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Research Article

Influence of Site-Specific and Non-Site-Specific Fertilizer Application on Soil Fertility Status of Some Farmlands in Southern Part of Nasarawa State, Nigeria.

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ABSTRACT
Excess application of nutrients can lead to nutrient leakages to the environment resulting in adverse environmental impacts such as pollution of surface and groundwater. This study titled "Influence of site-specific and non-site-specific fertilizer application on soil fertility statuses of some farmlands in southern part of Nasarawa State' was conducted with aim of analyzing soil fertility status in farmlands with two distinct fertilizer application methods. Laboratory analysis of soils was conducted to determine the key soil parameters. Multi-stage random sampling technique was adopted for this study. Three (3) LGAs (Doma, Obi and Awe) were selected to represent the study area. In each LGAs, three wards were selected for sample collection, making a total of Nine (9) wards (Alagye, Rukubi, Agbashi, Awe, Ribi, Tunga, Obi, Agwende, and Agyaragu). A total of 180 composite samples were collected for laboratory analyses across the three LGAs (90 from site-specific fertilizer application and another 90 from non-site-specific fertilizer application farms). Soil samples were analyzed for physicochemical properties. From the results, site-specific farmlands showed consistently higher fertility than non-site-specific across the three LGAs. pH for site-specific across the three LGAs ranges between 5.83 to 6.21 which is between moderately acidic to slightly acidic ranges. Total N, P, K were generally medium–high in site-specific soils; OC/OM were high in Awe and Doma but low in Obi. Ca, Mg, Na were very low everywhere; base saturation was very high in Obi. Textures mostly were mostly sandy loam while Agyaragu was observed to have loamy sand texture. Site-specific fields were associated with higher nutrient levels (notably Awe and Doma). It is therefore recommended that extension-led farmer education be provided to enable efficient nutrient management in the study area.

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1.0 INTRODUCTION

Soil fertility refers to the soil's ability to supply plant/crop nutrients in the right quantities and qualities over a sustained period of time (Vanlauwe *et al.,* 2015). The loss of soil fertility may continue until adequate amount of nutrients amendment are replenished through appropriate management practices or until a fallow period is put in place to allow a gradual recovery through natural ecological processes. More than 83% of Africa's 874 million hectares of arable land (58% of the global arable land) is reported to face serious fertility problems with more than 75% of the farmlands being classified as severely depleted (FAO, 2004). This may be due to poor soil management practices on the fragile soils, and thus require costly investments to ensure sustained productivity. In developing countries like Nigeria, harsh climatic conditions, population pressure, repetitive cultivation of the same land and the decline of traditional soil management practices have often induced soil fertility problems (Henao and Baanante 2006). These phenomena are enhanced as a result of the increasing rates of wind and water erosion and accelerated rates of soil acidification, nutrient decline, and carbon losses (Jayeoba et al., 2012).

Most of small householder farmers in Nigeria practiced blanket application of fertilizer which is also known as non-site-specific fertilizer application on their farms as a way of soil fertility management irrespective of the initial soil fertility status (Kamaluddin *et al.,* 2023). More often these farmers apply the fertilizer of their choice without considering the crop requirement before deciding upon the quantity and quality of fertilizer to be applied. Consequently, with blanket fertilizer recommendations, nutrients can be applied in excess or inadequately for different locations, reducing the efficient utilization of applied nutrients. Excess application of nutrients can lead to nutrient leakages to the environment resulting in adverse environmental impacts such as pollution of surface and groundwater. Blanket application of fertilizer lead to inefficient use of nutrients by plants and may cause lower yield and profitability (Rodriguez, 2020). Also, non-site specific fertilizer application to crops, where very high doses of nutrients like N and P are used, is detrimental to crops' qualities and human health respectively. However, site-specific fertilizer application on the other hand constitutes the formulation and application of fertilizer recommendations tailored toward specific crop requirement, climate and soil fertility conditions, as well as farmers' socioeconomic status. This is an effective means to address low crop response to fertilizers and seed inputs as well as to reduce the overall environmental impact due to inorganic fertilizer pollution in agricultural landscapes (Kihara *et al.,* 2020).

