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Soil Properties Variability Impact On Agricultural Ecosystem Services In Ibadan City, Nigeria

by

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Abstract

Soil properties exhibit significant spatial and temporal variability, influencing the delivery of Agricultural Ecosystem Services (AES). Variability in physical, chemical, and biological soil characteristics affects crop productivity, water regulation, carbon sequestration, and biodiversity support. Key factors contributing to soil variability include parent material, topography, climate, land use, and management practices. These variations affect soil functions, including nutrient cycling, water retention, and microbial activity, which are crucial for sustainable agricultural production. However, agricultural ecosystem services have been facing a lot of challenges in recent times, especially in and around major traditional cities sharing similar characteristics in the developing world. The challenges range from gradual depletion in biodiversity, soil erosion, soil nutrients and properties depletion, etc., all of which have led to a decline in crop yields. The study, therefore, focused on Ibadan city, which exhibits characteristics of a typical traditional city in Nigeria. The methodology was exclusively based on primary and secondary data which were soil samples and satellite imagery respectively. Landsat ETM+ was acquired to classify the land use/land cover of the city into 4 themes. However, 48 soil samples were taken from the 6 Local Government Areas that constitute the peri urban area of Ibadan city, with 24 samples each from farmland and control plots at a depth of 30cm. The samples were collected in the month of June, 2023 using soil auger and clean pan to prevent contamination, and later subjected to laboratory analysis using the standard protocol. Major soil properties required for agriculture, such as Potential Hydrogen (pH), Nitrogen (N), Potassium (K), and Sodium (Na), were major focus for the analysis because of their importance in agriculture. Descriptive statistics was used to assess the soil properties variability between agricultural and natural ecosystems while the relationship between the two was tested using the Pearson's Product Moment Correlation. Results therefore showed a vertical and horizontal variation of these elements across the area, which has in one way or the other affected the agricultural ecosystem services in the form of reduction in crop production. It was therefore established that understanding soil variability through advanced soil mapping and remote sensing techniques enables farmers and policymakers to make informed decisions, improving agricultural sustainability while minimizing environmental degradation. Addressing soil property variability is therefore recommended to ensure food security, reduce land degradation, and maintain ecosystem stability.

Key words: Ecosystem services, Soil nutrients, Biodiversity, Environmental degradation, Agricultural sustainability

Introduction

Urban soils are highly heterogeneous and spatially variable due to the complex interplay of natural soil-forming processes and intensive anthropogenic activities such as construction, waste disposal, industrial emissions, and landscaping (Lehmann and Stahr, 2007). Unlike agricultural or forest soils, urban soils are often disturbed, compacted, or contaminated, leading to significant variability in physical, chemical, and biological properties across small spatial scales (Pouyat *et al*., 2007; Craul, 1992). This variability poses challenges for land management, especially in contexts such as urban agriculture (UA), green infrastructure development, and environmental monitoring. Urban soils may exhibit wide-ranging differences in fertility, pH, organic matter, heavy metal concentrations, and soil texture, often within the same city block or neighborhood (Martin *et al*., 2016; De Kimpe and Morel, 2000). For instance, Martin *et al*. (2016) found that community gardens in Montreal showed significant within-site and between-site variability in soil nutrients and contaminants, affecting both crop productivity and food safety. Understanding and mapping urban soil variability is therefore crucial for evaluating land suitability for UA, mitigating public health risks, and planning sustainable land use (Hallett *et al*., 2016; Karg *et al*., 2019). Digital soil mapping (DSM) techniques, combined with geospatial tools and environmental datasets, offer promising approaches for identifying spatial patterns in soil properties across urban landscapes (McBratney *et al*., 2003). Such tools support evidence-based decisions on site selection, soil remediation, and crop planning in urban environments increasingly turning to local food production.

Agricultural ecosystems provide a range of ecosystem services that are vital not only for food production but also for sustaining environmental quality and human well-being. These services include provisioning services (food, fiber, fuel), regulating services (climate regulation, water purification, pest control), supporting services (soil formation, nutrient cycling), and cultural services (landscape aesthetics, cultural heritage) (MEA, 2005; Power, 2010). While agriculture is traditionally valued for its role in food production, there is growing recognition of its broader ecological functions. Agricultural practices influence the delivery of ecosystem services in both positive and negative ways. Sustainable management can enhance biodiversity, improve soil health, and regulate hydrological cycles (Zhang *et al*., 2007; Bommarco *et al*., 2013). However, intensive and industrial farming practices can degrade ecosystem services through soil erosion, chemical runoff, loss of pollinators, and greenhouse gas emissions (Foley *et al*., 2005). As a result, balancing agricultural productivity with ecosystem health has become a central goal of sustainable agriculture. Recent studies advocate for ecosystem service-based assessments to inform land use planning, agricultural policy, and conservation strategies (Adhikari and

Hartemink, 2016; Smith *et al*., 2013). By quantifying and mapping these services, decision-makers can better understand trade-offs, design multifunctional landscapes, and promote agro-ecological approaches that support both livelihoods and environmental resilience.

However, variability in soil fertility, pH, and contamination levels directly affects crop yield and quality in urban farms and gardens. Soils with poor nutrient content or imbalanced pH reduce plant productivity, while localized contamination with heavy metals can pose risks to food safety (Edmondson *et al*., 2014; Clark *et al*., 2008). Similarly, soil texture and organic matter content influence water infiltration and retention, while compacted or sandy soils, often found in urban areas, may also lead to poor water retention or runoff, thereby affecting irrigation efficiency and increasing flood risks (Ziter, 2016). As a result of these and many other challenges that are confronting urban agriculture due to soil properties variability, It became expedient to premise this study on assessing the nature of soil properties variability in Ibadan city being a typical traditional urban centre undergoing expansion and land use transformation in the recent time. The study therefore used some few property parameters to determine the spatial variability and pattern, and how this has affected agricultural ecosystem services delivery in and around the city.

Study Area

Ibadan city is located approximately on longitude $3^{0}50'$ to $4^{0}36'$ east of the Greenwich Meridian, and latitude $7^{0}23'$ to $7^{0}55'$ north of the Equator. It is one of the fastest growing cities in Nigeria located in Oyo State in the southwest Nigeria. It is the capital of Oyo State, located approximately 145 km north of Lagos and 530 km southwest of Abuja, the Federal Capital Territory. It lies about 120km east of the border with the Republic of Benin (Raheem and Adeboyejo, 2016). Among the 11 local governments that constitute the larger Ibadan city, Ido local government area has been identified as the biggest in terms of land mass. Until 1970, Ibadan was the largest city in Sub-Saharan Africa. In 1952, it was estimated that the total area of the city was approximately 103.8 km^2. However, only 36.2 km^2 was built up. This meant that the remaining 67 km^2 were devoted to non-urban uses, such as farmlands, river floodplains, forest reserves and water bodies. These "non-urban land uses" disappeared in the 1960s: an aerial photograph in 1973 revealed that the urban landscape had completely spread over about 100 km^2. The land area increased from 136 km^2 in 1981 to 210–240 km^2 in 1988-89 (Areola, 1994). By the year 2000, it was estimated that Ibadan covered 400 km^2. The growth of the built-up area during the second half of the 20th century (from 40 km^2 in the 1950s to 250 km^2 in the 1990s) shows clearly that there has been an underestimate of the total growth of the city. In the 1980s, the Ibadan-Lagos expressway generated the greatest urban sprawl (east and north of the city), followed by the Eleiyele expressway (west of the city). Since then, Ibadan city has spread further into the neighbouring local government areas of Akinyele, Egbeda and Ido in particular.

