium suggest greater nutrient accumulation in the upper soil layer, potentially reflecting fertiliser inputs, organic residue decomposition and reduced downward movement of these exchangeable bases.

DISCUSSION

Generally, the results demonstrate spatial variation in soil chemical properties between areas of active agrochemical application and areas with no recent agrochemical use across the farming communities of Oju LGA. The most pronounced treatment-associated difference was observed for soil organic carbon (%), which was consistently higher in control soils than in actively treated soils, whereas pH (pH units), total nitrogen (%), available phosphorus (mg/kg), exchangeable potassium (cmol(+)/kg), and exchangeable calcium (cmol(+)/kg) exhibited more variable patterns across communities and soil depths. The results therefore suggest that active agrochemical use may be associated particularly with changes in soil organic carbon, while the spatial distribution of other chemical properties appears to reflect a combination of agrochemical application, depth, soil characteristics and local farming practices.

Specifically, the consistently lower soil organic carbon (10.1–10.8%) in treated soils compared with controls (12.3–14.3% in several communities). This finding agrees strongly with Okafor et al. (2023), who reported lower organic carbon and total nitrogen in agrochemical-treated rice soils than in adjacent control soils in Ifite-Ogwari, Anambra State; their study also found significant responses of pH, calcium and available phosphorus to regular agrochemical application. Similarly, Hassan et al. (2025) identified agrochemical use as an important soil-quality concern in farming communities of Kano State, while Osinuga et al. (2023) reported changes in soil-quality indicators under agrochemical-intensive wetland farming in Abeokuta. The relatively narrow pH range observed in Oju (6.08–6.52) suggests that active agrochemical use has not produced severe acidification, although the slightly lower pH values at some locations warrant monitoring. This contrasts with the stronger acidification reported by Ogbodo (2013) in continuously fertilised soils of Ebonyi State, where pH ranged from 4.0 to 5.6. The observed variation in total nitrogen, available phosphorus, potassium and calcium is also consistent with the findings of Oyun et al. (2025), who demonstrated substantial spatial differences in OC, TN, available P and exchangeable cations across Nigerian farming communities.

The depth-related pattern in Oju, particularly the generally higher concentrations of exchangeable K and Ca in the 0–15 cm layer, is consistent with studies showing that soil chemical properties vary considerably with depth and management. Nwachukwu et al. (2020) found significant effects of soil depth and tillage on several soil chemical properties in southeastern Nigeria, while Sauwa et al. (2018) reported slight deterioration of chemical quality in continuously cultivated soils, especially within the surface layer. The findings are further supported by Ayoola et al. (2023), who found substantial variation in soil chemical characteristics and higher concentrations of exchangeable cations in topsoil from farms receiving herbicide inputs in Oyo State. Ogundijo et al. (2015) similarly showed that fertiliser management could alter SOC, total N, pH and exchangeable nutrients in Nigerian soils, while Wang et al. (2019) demonstrated that long-term chemical NPK fertilisation can promote soil acidification, whereas organic inputs improve SOC and moderate acidity.

CONCLUSION AND RECOMMENDATIONS

The study concludes that soil chemical properties vary spatially across the selected farming communities of Oju Local Government Area, with differences observed between actively agrochemical-treated soils and control soils with no agrochemical use or no use since 2021. The most consistent difference was observed in soil organic carbon, which was generally higher in the control soils than in the actively treated soils, suggesting a possible association between intensive agrochemical use and reduced soil organic carbon. Soil pH remained slightly acidic to near-neutral, while total nitrogen, available phosphorus, exchangeable potassium and calcium showed variable responses across communities and soil depths. The results indicate that agrochemical use is an important factor influencing soil chemical characteristics, although the magnitude and direction of its effects vary according to location, soil depth and local farming practices.

Based on these findings, farmers should adopt integrated soil fertility management practices that combine judicious agrochemical application with organic amendments such as compost, farmyard manure and crop residues to maintain soil organic matter and nutrient availability. The extension services of the Benue State Ministry of Agriculture should strengthen farmer education on appropriate agrochemical types, application rates, timing and frequency, while promoting soil testing before repeated chemical application. Regular monitoring of soil chemical properties, particularly soil organic carbon, nitrogen, phosphorus and exchangeable bases, should also be encouraged in farming communities to detect progressive soil degradation. Furthermore, agrochemical-use guidelines and community-based soil management programmes should be strengthened to promote sustainable agricultural production and protect the long-term fertility of soils in Oju LGA.

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