System of allowing the land to fallow and regain it fertility is no longer practice by the smallholder farmers in the study area, use of chemical fertilizers on the fields is mostly preferred by the farmers, because of its quick responses to crop needs. However, the need to adhere to site specific fertilizer recommendations in diverse farm types had advocated (Rurinda *et al.,* 2020). With all the advocacies, smallholder farmers in the study have been promoting non-site-specific fertilizer recommendations in which a single fertilizer rate is used for large but heterogeneous fields. This always leads to unbalanced application of fertilizer nutrients relative to the needs of the crop and low use efficiency of fertilizer. It is therefore very indispensable to determine the influences of such different approaches on soil fertility status. It's against this background that this study was design with the aim of analyzing soil fertility status in farmlands with site specific and non-site-specific fertilizer application methods

MATERIALS AND METHODS

Description of the Study Area

Nasarawa State lies between latitude 7° 45'N and 9° 25'N of the equator and between longitude 7° 00'E and 9° 37'E of the Greenwich meridian. The agricultural zones of the state were delineated by Nasarawa Agricultural Development Programme (NADP) into three zones (southern, central and western zones). Nasarawa south agricultural zone comprises five local government areas (LGAs) namely, Lafia, Doma, Obi, Awe and Keana (Fig. 1). The study area falls within southern guinea savanna agro ecological zone of Nigeria. The geology of the study area is made up of granitic sandstones, undifferentiated basement complex and shale. The southern landscape forms part of the low plains of Benue origin and this part of the state is composed of sandstones. The soil type of the study area is composed of highly leached alfisols with high base saturation. The soil is strongly acidic and has high content of iron and aluminium oxides hence reddish brown in colour with very low organic matter content and low total nitrogen and available phosphate (Agbede *et al.,* 2011). The vegetation of the study area is that of the southern Guinea Savanna with interspersion of thicket, grassland, trees, fringing woodlands or gallery forest along the streams. The natural vegetation of the area is made up of grasses and some traces of scattered wild and economic trees like *Vittellaria paradoxa* (Shear butter tree); *Parkia* spp (locust bean tree); *Gmelina* arborea (beechwood or gmelina); *Anacadium* spp (Cashew trees); *Magnifera indica* (Mango*)*. The priority is food crops with a mixture of cereals tubers crops. Most farmers are subsistence small holder farming 2-3ha per year. The cultivated land is fragmented and scattered over a wide area. Yam, cassava, sorghum, and maize are grown in the uplands while rice, sugar cane, sweet potato and vegetable in the flood plains (Agbede *et al.,* 2011).