Ibadan is underlain by basement complex rocks which are mainly metamorphic rocks of Precambrian origin. Ibadan city sits on a rolling topography with the basement rock types characterized by low porosity and permeability. The city sprawls on either side of Aremo and Mapo ridges. The upland areas are places above 200m. Among the upland areas is the central ridge called 'Oke Aremo'. It has a north south trend with a gap in its northern section through which Ogunpa River cuts its valley. The ridge is the main watershed from the headstream of the Ogunpa, Ona and Kudeti rivers. The highest point on the ridge is about 280m and this is at the Bower hill. The lowland areas are places below 200m. There is generally a decline in the elevation of the land from north-east to the south-east. The main rivers draining Ibadan are Ona, Ogunpa and Ogbere rivers with their tributaries, including the River Omi, Kudeti, Alaro, Alapata, Maje, Elere, etc. The city area sits on the basement complex rocks comprising older granite, quartz schists/quartzite and gneiss. There are ridges of quartzite/quartz schists, inselbergs of gneiss and older granite. These rocks are quite old predating the Pan African orogeny. Each rock type possesses its own typical failure plane. Gneiss foliations are marked by alternating white and black bands. In quartzite, micaceous bands constitute possible failure planes. The granite and granite gneiss complex have high residual stress and sub aerial weathering.

Material and Methods

There is a great inequality in the distribution of soil properties and characteristics which has made it to be highly variable, even over short distances. This variability has made it very difficult and insufficient to collect soil sample at just one location. It is therefore preferable to collect composite samples. Composite samples are a mixture of individual samples, or sub-samples, generally collected from multiple locations and mixed together to form a single composite sample. By combining multiple sub-samples into a single composite sample, the effects of soil variability by averaging the soil properties over larger areas could be highly minimized. This procedure was however used to collect soil samples (composite samples) on both selected farmlands and controlled plots within the six Local Government Areas. A total number of 48 composite samples were taken from the six LGAs; 24 from farmlands and 24 from controlled plots. The controlled plots were undisturbed sections of the land which had remained uncultivated for a minimum of 50 years thereby still retaining its natural properties. The samples were collected using a soil auger at depths of 0-15cm (topsoil) since the objective is focusing on the layer suitable for agriculture. This was done to determine the physical and chemical properties of the soil such as texture and consistency (using the feel methods). The distribution of these composite samples is therefore illustrated in table 1. Soil samples were taken from both farmlands and undisturbed plots (controlled plots) with the objective of comparing the soil quality of farmlands with that of forested areas being used as controlled plots, haven determined the years through the available remote sensing data, and by extension through enquires from individual farmers and community members who knew the history of the past environmental condition. This was done in the six outer Local Government Areas constituting the less city from which 8 composite samples were taken from each Local Government making a total of 48 samples from the entire study sites. The justification for selecting these 6 peri urban LGAs is attributed to the land use transformation from agriculture to urban in the area as a result of spatial expansion in Ibadan city. See table 1 for details of sample distribution. Some ecosystem services such as make-up of top soil, cation exchange capacity (CEC), pH level, microbial life as well as cultural identity and aesthetics were also considered.

A plot was selected from one hectare of land on both farmlands and control lands representing agricultural and natural ecosystems. These plots were gridded into 20m by 20m quadrats. Five of these were selected for the study using a random sampling technique. Each quadrat was subsequently divided into sixteen 5m by 5m quadrats, four of which were selected for the study using the table of random numbers. The samples, taken by soil auger were collected in a clean galvanized bucket to avoid contamination from where they were thoroughly mixed up to obtain a single sample that represented the soil properties in the area.

Table 1: Distribution of Composite (Soil) Samples across the Study Area

Local Government Areas	Sample sites and distribution	
	Farm Plot	Control Plot
Ido LGA	4	4
Akinyele LGA	4	4
Egbeda LGA	4	4
Ona Ara LGA	4	4
Oluyole LGA	4	4
Lagelu LGA	4	4
Total	48	

Source: Fieldwork, 2023

Soil analysis

The soil samples were analyzed using the following standard procedures. Particle size analysis was carried out using the Bouyoucous hydrometer method [22]. Soil pH was determined potentiometrically in water and in KCl using soil to distilled water ratio of 1:2.5, while pH in KCl was also determined at a ratio 1:2.5 soil to solution. The readings were taken using the glass electrode (Methler) standardized at pH 7. Organic carbon was determined by the Walkley-Black method [23], total nitrogen by Kjeldahl method [24], available Phosphorus was determined by the Bray P1 method [25]. Exchangeable bases (Ca, Mg, K, Na) were extracted with IN neutral ammonium acetate (NH4OAC). Exchangeable Ca and Mg were determined by atomic absorption spectrometer while K and Na were determined by flame photometer. Exchange acidity (A13+, H+) was determined by titration of soil solution with IN KCI (Nelson *et al.*, 1996). Effective cation exchange capacity (ECEC) was computed by the summation of exchangeable bases (Ca, Mg, K and Na) and exchange acidity (Al and H).

Results

The availability of some plant nutrients is greatly affected by soil potential hydrogen otherwise known as pH level. Soil pH is close to neutral, and neutral soils are considered to fall within a range from a slightly acidic pH of 6.5 to slightly alkaline pH of 7.5. It has been established that most plant nutrients are optimally available to plants within this 6.5 to 7.5 pH range, combined with the fact that this range is generally compatible to plant root growth, hence its ability to support crop cultivation. Nitrogen (N) and Potassium (K) are major plant nutrients that appear to be less affected directly by soil pH than other minerals. Phosphorus (P), however, is directly affected by soil pH level. At alkaline pH values, greater than pH 7.5 for example, phosphate ions tend to react quickly with calcium (Ca) and magnesium (Mg) to form less soluble compounds. At acidic pH values, phosphate ions react with aluminum (Al) and iron (Fe) to again form less soluble compounds. Most of the other nutrients (micronutrients especially) tend to be less available when soil pH is above 7.5, and in fact are optimally available at a slightly acidic pH value ranging between 6.5 to 6.8.

Vegetables, grasses and most ornamentals tend to do best in slightly acidic soils (pH 5.8 to 6.5). Soil pH values above or below these ranges may result in less vigorous growth and nutrient deficiencies. Similarly, higher soil organic carbon promotes soil structure and also facilitates physical stability. This improves soil aeration (oxygen in the soil) and water drainage and retention, and reduces the risk of erosion and nutrient leaching.

