DOI: https://dx.doi.org/10.4314/gjass.v23i1.3

GLOBAL JOURNAL OF AGRICULTURAL SCIENCES VOL. 23, 2024: 27-39
COPYRIGHT© BACHUDO SCIENCE CO. LTD PRINTED IN NIGERIA ISSN 1596-2903 e-ISSN: 2992 – 4499
www.globaljournalseries.com.ng, Email: globaljournalseries@gmail.com

FERTILITY EVALUATION OF SOILS AFTER TEN YEARS OF INTENSIVE RURAL VEGETABLE PRODUCTION IN NSUKKA, SOUTHEASTERN NIGERIA

OKPARA, PROMISE OGECHI AND OKEBALAMA, CHINYERE BLESSING
chinyere.okebalama@unn.edu.ng; ORCID iD, 0000-0001-5921-7990

(Received 22 March 2024; Revision Accepted 9 May 2024)

ABSTRACT

A medium-term assessment of soil fertility of continuously cultivated fields for vegetable production is an important factor for long-term soil sustainability. This study investigates the potentials and limitations of ten-year nutrient management on the fertility of soils under semi-commercial cultivation of four different vegetables [fluted pumpkin (Telfairia occidentalis), tomato (Solanum lycopersicum), red, and green pepper (Capsicum annuum)] in Nsukka, Southeastern Nigeria. Topsoil samples (0-30 cm) were collected in triplicate from the different vegetable fields and characterized. The results showed that the soils were sandy loam, loamy sand and sandy clay loam (SCL) with similar bulk density, total porosity and saturated hydraulic conductivity. However, the soils under red and green peppers had the lowest percentage of the 0.50-1.00 mm water-stable aggregate (WSA), but the highest percentage of aggregate stability (AS) than the other soils. The soils differed significantly in pH, organic matter (OM), available phosphorus (Av.P), exchangeable magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), hydrogen (H^{+}) and effective cation exchange capacity (ECEC). The moderately acid pH soils under red pepper and tomato cultivation had the highest values for OM, Na^{+}, K^{+} and H^{+}, as well as ECEC, while the slightly acid pH soil under fluted pumpkin cultivation had the highest Mg^{2+} content. The soils had low N but high Av.P reserves, indicating low P use efficiency. While the favourable pH, organic matter, and Av.P represent the potential of the soils for vegetable cultivation, N and K are the main potentially limiting nutrients in the studied soils. Overall, the soils under red pepper and tomato cultivation had a better fertility status due to their SCL texture and the application of organic and inorganic fertilizers, which contributed to better soil structure and greater nutrient retention compared to the soils under fluted pumpkin and green pepper.

KEYWORDS: Soil physiochemical properties, water-stable aggregates, aggregate stability, ECEC, vegetable crops

INTRODUCTION

One of the greatest challenges facing humanity today is the urgent need to provide nutritious food for more than 9 billion people in the world (FAO, 2017). This is a double challenge, as food production must be increased and intensified without compromising the ecosystem services necessary for life on earth. Decades of research have achieved significant success in advancing farming methods that minimize the impact on the ecosystem and soil health. These successes have been made possible through the use of conservation practices such as minimum tillage, as well as strategies to reduce fertilizer use, including crop rotation and less frequent fallowing

Okpara, Promise Ogechi, University of Nigeria Nsukka, Faculty of Agriculture, Department of Soil Science, 410001 Nigeria
Okebalama, Chinyere Blessing, University of Nigeria Nsukka, Faculty of Agriculture, Department of Soil Science, 410001 Nigeria

(Doran, 2002; Hobbs, 2007; Knowler and Bradshaw, 2007; Norris and Congreves, 2018). Nevertheless, these successes were only relevant for crops such as cereals, oilseeds and grains, 70 % of which are mainly produced for animal feed and not for nutritious crops such as vegetables for human consumption (FAO, 2013).