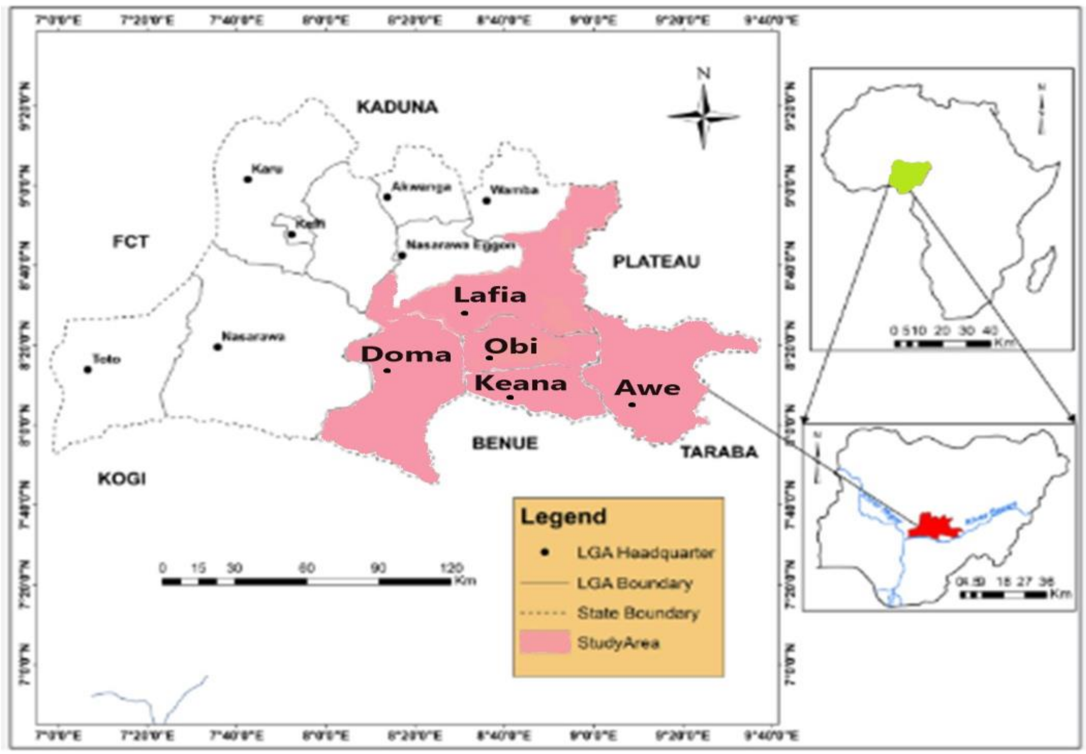

Figure 1: Map of Nasarawa State showing the study area

Sampling Technique and Sample Size

Three (3) LGAs: Doma, Obi and Awe were selected to represent the study area. In each LGA, three wards were selected for sample collection, making a total of Nine (9) wards (Alagye, Rukubi, Agbashi, Awe, Ribi, Tunga, Obi, Agwende, and Agyaragu). Purposive sampling was chosen because the researcher wants sites that best illuminate the fields that have a clear history of either site-specific (e.g., variable-rate) or non-site-specific (blanket) fertilizer use. That was done to reduce the sampling size while providing enough soil information, allowing the study to draw meaningful conclusions about how site-specific and blanket fertilizer applications affect soil fertility across the region.

Identification of Site-Specific Fertilizer Application in Farmers Field

Twenty (20) farmers were purposively selected from each of the above selected wards which gave a total of one hundred eighty (180) farmers that were interviewed. Purposive sampling was chosen in order to have participants and sites that best illuminate the fields that have a clear history of either site-specific (e.g., variable-rate) or non-site-specific (blanket) fertilizer use, allowing the study to draw meaningful conclusions about how the application methods affected yield of crops in the region. The data were collected through the use of well-structured questionnaires; which were administered to the respondents. Information collected included soil management data and the crop type (crops identified were maize, rice and yam). Comparisons were for similar crops with two distinct fertilizer application methods.

Soil Sample Collection

Each sampling farm was stratified into three transects of 10m × 10m plots approximately; six spots were randomly marked from each segment for soil sample collection. Soil samples were collected at 0-30 cm depths with auger sampler and bulked to form a composite sample per each farmland. A total of 20 composite soil samples were collected in each village. Ten (10) composite soil samples were collected from farmer's farm that practice site-specific fertilizer application and additional 10 composite soil samples from non-site-specific fertilizer application farms. Therefore, in each LGA a total of 60 composite soil samples were collected. A grant total of 180 composite soil samples were finally collected for the study.

Laboratory Analyses of Soil Samples

All soil samples collected were air-dried and gently crushed, then passed through 2mm sieve to obtain a homogeneous particle size, after which both physical and chemical properties of these samples were determine. Hydrometer method (Bouyoucos, 1962) was used to determine the particle sizes (Idoga *et al*., 2007). The soil reaction (pH) was determined in the supernatant suspension of 1:2.5 soil-water suspensions using a glass electrode pH metre (Thomas, 2020). Buffer solutions of pH 4, 7 and 9 and calcium chloride solution 0.01M were used as reagents for the soil pH determination. The exchangeable cations (Ca, Mg, K and Na) (cmol$^{(+)}$/kg) were determined by saturating the samples with ammonium acetate (NH_4OAc) 1.0 M (Sparks, 2019). The Cation Exchange Capacity (CEC) was determined by summation of values of all the measured exchangeable cations (Brady and Weil, 2012) while soil organic matter was determined using Walkley-Black method as described by Nelson and Sommers, (2019). Total Nitrogen (%) was determined using the Kjeldahl distillation method as describe by Durak *et al.* (2007). Available P (ppm) was determined using ammonium fluoride (0.03N NH_4F) extraction method (Bray and Kurtz, 1945). Record of each parameter was taken in three replicates.