Spatial pattern of agricultural and natural ecosystem soil properties in Lagelu LGA

Table 2 presents a comparative overview of key soil properties in both agricultural and natural ecosystems for Lagelu LGA, focusing on minimum, maximum, and standard deviation (SD) values. This analysis helps reveal the impact of land use on soil quality and variability. According to the table, soil pH value under agricultural ecosystem ranged between 6.48 and 6.87 (SD = 0.17), while the natural ecosystem value ranged between 6.53 and 6.92 (SD = 0.18). The pH in both systems is slightly acidic and quite similar, indicating minimal impact of cultivation practices on soil acidity. The slightly higher variation in the natural ecosystem could be due to undisturbed natural processes and varied organic matter input. The organic carbon value under agricultural ecosystem ranged between 28.42 and 40.60 g/kg (SD = 5.24) while the natural ecosystem ranged between 32.77 and 60.61 g/kg (SD = 12.63). The organic carbon is therefore significantly higher in natural ecosystems, indicating richer organic matter likely from litter and biomass decomposition. The wider range and greater SD suggest more heterogeneity in organic input in natural systems, whereas agricultural soils may have experienced organic matter loss due to tillage and harvesting. Furthermore, the total nitrogen value in agricultural ecosystem was within 3.13 and 4.41 g/kg (SD = 0.58) while the natural ecosystem gave a value ranging from 3.61-6.67 g/kg (SD = 1.39). The total nitrogen pattern therefore follows a similar trend as organic carbon, being higher and more variable in the natural ecosystem. This suggests a strong correlation between organic matter and nitrogen availability, which is typically disrupted in cultivated soils through cropping and reduced organic input. As for the phosphorus value, it ranged between 9.00 and 61.28 mg/kg (SD = 25.75) under agricultural ecosystem, and from 8.84-16.32 mg/kg (SD =3.40) in the natural ecosystem. This suggests that the phosphorus levels are higher and more variable in agricultural soils, likely due to fertilizer application. This artificial input explains the broader range and higher standard deviation, which may also reflect uneven application or phosphorus fixation issues. Total acidity ranged between 0.30–0.40 cmol/kg (SD=0.06) and 0.30–0.50 cmol/kg (SD= 0.10) under agricultural and natural ecosystems respectively, indicating that natural soils show slightly greater variability and a higher maximum in acidity, possibly due to natural organic acid accumulation from decomposition. Agricultural soils are more homogenized, likely due to liming practices. The exchangeable cation (Ca) was 3.27–4.20 cmol/kg (SD = 0.40) and 3.27–4.11 cmol/kg (SD = 0.39) for agricultural and natural ecosystems respectively, suggesting that suggesting that Ca levels are stable across land uses, possibly due to inherent soil mineralogy. Both ecosystems have similar sand content (78–81%) and clay content (7–10%), suggesting that texture is controlled by parent material rather than land use. Silt in the natural ecosystem shows slightly more variability (SD = 1.29 vs. 0.82), possibly due to natural erosion or deposition patterns.

Table 2: Physico-chemical properties of agricultural and natural ecosystem soil in Lagelu LGA

Soil Properties	Agricultural Ecosystem			Natural Ecosystem		
	Minimum	Maximum	SD	Minimum	Maximum	SD
pH (H_2O)	6.48	6.87	0.17	6.53	6.92	0.18
Organic Carbon (g/kg)	28.42	40.60	5.24	32.77	60.61	12.63
Total nitrogen (g/kg)	3.13	4.47	0.58	3.61	6.67	1.39
Phosphorus (mg/kg)	9.00	61.28	25.75	8.84	16.32	3.40
Total acidity (cmol/kg)	0.30	0.40	0.06	0.30	0.50	0.10
Ca (cmol/kg)	3.27	4.20	0.40	3.27	4.11	0.39
Mg (cmol/kg)	.74	1.12	0.16	.62	.81	0.08
K (cmol/kg)	.26	.32	.025	.23	.32	0.04
Na (cmol/kg)	.16	.23	0.03	.17	.24	0.03
Sand (%)	78.00	81.00	1.29	78.00	81.00	1.29
Silt (%)	11.00	13.00	0.82	11.00	14.00	1.29
Clay (%)	7.00	10.00	1.29	7.00	10.00	1.41

SD = Standard deviation

Source: Researcher's Fieldwork, 2023

Spatial pattern of agricultural and natural ecosystem soil properties in Ido LGA

Table 3 provides insights into how land use influences soil chemical and physical properties in Ido Local Government Area of Ibadan city. The values represent the minimum, maximum, and standard deviation (SD) for each soil parameter in both systems. According to the table, the pH under agricultural ecosystem ranged between 7.22–7.87 (SD = 0.28), while that of natural ecosystem varied between 6.06–7.53 (SD = 0.67), suggesting that agricultural soils are more alkaline, with a narrower pH range and lower variability, likely due to liming. In contrast, natural soils are more acidic and variable, possibly due to organic matter decomposition and leaching of bases. The organic carbon was within 23.20–45.24 g/kg (SD=9.10) and 25.23–52.20g/kg (SD=11.67) for agricultural and natural ecosystems respectively, indicating that organic carbon is slightly higher in natural ecosystems, reflecting greater litter input and less disturbance. The higher SD in natural soils also indicates more variability in organic matter accumulation due to differing vegetation and microhabitats. The result puts the total nitrogen at between 2.55 and 4.98 g/kg (SD = 1.00) and 2.78–5.74 (SD = 1.28) for agricultural and natural ecosystems respectively. This also suggests that nitrogen is higher in natural soils, suggesting a close correlation. This reinforces the idea that nitrogen availability is tied to organic matter content, which is generally reduced in cultivated soils due to harvesting and lower biomass input. However, the phosphorus value ranged between 10.20 and 14.48 mg/kg (SD = 2.28) under agricultural ecosystem and 8.64–18.96 mg/kg (SD = 4.83) under the natural ecosystem, which suggests that while phosphorus is moderately higher in agricultural soils (likely due to fertilizer application), the natural ecosystem exhibits greater variability. This could be due to differences in parent material or organic matter mineralization. However, the table shows that natural soils have a wider range and greater variability in acidity, possibly reflecting natural processes while the agricultural soils tend to have slightly less acidity, likely influenced by liming or base-forming inputs. The cation exchange (Ca) shows that agricultural soils have significantly higher Ca, suggesting supplementation through fertilizers or liming, while the natural system has lower Ca, likely due to leaching in the more acidic conditions. Natural soils surprisingly show slightly higher maximum K and more variability, which may reflect natural mineral weathering or plant root activity in undisturbed systems while the sodium levels are low and comparable in both systems, suggesting minimal impact from land use or salinization. The Texture is dominated by sand in both systems, indicating similar parent material (77–80%, SD = 1.29; and 78–80%, (SD = 0.96). Agricultural soils are however slightly more variable. Lastly, natural soils show more silt variation (7–10%, SD = 1.29 and 6–8%, SD = 0.96), potentially due to natural deposition or runoff patterns, natural soils show more silt variation (12–14%, SD = 0.82 and 12–15%, SD = 1.29), potentially due to natural deposition or runoff patterns, while clay content is slightly higher in agricultural fields (7–10%, SD = 1.29 and 6–8%, SD = 0.96), possibly due to compaction and finer particle accumulation from erosion.

Table 3: Physico-chemical properties of agricultural and natural ecosystem soil in Ido LGA

Soil Properties	Agricultural Ecosystem			Natural Ecosystem		
	Minimum	Maximum	SD	Minimum	Maximum	SD
pH (H_2O)	7.22	7.87	0.28	6.06	7.53	0.67
Organic Carbon (g/kg)	23.20	45.24	9.10	25.23	52.20	11.67
Total nitrogen (g/kg)	2.55	4.98	1.00	2.78	5.74	1.28
Phosphorus (mg/kg)	10.20	14.48	2.28	8.64	18.96	4.83
Total acidity (cmol/kg)	.30	.45	0.07	.25	.50	0.11
Ca (cmol/kg)	3.26	4.01	0.34	2.20	2.74	0.27
Mg (cmol/kg)	.56	0.88	0.15	.43	.58	0.07
K (cmol/kg)	.27	.34	0.03	.29	.37	0.04
Na (cmol/kg)	.19	.21	0.01	.18	.21	0.01
Sand (%)	77.00	80.00	1.29	78.00	80.00	0.96
Silt (%)	12.00	14.00	0.82	12.00	15.00	1.29
Clay (%)	7.00	10.00	1.29	6.00	8.00	0.96