Vegetables have a high nutritional value and contain bioactive compounds, making them an essential part of the human diet (Slavin and Lloyd, 2012; Kyriacou and Rouphael, 2018). Global vegetable production is increasing very rapidly as health guidelines recommend an increase in vegetable consumption (WHO, 2003). Taking into account high-intensity farming systems such as protected cultivation, vegetable production can contribute to improving food security (Rouphael et al., 2018). However, soils under vegetable production are the most intensively managed due to growth requirements and inherent nutrient content; vegetable production requires significantly higher inputs (such as; frequent or deep tillage operations, fertilizers and irrigation) compared to field crops (Jackson et al., 2004; Congreves and Van Eerd, 2015; Norris and Congreves, 2018).

Studies have been conducted to examine the effects of fertilizer additions on soil fertility status in vegetable production over short, medium, and long-term periods (Willekens et al., 2014; Akinrinde et al., 2013; Zhang et al., 2022). Wei. et al. (2016) conducted a long-term greenhouse experiment to study the impact of organic and inorganic fertilizers on soil fertility status and crop yields. The study showed that both types of fertilizer were effective in enhancing soil fertility status and crop yields compared to the control treatment. In southwestern Nigeria, Akinrinde et al. (2013) found that inorganic fertilizer significantly improved both soil fertility status and vegetable yields over the short and medium term. Zhang et al. (2022) showed that the use of both organic and inorganic fertilizers initially had a positive effect on soil fertility and vegetable yields, but over a five-year period, both the soil fertility and vegetable yields were reduced. From these reports, it appears that the use of fertilizers can help increase soil fertility and improve yields of vegetable crops in the short and medium term, while the long-term effects can vary due to various factors, including the type and amount of fertilizer used, soil characteristics, climate patterns, and agricultural practices.

Food production is fundamentally affected by the fertility and productivity characteristics of the soil. Soil fertility is the condition of the soil in terms of its ability to supply nutrients in adequate and appropriate quantity to plants, while soil productivity on the other hand is the capacity of the soil to produce crops which includes farmers' management practices (Okorie et al., 2021). Thus, all productive soils are fertile, but not all fertile soils are productive due to poor management practices by farmers. In most smallholder farming communities, the decline in soil fertility has lead to a decrease in agricultural land productivity (Amede, 2003). The need to maintain soil fertility and productivity has necessitated some farmers to adopt management practices such as, crop rotation, manure application, use of inorganic fertilizers, residues burning, monoculture, fallowing, use of cover crops, multiple cropping, mixed cropping, , weeding and tillage practices and irrigation practices. The adoption of good nutrient balance management has led to an increase in agricultural productivity and therefore a reduction in poverty and hunger (Mitchell, 2008).

Vegetable farming is an important source of income and food for farmers in Opi, Nsukka Local Government of Enugu State, Nigeria. The rural, semi-commercial farm has been in existence for over ten (10) years and has operated as a semi-commercial farm using both organic and inorganic fertilizers to grow vegetables. The farmers cultivate a variety of vegetable crops, most of which are harvested and sold for commercial purposes. However, the impact of such continuous vegetable cultivation on the same piece of land on aspects of soil sustainability, including the improvement of soil organic matter (SOM) for nutrient cycling, is unknown. Knowledge of the variations in soil fertility among soils under different vegetable crops and different fertility management practices is a fundamental decision-making tool for soil fertility management and an ideal indicator of sustainable soil management. This study would identify and provide site-specific nutrient management requirements that enable precision fertilization to increase crop yield and farmer’s income, as well as judicious use of soils for sustainable productivity. The effects of long-term fertility management practices on the productivity and sustainability of these soils have not been extensively studied. This study also aims to determine the potential and limitations of soils under different vegetable cultivation by farmers in Opi, Enugu State, by assessing their fertility for sustainable production.

MATERIALS AND METHODS

Study area description

The study area comprised a semi-commercial farm in Opi, Nsukka, Enugu State, Nigeria. The location lies within the geographical coordinates of latitude 6° 46' N and longitude 7° 26' E, with an altitude of 553 m above sea level (GPS Coordinates Mobile App, 2023). Nsukka lies on two primary geologic formations including the false bedded sand stone (Ajali sandstone) and the lower coal measure (Nsukka Formation), which contribute to the development of distinct soil types (Asadu et al., 2001). Nsukka soils consist of dark shale, sandy shale, sandstone, siltstone and coal (Ocheli et al., 2021). The climate is classified as a tropical wet and dry climate based on Koppen’s classification system (Phil-Eze, 2004). The area has an average annual maximum and minimum temperature of 31°C and 21°C, respectively, while the average monthly rainfall varies between 250 mm in April and 380 mm in October, with an average annual total of 1500 mm (UNN Meteorological Station, 2010).