Data Analysis

The soil data collected were subjected to analysis of variance using VSN GENSTAT (2008 Ed), and where there was a significant difference, the means were separated using F-LSD at 5% significance level.

RESULTS

Soil fertility status of site-specific and non-site-specific fertilizer application farmlands in Awe LGA

The result on table 1 showed the soil fertility status of soils in site-specific farms were significantly better than those in non-site-specific fertilizer application farmlands in Awe LGA. The soils of site-specific farmland were slightly acidic with soil pH of 6.21, 5.95 and 5.83 in Kanje, Ribi and Tunga soils respectively. While soils in non-site-specific farms had pH close to neutral. Total nitrogen, phosphorus and potassium were medium to high in the soil of site-specific farmlands in all the three villages studied in Awe LGA. Also, the organic carbon and organic matter of all the soils in site-specific farmlands in Awe LGA were high. However, the cation exchange (Ca, Mg, and Na) of soils in site-specific and non-site-specific fertilizer application farmlands were very low in all the soils assessed. The sand contents were very high and the clay contents were also moderate; while the silt was very low in all the soils studied in Awe LGA. The soil textural class of all the soils assessed were sandy loam.

Soil fertility status of site-specific and non-site-specific fertilizer application Farmlands in Doma LGA

The result on table 2 showed that the soil fertility status of soils in site-specific was significantly better than the non-site-specific fertilizer application farmlands in Doma LGA. The soils of site-specific farmland were slightly acidic with soil pH of 6.13 in Alagye; pH of 6.21 in Agbashi; pH of 6.12 in Rukubi soil. While soils in non-site-specific had a pH close to neutral. Total nitrogen, phosphorus and potassium were medium to high in the soil of site-specific farmlands in all the three villages studied in Doma LGA. Also, the organic carbon and organic matter of all the soils in site-specific farmland in Doma LGA were high. However, the exchangeable bases (Ca, Mg, and Na) of soils in site-specific and non-site-specific fertilizer application farmlands were very low in all the soils assessed. The sand content were very high and the clay content was also moderate; while the silt was very low in Doma LGAS. The soil textural class of all the soils assessed are known as sandy loam.

Table 1: Soil fertility status of farmlands with site-specific and non-site-specific fertilizer application in Awe LGA

Fertilizer Application	H_2O pH	pH KCl	% O.C	% O.M	% N	Avail P(ppm)	K	Na	Ca	Mg	EA	CEC	% B.S	% Sand	% Silt	% Clay	Texture Class
							cmol$^{(+)}$/Kg							PARTICLE SIZE			
KANJE																	
Site-specific	6.05	6.21	2.28	3.92	0.41	4.99	0.25	0.38	1.94	1.34	0.90	4.70	87.66	80.05	3.93	16.07	SL
Non-Site-specific	6.36	6.77	1.70	2.92	0.17	4.05	0.20	0.31	1.59	1.10	0.60	4.05	77.71	70.67	7.13	24.97	SL
LSD(0.05)	0.04	0.04	0.03	0.05	0.01	0.11	0.01	0.01	0.06	0.02	0.50	0.07	1.13	1.18	2.67	0.90	
RIBI																	
Site-specific	6.25	5.95	3.50	5.93	0.38	4.98	0.25	0.42	2.14	1.34	0.88	4.83	86.00	78.75	4.47	16.79	SL
Non-Site-specific	6.96	6.75	1.71	2.82	0.15	4.14	0.17	0.23	2.07	1.07	0.61	4.42	79.87	76.41	18.87	4.72	SL
LSD(0.05)	0.03	0.04	0.03	0.01	0.01	0.09	0.01	0.01	0.01	0.08	0.02	0.03	0.45	0.51	0.41	0.42	
TUNGA																	
Site-specific	6.17	5.83	2.22	3.81	0.37	6.24	0.27	0.26	2.05	1.37	0.98	4.47	86.58	78.21	4.73	17.05	SL
Non-Site-specific	6.80	6.73	1.68	2.89	0.12	4.78	0.19	0.43	2.36	1.39	0.61	4.42	81.79	79.03	4.60	16.35	SL
LSD(0.05)	0.04	0.06	0.03	0.05	0.01	2.39	0.13	01	0.03	0.08	0.04	0.05	0.68	0.16	0.26	0.33	