SD = Standard deviation

Source: Researcher's Fieldwork, 2023

Spatial pattern of agricultural and natural ecosystem soil properties in Egbeda LGA

Table 4 provides an assessment of soil chemical and physical properties variability impact of land use on soil quality in Egbeda Local Government Area of Ibadan city, which could also influence soil's suitability for agriculture. While both ecosystems exhibit some shared characteristics due to similar parent materials and regional factors, key differences emerge in nutrient availability, pH balance, and textural composition. Both ecosystems show slightly acidic to near-neutral pH (6.44–6.98, SD = 0.28 for agricultural and 6.10–7.05, SD = 0.40 for natural ecosystem). Agricultural soils have less variability (lower SD), indicating more controlled pH conditions, likely due to liming or fertilizer inputs. In contrast, natural soils reflect broader pH fluctuations, possibly from organic matter decomposition and natural buffering processes. The natural soils contain higher baseline organic carbon and less variability (23.78–43.78 g/kg SD = 8.39 for agricultural soil and 31.32–42.34g/kg, SD = 5.13 for natural soil), suggesting stable organic input from litter and minimal disturbance. Similarly, total nitrogen is higher and more consistent in the natural ecosystem (2.62–4.82g/kg, SD = 0.92 and 3.45–4.66g/kg, SD = 0.56), reflecting strong organic matter-nitrogen coupling. Agricultural soils, with slightly lower nitrogen and greater variability, may experience N-mining, especially where synthetic fertilizers dominate over organic amendments. Phosphorus is slightly higher in agricultural soils **(**9.84–13.20mg/kg, SD = 1.42 vs 9.48–10.84mg/kg (SD = 0.63 in natural), likely due to fertilizer application**.** However, the range is narrow, and both systems exhibit generally low P levels, suggesting that phosphorus availability could be a limiting factor in both ecosystems, particularly in weathered tropical soils.

In summary and looking at tables 5, 6 and 7, soil pH is more stable **in** agriculture in Akinyele, Ona Ara and Oluyole Local Government Areas of the city, though with a little higher variability in natural soils. Also, total acidity is more variable in natural ecosystem, with the exception of Akinyele LGA where soil under agricultural ecosystem has more range. Phosphorus is also highly variable especially in Oluyole LGA where the SD = 26.66. The total acidity is generally more variable in agriculture except in Ona Ara LGA where natural soils are more stable. Total nitrogen shows a greater variability in agricultural ecosystem soils across the LGAs. Calcium (Ca) has more variability in agricultural soils across all local government areas. There is also a significant variation in magnesium value under agricultural ecosystem soils than the natural soils. However, Potassium (K) is slightly variable in agricultural ecosystem soils but generally consistent across the LGAs. Sodium (Na) has low variability in all cases under agricultural ecosystem but slightly higher under natural soils. Lastly, physical properties, such as sand, clay and silt show that natural soils depict a greater variability especially in sand and clay contents across the remaining local government areas (Akinyele, Ona Ara and Oluyole of the city, which shears similar characteristics with the previous LGAs discussed in tables 2 to 4.

Table 4: Physico-chemical properties of agricultural and natural ecosystem soil in Egbeda LGA

Soil Properties	Agricultural Ecosystem			Natural Ecosystem		
	Minimum	Maximum	SD	Minimum	Maximum	SD
pH (H_2O)	6.44	6.98	.28	6.10	7.05	.40
Organic Carbon (g/kg)	23.78	43.78	8.39	31.32	42.34	5.13
Total nitrogen (g/kg)	2.62	4.82	.92	3.45	4.66	.56
Phosphorus (mg/kg)	9.84	13.20	1.42	9.48	10.84	.63
Total acidity (cmol/kg)	.30	.40	.05	.30	.50	.10
Ca (cmol/kg)	2.69	4.10	.66	2.46	3.04	.25
Mg (cmol/kg)				.57	.81	.11
K (cmol/kg)	.24	.36	.05	.22	.27	.02
Na (cmol/kg)	.14	.22	.04	.16	.21	.02
Sand (%)	77.00	81.00	1.71	76.00	82.00	2.75
Silt (%)	13.00	14.00	.58	10.00	13.00	1.50
Clay (%)	6.00	9.00	1.26	7.00	12.00	2.38

SD = Standard deviation

Source: Researcher's Fieldwork, 2023

Table 5: Physico-chemical properties of agricultural and natural ecosystem soil in Akinyele LGA

Soil Properties	Agricultural Ecosystem			Natural Ecosystem		
	Minimum	Maximum	SD	Minimum	Maximum	SD
pH (H_2O)	6.65	6.94	0.15	6.07	6.97	0.40
Organic Carbon (g/kg)	24.07	49.88	12.92	15.08	32.48	7.31
Total nitrogen (g/kg)	2.65	5.49	1.42	1.66	3.57	0.80
Phosphorus (mg/kg)	10.36	56.04	23.30	13.56	45.24	15.05
Total acidity (cmol/kg)	.25	.45	0.10	.30	.40	.048
Ca (cmol/kg)	2.65	4.30	0.85	2.70	3.88	0.57
Mg (cmol/kg)	.72	0.82	0.05	.52	.68	0.07
K (cmol/kg)	.20	.32	0.06	.25	.34	0.04
Na (cmol/kg)	.18	.22	0.02	.20	.26	0.03
Sand (%)	79.00	81.00	1.00	80.00	83.00	1.41
Silt (%)	11	13	1.00	10.00	12.00	0.96
Clay (%)	7.00	9.00	1.00	7.00	9.00	0.96

SD = Standard deviation

Source: Researcher's Fieldwork, 2023

Table 6: Physico-chemical properties of agricultural and natural ecosystem soil in Ona-Ara LGA

Soil Properties	Agricultural Ecosystem			Natural Ecosystem		
	Minimum	Maximum	SD	Minimum	Maximum	SD
pH (H_2O)	6.02	6.46	0.18	6.06	6.26	0.10
Organic Carbon (g/kg)	22.33	26.10	1.56	13.20	39.44	12.31
Total nitrogen (g/kg)	2.46	2.87	0.17	1.45	4.34	1.36
Phosphorus (mg/kg)	10.88	11.04	0.07	10.56	16.96	3.03
Total acidity (cmol/kg)	.30	.55	0.11	.30	.40	0.04
Ca (cmol/kg)	2.39	2.91	0.23	2.20	3.20	0.45
Mg (cmol/kg)	.62	0.83	0.09	.61	.83	0.10
K (cmol/kg)	.28	.37	0.04	.28	.38	0.04
Na (cmol/kg)	.22	.28	0.03	.23	.24	0.01
Sand (%)	80.00	82.00	0.96	80.00	83.00	1.26
Silt (%)	11.00	13.00	0.82	11.00	13.00	0.82
Clay (%)	6.00	9.00	1.26	5.00	8.00	1.50

SD = Standard deviation

Source: Researcher's Fieldwork, 2023

Table 7: Physico-chemical properties of agricultural and natural ecosystem soil in Oluyole LGA