The dry season, which is the rainless period of the year, lasts from November to March, while the harmattan season, characterized by dry and dusty wind (harmattan wind), occurs between late November and February (Akubue and Ugwuoke, 2016). The vegetation of Nsukka is predominantly secondary as a result of human activities such as urbanization, deforestation and agricultural expansion (Onyeakwelu et al., 2010), thus, the location falls within the derived savannah agroecology (Savannah-mosaic) (Ezeaku and Iwuanyanwu, 2013).

Field study

During a field reconnaissance survey of the study area, fields under four vegetable crops [fluted pumpkin (Telfairia occidentalis), red pepper (Capsicum annuum), green pepper (Capsicum annuum) and tomato (Solanum lycopersicum)] with different histories of nutrient management and cropping systems (Table 1) were selected for the study. Topsoil samples were collected at random points using a soil core sampler, a spade and an auger at a depth of 0-30 cm in three replicates. The samples were packed in clean polythene bags, labelled and transported to the Soil Science Undergraduate Laboratory of the University of Nigeria, Nsukka for laboratory analysis

Table 1: Cropping systems and fertilizer applications in the soils under different vegetable cultivation

Cultivated vegetables	Cropping system	Fertilizer input
Fluted pumpkin	Sole cropping	NPK
Red pepper	Mixed cropping (red pepper, maize and scent leaf)	Poultry manure and NPK
Green pepper	Sole cropping	NPK
Tomatoes	Sole cropping	Poultry manure and NPK

Laboratory analysis

The auger soil samples were air-dried, crushed and sieved with a 2 mm mesh and then used to determine the physicochemical properties of the soils. The particle size distribution was determined using the Bouyoucos hydrometer method (Saketu and Gezahagan, 2020). Bulk density was determined using the core-method (Bulluck et al., 2002). Total porosity was determined by calculation using particle density (Nimmo, 2004), while the falling head method was used to determine saturated hydraulic conductivity (Musa and Gupa, 2016). The air-dried bulk soil samples were sieved with a 4.75 mm mesh and the < 4.75 mm samples were subjected to aggregate stability analysis. The wet sieving method described by Kemper and Rosenau (1986) was used for aggregate size separation [> 2.00, 1.00-2.00, 0.50-1.00, 0.25-0.50 and < 0.25 mm water-stable aggregate (WSA)] and the percentage of each WSA fraction determined as shown in Equation 1. The aggregate stability (AS) of the soils (equation 2) and the mean weight diameter of aggregates (equation 3) were computed as follows:

$$\% \text{ WSA} = \frac{\text{mass of WSA}}{\text{mass of sample}} * 100 \quad \ldots\ldots (1)$$

$$\% \text{ AS} = \frac{\text{mass of WSA} (\geq 0.50) - \text{mass of sand}}{\text{mass of sample} - \text{mass of sand}} * 100 \quad \ldots\ldots (2)$$

Where % AS = percentage aggregate stability, WSA (≥ 0.50) = water stable aggregate ≥ 0.50 mm.

$$\text{MWD} = \sum_{i=1}^{n} X_i W_i \quad \ldots\ldots (3)$$

Where MWD = mean weight diameter of aggregates (mm), X_i = mean diameter of each size fraction (mm), W_i = proportion of the total sample weight occurring in the corresponding size fraction.

The soil pH was determined in soil-liquid ratio of 1:2.5 in water (Cezary et al., 2016). The Walkley and Black chromic acid oxidation method was used to determine soil organic carbon (SOC) (Bhardwaj et al., 2022), while total nitrogen was determined using the Kjedahl method (Bulluck et al., 2002).