EA = Exchangeable Acidity, **CEC** = Cation Exchange Capacity, **SL** = Sandy Loam

Table 2: Soil fertility status of farmlands with site-specific and non-site-specific fertilizer application in Doma LGA

Fertilizer Application	pH H_2O	pH KCl	% O.C	% O. M	% N	Avail P(ppm)	cmol$^{(+)}$/Kg K	Na	Ca	Mg	EA	CEC	% B.S	PARTICLE SIZE % Sand	% Silt	% Clay	Texture Class
ALAGYE																	
Site-specific	6.43	6.13	2.77	4.77	0.48	5.48	0.36	0.22	2.36	1.11	0.50	4.08	89.90	81.60	4.70	13.70	LS
Non-Site-specific	6.70	6.52	2.45	4.52	0.43	5.05	0.33	0.20	1.39	1.19	0.47	4.60	87.00	81.40	5.00	12.80	LS
LSD(0.05)	0.01	0.10	0.21	0.12	0.02	0.10	0.01	0.01	0.20	0.07	0.02	0.25	0.21	0.11	0.02	0.16	
AGBASHI																	
Site-specific	6.54	6.21	2.71	4.48	0.35	4.44	0.37	0,17	1.42	0.90	0.62	3.41	84.00	85.20	4.91	10.00	SL
Non-Site-specific	6.62	6.42	2.69	4.47	0.32	4.40	0.32	0.16	1.66	0.88	0.53	3.55	81.20	85.00	4.80	10.00	SL
LSD(0.05)	0.04	0.08	0.02	0.03	0.01	0.03	0.02	0.01	0.13	0.04	0.04	0.14	1.86	0.17	0.17	0.15	
RUKUBI																	
Site-specific	6.55	6.12	2.65	4.65	0.29	4.43	0.29	0.17	1.60	0.88	0.73	3.67	89.00	85.00	5.00	10.00	SL
Non-Site-specific	6.77	6.46	2.61	4.52	0.27	4.05	0.30	0.17	1.51	0.83	0.74	3.53	79.00	84.20	4.90	10.90	SL
LSD(0.05)	0.10	0.11	0.02	0.04	0.02	0.22	0.02	0.01	0.17	0.05	0.06	0.18	2.21	0.16	0.06	0.21	

EA = Exchangeable Acidity, **CEC =** Cation Exchange Capacity, **LS** = Loamy Sand

Soil fertility status site-specific and non-site-specific fertilizer application Farmlands in Obi LGA

Soil fertility status of soils with site-specific applications were significantly higher than soils with non-site-specific fertilizer applications in Obi LGA as presented in Table 3. The soils of site-specific farmland were slightly acidic with soil pH of 5.83, 5.95 and 5.73 in Agwatashi, Agwende and Agyaragu respectively. Then, the soils in non-site-specific had a pH that is slightly acidic in the three villages. Total nitrogen was low in soils with both site-specific and non-site-specific fertilizer application on farmlands in Agwatashi; in Agwende and Agyaragu there were higher levels of nitrogen in both soils in site-specific and non-site-specific fertilizer application farmlands. The phosphorus and potassium levels were medium to high in the soil of site-specific farmlands in Agwatashi, Agwende and Agyaragu soils studied in Obi LGA. Also, the organic carbon and organic matter of all the soils in site-specific farmland in Obi LGA were low. The cation exchange (Ca, Mg, and Na) of soils in site-specific and non-site-specific fertilizer application farmlands were very low; however base saturation in all the soils assessed in Obi LGA was very high. The sand content was very high in Agwatashi and Agwende soil; while in Agyaragu, the clay content was also moderately high; while the silt was very low in all the soils studied in Obi LGA. The soil textural class of Agwatashi and Agwende was sandy loam and the Agyaragu soil textural class was loamy sand.