Soil Properties	Agricultural Ecosystem			Natural Ecosystem		
	Minimum	Maximum	SD	Minimum	Maximum	SD
pH (H_2O)	5.98	6.45	0.20	5.48	6.62	0.53
Organic Carbon (g/kg)	8.25	22.11	5.96	8.58	24.09	6.36
Total nitrogen (g/kg)	0.91	2.43	0.65	.94	2.65	0.70
Phosphorus (mg/kg)	10.04	16.68	3.04	10.80	64.56	26.66
Total acidity (cmol/kg)	.32	.40	0.03	.30	.40	0.05
Ca (cmol/kg)	2.74	3.04	0.13	3.26	4.85	0.68
Mg (cmol/kg)	.49	0.74	0.12	.80	1.33	0.24
K (cmol/kg)	.26	.34	0.04	.22	.29	0.03
Na (cmol/kg)	.19	.24	0.02	.19	.22	0.01
Sand (%)	79.00	81.00	0.96	78.00	83.00	2.22
Silt (%)	12.00	14.00	0.96	11.00	14.00	1.29
Clay (%)	5.00	9.00	1.83	5.00	9.00	1.71

SD = Standard deviation

Source: Researcher's Fieldwork, 2023

Some selected soil properties were used to determine the variation in soil properties within the 6 selected Local Government Areas. The charts in figures 2 to 7 therefore show the disparity in these properties between the agricultural ecosystem and natural ecosystem which had been abandoned and devoid of cultivation over a long period of time. Theses plots were therefore used as control plots to determine the level of degradation in the farm plots. These properties include the water acidity in soil- pH (H^2O), Organic carbon contents, Total Nitrogen and the available phosphorus.