The Bray II method was used to determine soil available phosphorus (Av.P) (Olsen and Sommers, 1982). Exchangeable calcium (Ca) and magnesium (Mg) were determined using the ethylenediaminetetra-acetic acid (EDTA) titration method (Harris, 2010), while exchangeable potassium (K) and sodium (Na) were determined using the ammonium acetate extraction method and measured by flame photometry (Bhardwaj et al., 2022).

Soil exchangeable acidity (hydrogen, H and aluminium, Al) was determined using the titration method (Wen and Ke, 2022). The effective cation exchange capacity (ECEC) was determined by the summation of the exchangeable acids (H and Al) and exchangeable bases (Ca, Mg, Na and K). All analyses were performed in triplicate and according to standard laboratory procedures.

Statistical Analysis

The data generated from the laboratory analysis were subjected to analysis of variance (ANOVA) in a completely randomized design (CRD) using the Genstat Statistical package. Fisher's least significance difference (LSD) test was used to compare means at $p \leq 0.05$ significant level.

RESULTS

Physical properties of the soils

The results on the particle size distribution of the soils (Table 2) showed a sand content of over 70 % and a small proportion of silt and clay. The silt content was lowest and range from 3.00 to 8.33 % in the soils. The red pepper and the tomato cultivated soils had a similar clay content of 20 %, while the other soils had the same clay content of 12 %. The silt, coarse sand and fine sand content of the soils showed statistical differences, while the clay content was not specified due to lack of variation in replicate values. Accordingly, the soils under the red pepper and the tomato crops had a sandy clay loam texture,while the soils under the fluted pumpkin and the green pepper crops were sandy loam and loam sand, respectively. There was no significant difference in bulk density, total porosity and saturated hydraulic conductivity among the soils, which ranged from 1.66 to 1.72 g cm^{-3}, 35.22 to 37.23 %, and 12.50 to 23.20 cm h^{-1}, respectively.

In general, the proportions of microaggregates (< 0.50 mm) were high compared to those of macroaggregates (> 0.50 mm). With the exception of the 0.50-1.00 mm WSA fraction, the percentage of the other WSA fractions and the mean weight diameter (MWD) of aggregates were statistically similar among the studied soils (Table 3). The proportion of the 0.50-1.00 mm small macroaggregates was higher in the fluted pumpkin and the tomato cultivated soils than in the red and the green pepper cultivated soils. Nonetheless, the latter soils had the highest percent AS, although the percent AS was statistically similar in the green pepper and the tomato cultivated soils.

Table 2: Particle size distribution, textural classification and some physical properties of the studied soils

Cultivated vegetables	Clay	Silt	Coarse sand	Fine sand	Textural class	Bulk density	Porosity	Ksat
	…………………… % …………………					g cm^{-3}	%	cm h^{-1}
Fluted pumpkin	12.00	5.00	63.00	16.70	Sandy loam	1.72	35.22	20.20
Red pepper	20.00	8.33	42.00	29.70	Sandy clay loam	1.68	36.61	23.20
Green pepper	12.00	3.00	63.00	22.00	Loamy sand	1.66	37.23	12.50
Tomato	20.00	5.00	51.00	24.00	Sandy clay loam	1.66	37.23	14.60
Mean	16.00	5.33	54.75	23.10		1.68	36.57	17.64
$LSD_{P\leq 0.05}$	nd	2.00	7.54	8.20		NS	NS	NS

Table 3: Proportions of water-stable aggregate fractions, aggregate stability and mean weight diameter of aggregates of the studied soils

Cultivated vegetables	Water-stable aggregates (mm)					AS	MWD
	> 2.00	1.00-2.00	0.50-1.00	0.25-0.50	< 0.25		
	--% --					%	
Fluted pumpkin	2.33	3.68	5.70	6.65	6.92	9.00	0.91
Red pepper	3.51	4.70	4.97	5.92	5.31	24.90	1.02
Green pepper	3.41	4.00	4.96	6.43	7.27	18.70	1.20
Tomato	1.96	3.58	8.24	7.16	4.40	14.80	0.86
$LSD_{P≤0.05}$	NS	NS	1.99	NS	NS	9.42	NS

AS = aggregate stability, MWD = mean weight diameter, $LSD_{P≤0.05}$ = least significant difference at 5 % probability level, NS = not significant.