Table 3: Soil fertility status of farmlands with site-specific and non-site-specific fertilizer application in Obi LGA

Fertilizer Application	H_2O pH	pH KCl	% O.C	% O.M	% N	Avail P(ppm)	Cmole/Kg K	Na	Ca	Mg	EA	CEC	% B.S	PARTICLE SIZE % Sand	% Silt	% Clay	Texture Class
AGWATASHI																	
Site-specific	6.18	5.83	2.18	3.75	0.24	4.66	0.25	0.38	2.45	1.26	0.94	4.91	87.36	83.04	4.20	13.43	SL
Non-Site-specific	6.82	6.34	1.68	2.81	0.20	3.63	0.23	0.32	2.15	1.17	0.62	4.32	80.51	81.08	6.60	12.33	SL
LSD(0.05)	0.05	0.03	0.02	0.06	0.06	0.10	0.01	0.01	0.02	0.02	0.05	0.10	0.82	0.13	0.24	0.13	
AGWENDE																	
Site-specific	6.29	5.87	2.57	4.08	0.43	4.66	0.27	0.53	2.02	1.25	0.89	10.29	87.35	79.15	5.17	10.53	SL
Non-Site-specific	6.94	6.22	1.78	3.05	0.37	4.55	0.20	0.34	1.63	1.11	0.60	4.16	78.65	80.01	6.87	13.36	SL
LSD(0.05)	0.04	0.08	0.12	0.02	0.03	0.04	0.01	0.01	0.09	0.04	0.05	0.09	0.96	0.86	0.24	0.92	
AGYARAGU																	
Site-specific	6.21	5.73	2.17	2.17	0.39	4.47	0.21	0.33	2.14	1.27	0.99	4.40	86.37	72.99	4.47	22.60	LS
Non-Site-specific	6.87	6.25	1.61	1.61	0.36	4.02	0.19	0.31	2.52	1.18	0.66	5.19	81.41	72.88	4.93	21.39	LS
LSD(0.05)	0.12	0.07	0.02	0.0	0.02	0.12	0.01	0.14	0.06	0.02	0.05	0.09	0.83	0.02	0.13	0.05	

EA = Exchangeable Acidity, **CEC =** Cation Exchange Capacity, **SL** = Sandy Loam

DISCUSSION

The comparative analysis of soil fertility status between site-specific and non-site-specific (blanket) fertilizer application methods across the three Local Government Areas (Awe, Doma, and Obi) revealed significant variations in the physical and chemical properties of the farmlands. Overall, fields managed under site-specific regimes demonstrated superior nutrient retention and fertility indicators compared to those under blanket fertilizer applications.

The soil pH under site-specific management across the three LGAs consistently fell within the moderately acidic to slightly acidic range (5.73 to 6.21). This range is widely considered optimal for the availability of most essential plant nutrients in tropical soils (Chude *et al*., 2012). The slightly lower, more regulated pH in site-specific fields can be attributed to the balanced application of acidifying nitrogenous fertilizers based on real crop requirements. Uncontrolled, heavy blanket applications of fertilizers like urea or ammonium sulfate often induce severe, localized acidification or erratic pH swings over time due to spatial imbalances in nitrification processes (Vanlauwe *et al*., 2015). The stabilization of soil pH within the 5.5–6.5 zone in site-specific plots aligns with the findings of Jayeoba *et al*. (2012), who noted that targeted nutrient management cushions tropical savanna soils against extreme chemical degradation.