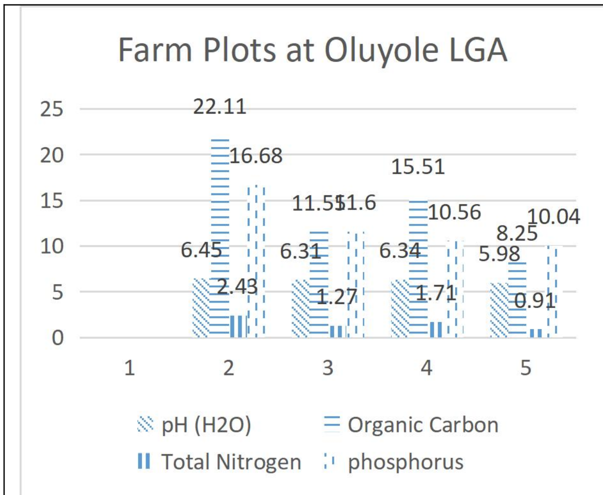


Fig. 2a: Agricultural ecosystem at Oluyole LGA

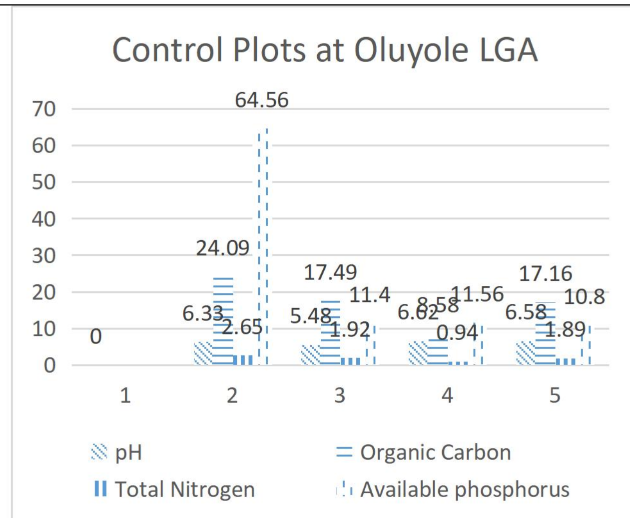


Fig. 2b: Natural ecosystem at Oluyole LGA

Fig. 2: Variation in agricultural and natural soil ecosystems in Oluyole LGA

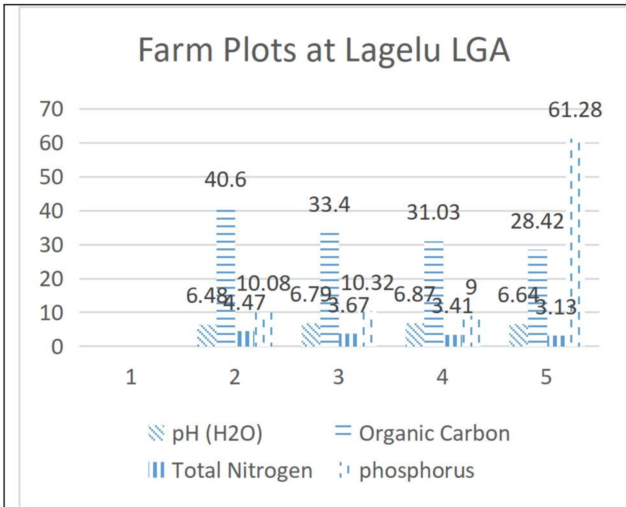


Fig. 3a: Agricultural ecosystem at Lagelu LGA

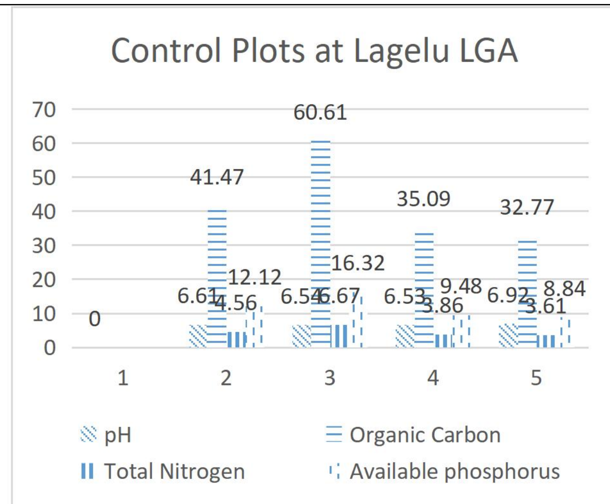


Fig. 3b: Natural ecosystem at Lagelu LGA

Fig. 3: Variation in agricultural and natural soil ecosystems in Lagelu LGA

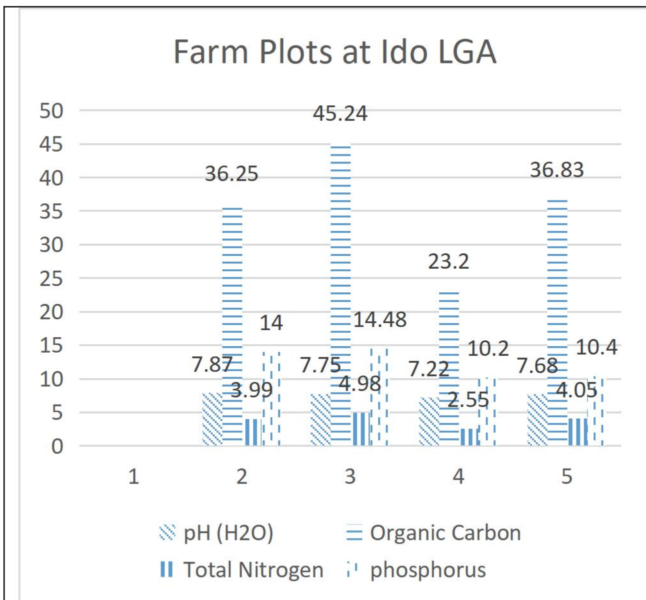


Fig. 4a: Agricultural ecosystem at Ido LGA

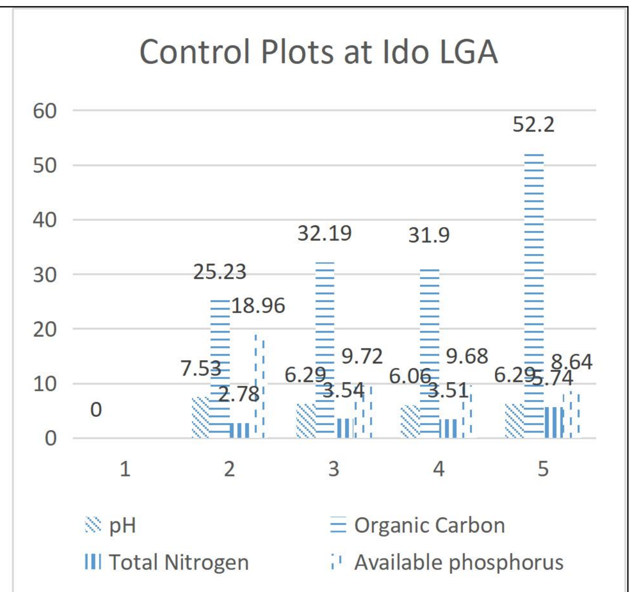


Fig. 4b: Natural ecosystem at Ido LGA

Fig. 4: Variation in agricultural and natural soil ecosystems in Ido LGA

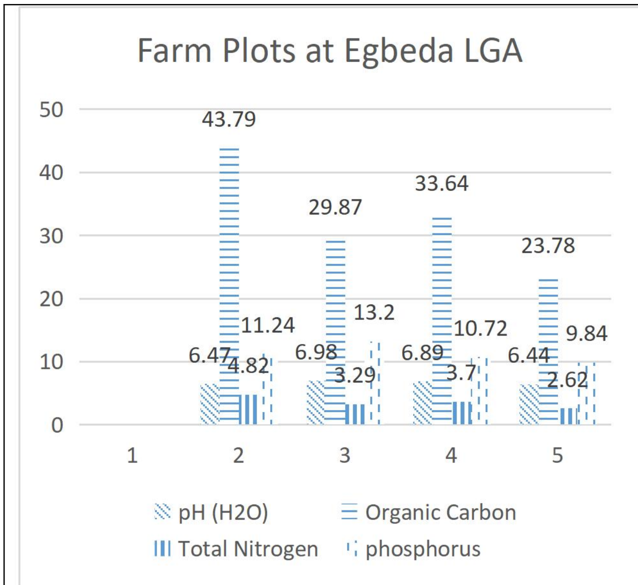


Fig.5a: Agricultural ecosystem at Egbeda LGA

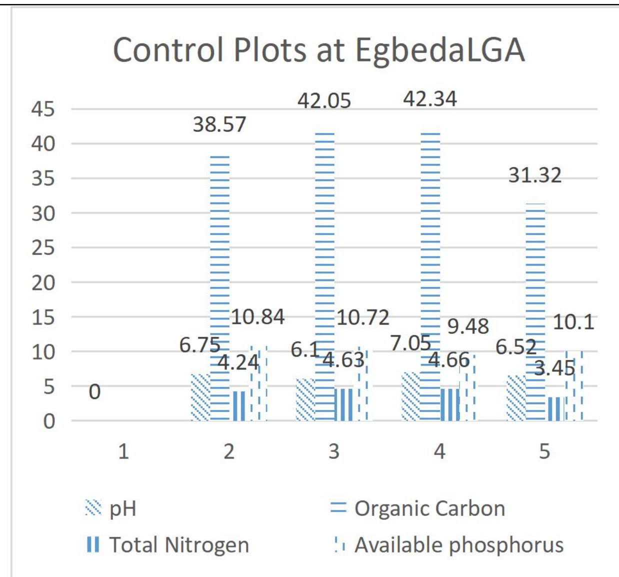


Fig. 5b: Natural ecosystem at Egbeda LGA

Fig. 5: Variation in agricultural and natural soil ecosystems in Egbeda LGA

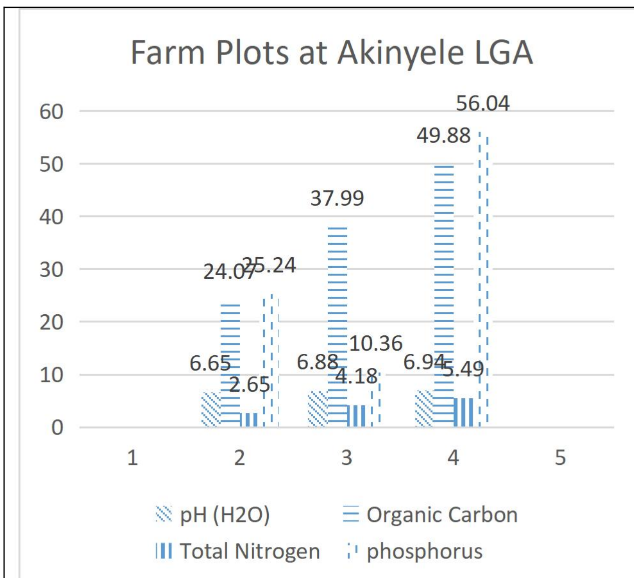


Fig.6a: Agricultural ecosystem at Akinyele LGA

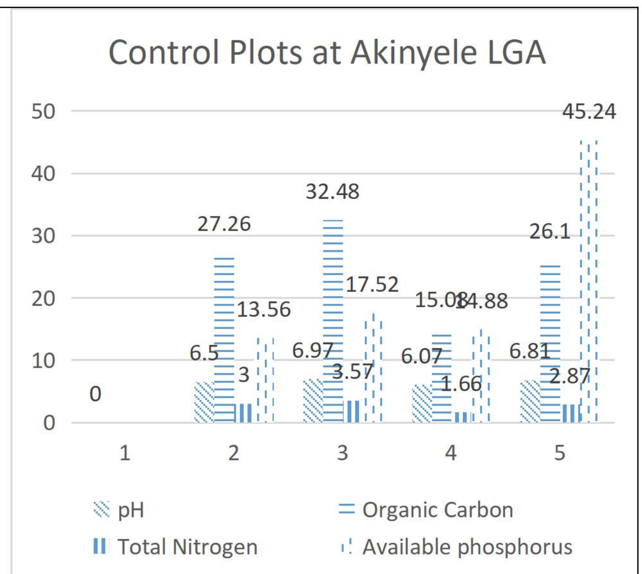


Fig. 6b: Natural ecosystem at Akinyele LGA

Fig. 6: Variation in agricultural and natural soil ecosystems in Akinyele LGA

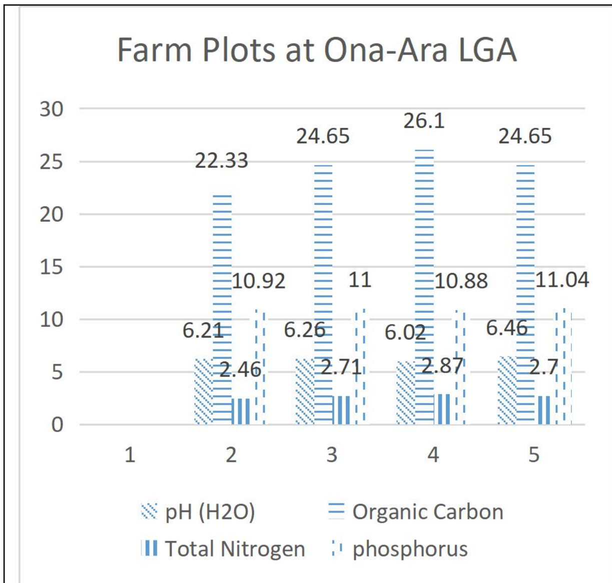


Fig.7a: Agricultural ecosystem at Ona-Ara LGA

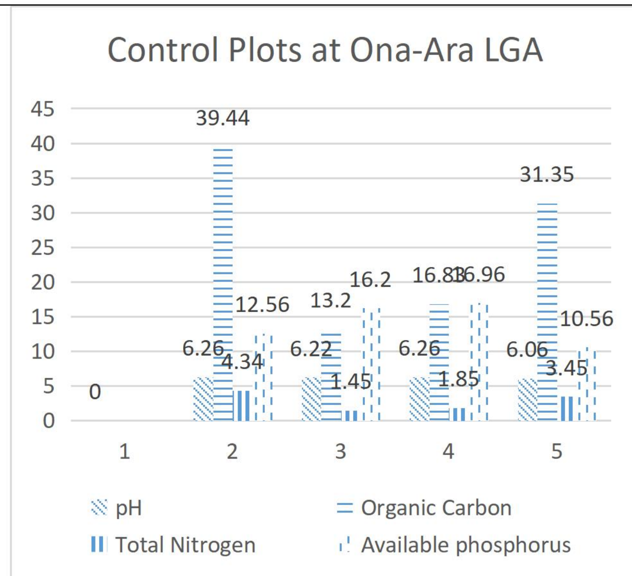
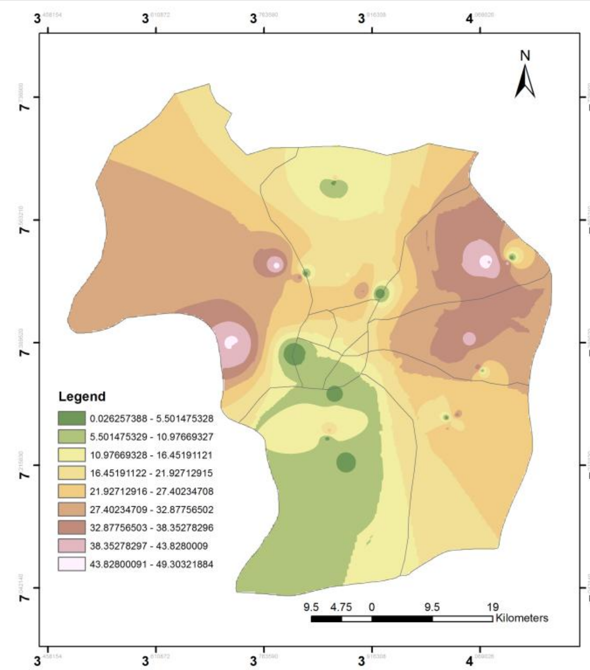


Fig.7b: Natural ecosystem at Ona-Ara LGA

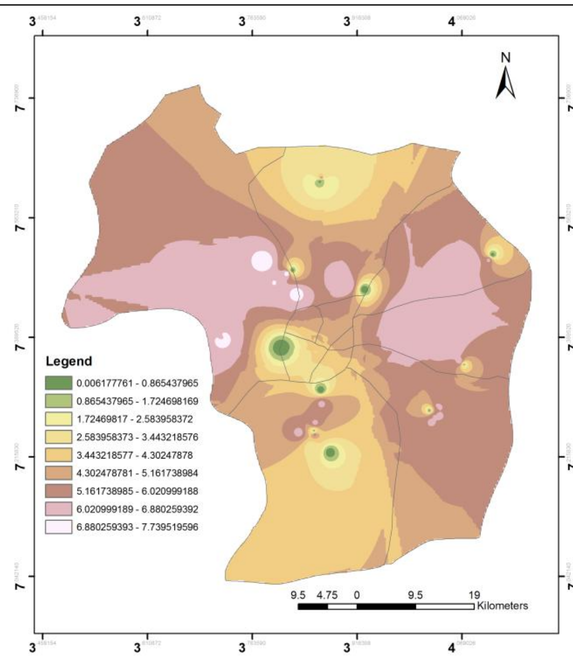
Fig. 7: Variation in agricultural and natural soil ecosystems in Ona-Ara LGA

Distribution of soil properties and implication on agricultural ecosystem