Ksat = saturated hydraulic conductivity, $LSD_{P≤0.05}$ = least significant difference at 5 % probability level, nd = not detected, NS = not significant.

Chemical properties of the soils

The chemical properties of the soils (Table 4) showed a significant variation in pH. The soil pH under the green pepper and the fluted pumpkin crops (6.53 and 6.67, respectively) was higher than the pH under the red pepper and the tomato crops (5.87 and 5.97, respectively). The OM content of the soils was significantly higher in the red pepper and the tomato cultivated soils than in the other soils. However, the total N content was similar among the soils and ranged from 0.05 to 0.08 %.The concentration of Av.P in the soils under fluted pumpkin (56.60 ppm) and tomato (64.00 ppm) crops was significantly higher than in the red pepper and the green pepper cultivated soils, with values of 46.00 ppm and 42.60 ppm, respectively.

With the exception of Ca^{2+} and Al^{3+}, the other exchangeable cations (Mg^{2+}, Na^{+}, K^{+} and H^{+}) in the soils differed significantly. The Mg^{2+} concentration was higher in the fluted pumpkin cultivated soil than in the other soils, while Na^{+}, K^{+} and H^{+} concentrations were higher in the red pepper and the tomato cultivated soils compared to the other soils.The soils under the green pepper and the fluted pumpkin crops had the lowest concentrations of K^{+} and H^{+}, respectively. The ECEC was highest in the red pepper cultivated soil and lowest in the green pepper cultivated soil.

DISCUSSION

Physical properties of the soils

The predominance of sand content and the low silt content in the studied soils is related to the parent material of the soils (Akamigbo and Asadu, 1982). The sandy clay loam texture of the soils for red pepper and tomato crops could provide some colloidal advantage over the other soils. Patnaik et al. (2013) reported that clay textured soil have high conductivity in contrast to the low conductivity of light (sandy loam) textured soil and that

Table 4: Chemical properties of the soils cultivated with different vegetables

Cultivated vegetables	pH H_2O	pH KCl	OC	OM	Total N	Av.P	Ca^{2+}	Mg^{2+}	Na^+	K^+	H^+	Al^{3+}	ECEC
			-------------%-------------			ppm	-------------------------$cmol_c kg^{-1}$-------------------------						%
Fluted pumpkin	5.30	6.67	1.12	1.92	0.05	56.60	0.73	1.00	0.05	0.10	1.13	0.40	3.42
Red pepper	4.73	5.87	1.65	2.89	0.07	46.00	0.87	0.40	0.06	0.13	2.00	0.47	4.28
Green pepper	5.20	6.53	1.02	1.74	0.07	42.60	0.53	0.47	0.04	0.08	1.47	0.40	2.99
Tomato	4.77	5.97	1.48	2.56	0.08	64.00	1.00	0.40	0.06	0.13	1.67	0.47	3.72
$LSD_{P\leq0.05}$	0.30	0.24	0.15	0.27	NS	14.60	NS	0.45	0.01	0.01	0.43	NS	0.59

OC = organic carbon, OM = organic matter, Total N = total nitrogen, Av.P = available P, Ca^{2+}, Mg^{2+}, Na^{2+}, K^+, H^+ and Al^{3+} = exchangeable calcium, magnesium, sodium, potassium, hydrogen and aluminium, respectively, ECEC = effective cation exchange capacity, $LSD_{P\leq0.05}$ = least significant difference at 5 % probability level, NS = not significant.

management of light textured soil poses challenges such as enhancing moisture retention capability and overcoming nutrient deficiency due to limited OM content. The similarities in bulk density, total porosity and saturated hydraulic conductivity of the soils suggest that the soils were derived from similar parent material and therefore have similar infiltration, permeability and aeration status, affecting roots development, nutrient intake, and growth of vegetable crops (Celik et al., 2010). The soils bulk density values (1.68 g cm^{-3}) are beyond the ideal values for plant growth (> 1.60 g cm^{-3}) and hence can affect plant root growth (NRCS, 2001). Typical for their respective soil textures is the moderately high total porosity of the soils. However, the saturated hydraulic conductivity of the soils was low, indicating slower water infiltration and water movement in the soils. This could be due to the formation of micro pores/channels by the growing fibrous roots of vegetable plants and the formation of macropores due to the higher proportion of the < 0.50 mm microaggregates, as shown in Table 3.