OC and OM were high in the site-specific farmlands of Awe and Doma but dropped to low levels across all fields in Obi LGA. The elevated OM levels in site-specific fields within Awe and Doma suggest that tailored fertilization encourages superior crop biomass production (both above-ground residues and root networks). When returned to the soil, this biomass sustains organic carbon pools (Kihara *et al*., 2020). Conversely, the universally low OM levels observed in Obi LGA point toward intense cultivation pressures, rapid mineralization rates typical of the savanna climate, or a lack of crop residue retention practices among local farmers. This depletion of organic matter is a well-documented challenge for Nigerian Alfisols, as highlighted by Agbede *et al*. (2011), who warned that continuous cropping without organic amendments rapidly decimates topsoil carbon fractions.

Total Nitrogen (N), Available Phosphorus (P), and Exchangeable Potassium (K) were significantly higher and consistently maintained at medium-to-high levels in site-specific farmlands compared to non-site-specific ones. This disparity underscores the primary inefficiency of blanket fertilizer recommendations. In non-site-specific fields, nutrients are frequently applied in unbalanced ratios, leading to poor nutrient use efficiency (NUE), rapid leaching of unabsorbed Nitrogen, and the chemical fixation of Phosphorus in the soil matrix (Rodriguez, 2020). Because site-specific applications sync nutrient delivery with the crop's specific growth stages and the soil's baseline supply power, residual macro-nutrients remain stable in the root zone rather than leaking into the environment (Buresh *et al*., 2010). The higher residual P levels in site-specific soils are particularly notable, as the extraction method (Bray-1) confirms that targeted application successfully satisfies the high P-fixing capacity of these iron- and aluminum-rich savanna soils (Rurinda *et al*., 2020).

A critical finding across all studied farmlands in Awe, Doma, and Obi LGAs was the extremely low concentrations of exchangeable basic cations, specifically Calcium (Ca), Magnesium (Mg), and Sodium (Na). Consequently, the overall Cation Exchange Capacity (CEC) remained low across the board. This is a characteristic of highly leached Alfisols and Ultisols dominant in the low plains of Benue origin within Nasarawa State (Agbede *et al*., 2011). These soils are dominated by low-activity kaolinitic clays that inherently possess poor nutrient-holding capacities (Brady & Weil, 2016). Interestingly, while the absolute values of exchangeable bases were low, the **Base Saturation (% BS)** in Obi LGA was exceptionally high. This implies that while the total capacity of the soil's exchange complex to hold nutrients is quite narrow, the available exchange sites are highly saturated with basic nutrients rather than acidic ions like Aluminum or Hydrogen. This chemical profile suggests that crops in Obi would respond dramatically well to localized, split-applications of fertilizers combined with liming materials or organic manures, which simultaneously raise absolute

CEC and supply critical divalent cations like Ca and Mg (Kamaluddin *et al*., 2023).
The particle size distribution across the study area revealed a heavy dominance of the sand fraction, with most farmlands classified texturally as **Sandy Loam**, except for Agyaragu (Obi LGA) and Alagye (Doma LGA), which exhibited a **Loamy Sand** texture. This coarse physical framework acts as a double-edged sword for local agricultural management. While sandy loam and loamy sand textures ensure excellent aeration, low bulk density, and easy tillage, they severely accelerate the risk of nutrient leaching and moisture stress due to high macro-porosity and low surface area (Brady & Weil, 2016). Under blanket fertilization regimes, the rapid downward movement of water easily washes away surface-applied mobile ions like nitrate and potassium. This physical vulnerability further justifies the mandatory adoption of site-specific nutrient management in southern Nasarawa; without micro-targeted, timed applications, chemical inputs are bound to bypass the shallow root zones of local food crops and contaminate underlying groundwater systems.

CONCLUSION

In conclusion, findings of the study showed that farmlands with Site-specific fertilizer application were more fertile than those on which blanket application of fertilizer was the common practice. Based on the findings of the study, it was recommended that:

i. Adequate sensitization to educate the farmers on the need to adopt site-specific fertilizer application should be carried out by Agricultural Extension Agents.
ii. Farmers should be encouraged by Agricultural extension agents to test the fertility of their soil at a subsidized cost before embarking on site – specific fertilizer application; because site-specific fertilizer application is based on crop needs, and also allows for the targeted delivery of nutrients, minimizing waste and maximizing efficiency.

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