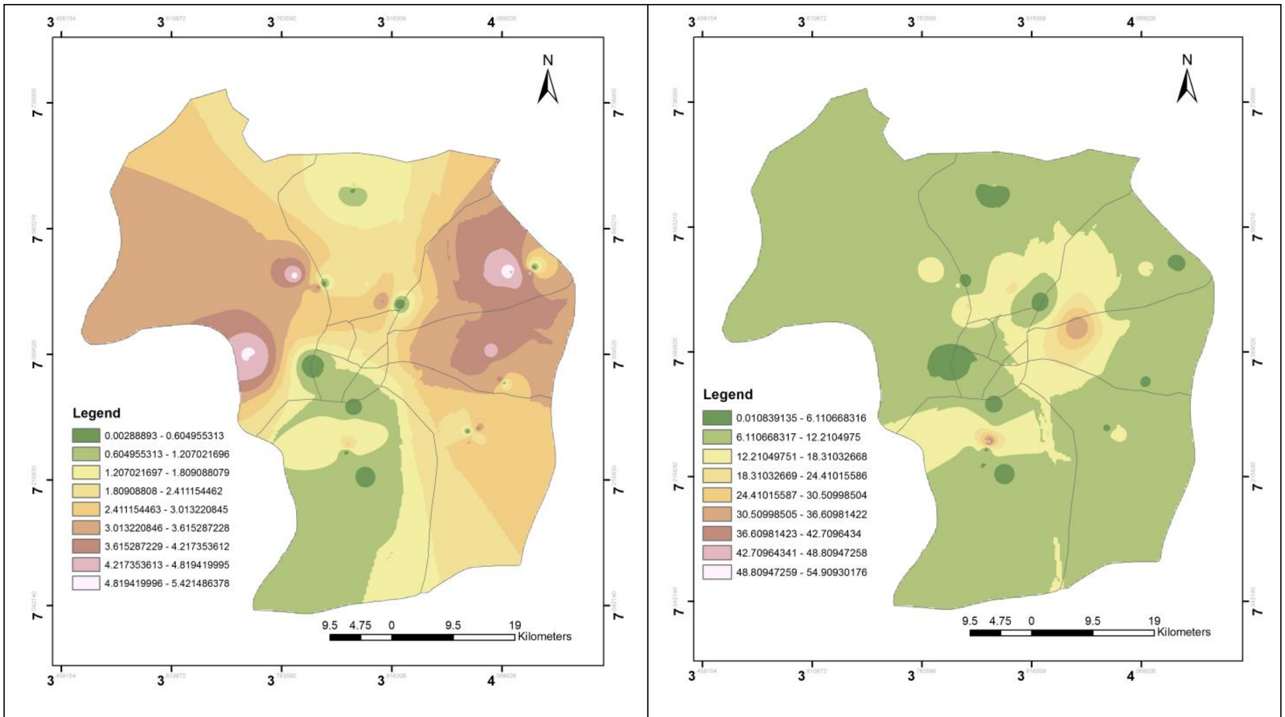
The study effectively assesses the spatial variability of key soil properties-organic carbon, nitrogen, phosphorus, and pH-across urban and peri-urban LGAs in Ibadan, evaluating their implications for agricultural productivity and ecosystem services. It highlights that soil organic carbon is notably low in Oluyole LGA, likely due to cooler microclimates and forest cover reducing decomposition rates, whereas fringe LGAs like Ido, Lagelu, and Egbeda show higher carbon content, supporting their role in urban agriculture. The analysis of soil pH reveals a predominance of slightly to strongly acidic soils-particularly suitable for agriculture-in areas with east-west orientation, though some parts such as Lagelu show values on the lower end. Nitrogen levels are generally adequate citywide except in Oluyole, underscoring its deficiency risk, while phosphorus concentrations remain low throughout, which is deemed favorable for sustainable agriculture as excess P can be detrimental. The variability is therefore illustrated in figure 8 as each area responded to the existing agricultural. However, figures 8 (a-d) shows the spatial variation in value of some basic soil properties across Ibadan city. Studies (Bray and Kurtz, 1945) have also showed some of the factors influencing distributional pattern of soil properties and the environmental implication of such varied properties on various human activities, especially agriculture. The importance of soil physical and chemical properties in plant growth and productivity had been emphasized (Enaruvbe, *et al*., 2020; Abass, et. al., 2018) focusing of soil properties of Okomu forest region of Benin City.



(a) Soil Organic Carbon



(b) Soil pH (H_2O) Level



(c) Soil Nitrogen

(d)Soil Phosphorus

Fig. 8 (a-d): Spatial distribution of basic soil properties in Ibadan city, Nigeria.

Source: Fieldwork, 2023

Discussion

Soil pH describes how acidic or alkaline the soil is, and is expressed as a number between 0 and 14. The study therefore revealed a moderately normal pH ranging from 4.3 to 6.8 aligning towards the north-south and east-west orientation. On the other hand, the value was a little low along the north-south direction (Akinyele LGA down to Lagelu LGA). It should be noted that Lagelu LGA also recorded a low level of organic carbon (CO_2). Using the United States Department of Agricultural Natural Resources Conservation Service (SSS, 2014) benchmark, Soil pH values are categorised into the following classes: ultra-acidic (<3.5), extremely acidic (3.5-4.4), very strong acidic (4.5-5.0), strong acidic (5.1-5.5), moderately acidic (5.6-6.0), slightly acidic (6.1-6.5), neutral (6.6-7.3), slightly alkaline (7.4-7.8), moderately alkaline (7.9-8.4), strongly alkaline (8.5-9.0) and very strongly alkaline (>9.0). Using this classification, it could be deduced that the three LGAs with east-west orientation ranged between a very strong acidic and slightly acidic soil type, which were considered to be more suitable for agriculture.

Nitrogen (N) plays a very important role in plant metabolism system. All vital processes in plants are associated with protein, of which nitrogen is an essential constituent. In order to get more crop production, nitrogen application is indispensable to crop yield. Nitrogen not only enhances the yield but also increases photosynthetic processes. All plants require a balanced amount of nitrogen for vigorous growth and development to ensure greatest harvest with better quality. According to the study, the nitrogen constituents in the soil is relatively high except for the southern part of the city (Oluyole LGA) where the nitrogen content is very low.

Phosphorus (P) is vital to plants growth and is found in every living plant cell. It is involved in several key plant functions, including energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next. It regulates the gene transcription, maintains the normal pH in extracellular fluid, and intercellular energy storage. The amount of phosphorus that is present in soil is considered to be low when it is less than 50mg. however, when it ranges between 51mg and 150mg it is classified as medium and anything beyond 150mg is considered to be high. High concentration of phosphorus is therefore not ideal for plant growth and agriculture generally, hence the low content of phosphorus recoded in the study area is considered to be ideal for agriculture. The study showed that the available phosphorus in the soil is generally low, which suggests that agriculture, if properly managed, can still thrive within the city despite the competition with urban infrastructural development.

The work of McBratney *et al* (2003) discusses digital soil mapping (DSM) and introduces soil inference system as well as the use of statistical and geostatistical methods for soil property prediction. Similarly, Minasny and McBrastney (2005) uses the the Kriging system to explore the use of Matern function to model soil property variability demonstrating how variogram models can improve the accuracy of soil maps. Similarly, Zhao *et al* (2009) investigates how grazing affects soil variability and maps spatial differences in soil properties using geostatistics and remote sensing. Adhikari *et al*'s (2014) review on soil mapping in precision agriculture which connects soil spatial variability to ecosystem services delivery cannot be left out. Lastly, the work of Campling *et al* (2002) on soil variability in tropical landscape cannot be underestimated. There is therefore a strong connection between soil variability mapping and urban agricultural ecosystem srvices delivery as indicates by Karg *et al* (2019), Adelekan and Fregene (2015), Martin *et al* (2016), Wortman and Lovell (2013) and Hallett *et al* (2016). Soil variability therefore directly impacts urban agriculture and food safety, while mapping urban soils, being patchy and degraded, helps optimize agricultural sites selection.

Table 8: Pearson Correlation Coefficients of Soil Properties

Soil Property	Farmland Mean	Natural Ecosystem Mean	R	p-value	Significance Level
Organic Matter (%)	2.3	5.8	-0.76	0.0001	***($p < 0.001$)
Bulk Density (g/cm^3)	1.45	1.20	+0.68	0.0012	**($p < 0.01$)
pH	6.8	5.9	+0.42	0.021	*($p < 0.05$)
Cation Exchange Capacity (cmol/kg)	12.1	20.3	-0.70	0.0008	***($p < 0.001$)
Total Nitrogen (%)	0.15	0.35	-0.81	<0.0001	***($p < 0.001$)

*$p < 0.001$: Highly significant; (*****); $p < 0.01$: Very significant (**); *$p < 0.05$**: Significant (*); Not significant ($p > 0.05$)

The correlation analysis in Table 8 reveals significant differences in soil quality between farmlands and natural ecosystems, with several strong correlations observed, in which organic matter and total nitrogen show a strong negative correlation with farmland use (r = -0.76 and -0.81, respectively). This however aligns with findings that continuous tillage and crop removal reduce organic inputs and deplete nitrogen content (Lal, 2015; Six *et al*., 2002). Similarly, bulk density is positively correlated with farmland use (r = +0.68), suggesting compaction due to machinery and livestock. Natural ecosystems tend to maintain looser, more porous soils due to undisturbed structure and root systems (Blanco-Canqui and Lal, 2004). The pH value shows a weak positive correlation. This could indicate liming practices in agriculture to counteract acidity, whereas natural soils tend to be more acidic, especially in forest ecosystems (Brady and Weil, 2016). Cation Exchange Capacity (CEC) is however lower in farmland soils, with a strong negative correlation (r = -0.70). This suggests degradation of clay and organic colloids, which are essential for nutrient retention (Schoenholtz *et al*., 2000). This therefore reflect a common pattern in land-use change. Conversion from natural to agricultural systems often leads to soil degradation unless sustainable practices (cover cropping, no-till farming, and organic amendments) are adopted (Montgomery, 2007).

Conclusion

Urban soil variability has significantly impacted agricultural ecosystem services of Ibadan city by directly and indirectly altering the properties and affected the fertility, water retention capacity, nutrient cycling, and plant productivity. Heterogeneous soil conditions caused by factors such as construction activities, pollution, and altered hydrology has created spatial inconsistencies in the provision of key services such as crop yield, carbon sequestration, and storm-water management. This also portends a health risk to human health due to the storage of some of these element in crops through urban agriculture, if the variability is not properly scrutinized. This variability can therefore hinder the predictability and efficiency of urban agriculture, necessitating site-specific soil management practices to optimize the ecosystem functions. Addressing urban soil variability through targeted interventions, such as soil remediation, compost amendment, and green infrastructure, can enhance the resilience and sustainability of urban agricultural systems, and ultimately supporting food security and ecological health in our cities.

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