The larger proportion of microaggregates than macroaggregate is an indication of the instability of macroaggregate in water, consistent with the report of Okebalama et al. (2020) who examined cucumber cultivated soils at the same location and agroecosystem. This condition is due to continuous cultivation (tillage), which predisposes the soils to aggregate disruption, clay dispersion, erosion and runoff. The maximum percentage AS of the red pepper cultivated soil could be related to the contribution of intensive soil fertility management (e.g., the application of organic manure and inorganic fertilizer, mulching, including mixed cropping of red pepper with maize and scent leaf) to improving the structural stability of the soils. This improved structural stability could result in soil resistance to erosion, improved water retention, and improved plant root growth (USDA NRCS, 2008). In contrast, the exclusive application of inorganic fertilizers and continuous tillage could be the reason for the low aggregate stability (%) in the fluted pumpkin cultivated soil.

Chemical properties of the soils

The soil pH showed slightly acidic to neutral pH for the green pepper and the fluted pumpkin soils and moderately acidic pH for the red pepper and the tomato soils (Soil Survey Staff, 2009). The significantly higher H^+ concentration in the latter soils contributed to the acid status of the soils. This could be due to the application of poultry manure, which produces H^+ upon OM decomposition. It is possible that the SCL texture of both soils contributes to the adsorption of H^+ at the exchange site. Nevertheless, the pH values of the soils are similar to those reported by Umeugokwe et al. (2022), and are within the ideal pH range (5.5 to 7.0), which favours the availability of plant nutrients (Oshunsanya, 2019). Thus, these favourable pH status represent the potential of the studied soils for vegetable crop production. Soil pH plays a vital role in determining the concentration and absorption of solutes (Akpoveta et al., 2010) and serves as a reliable indicator of the balance of nutrients available in the soil (Kinyangi, 2007).

According to the critical limits for interpreting fertility levels of soils (Esu (1991), the soil OM content was high in the soils under red pepper and tomato cultivation, while the soils under fluted pumpkin and the green pepper cultivation had medium OM content. The high OM content in the former soils could be related to the previously mentioned improved soil fertility management practises in these fields, especially the application of poultry manure to the soil during cultivation and the incorporation of plant residues in the soil after harvest. Another reason could be related to the differences in the clay content of the soils as the silt and clay content determine the accumulation of SOC in topsoils (Matus, 2021). These reasons are also responsible for the corresponding higher concentrations of Na^+ and K^+ in these soils. On the other hand, the moderate OM content in soils under fluted pumpkin and green pepper cultivation could be due to the lack of organic input despite the intensive use of the land for cultivation. This could partly explain the low concentrations of Na^+ and K^+ as well as the low ECEC of these soils, as soil OM provides proportional amount of the ECEC of soils (Nwachukwu et al., 2021).

The total N of the soils were low, which could be due to their sandy soil texture (> 70 % sand content) and the moderately high porosity, contributing to well-drained soils with increased nutrient leaching. The moderately high OM of the soils are expected to contain a significant amount of decomposed plant material, which would result in higher N levels. More so, the low N retention despite the addition of inorganic fertilizer indicates N losses in these soils. Nitrogen fertilizers have contributed to the remarkable increase in food production, but N uptake by plants is relatively inefficient and often results in average losses of 50 % due to leaching, volatilization or denitrification (Zublena, 1997). Nutrient management is one of the important strategies for the low N retention capacity and high N losses upon application (Mandal et al., 2023). Nitrogen is an important element for plant growth and the yield-determining nutrient in most farming systems (Goulding et al., 2008). For economic reasons, maintaining high crop productivity with minimal N input is ideal. Accordingly, innovative N management strategies should be adopted to reduce N losses in these soils while maintaining high yields. For instance, strategic application of N fertilizers as top-dressings and split applications should aim at synchronizing N availability and crop needs at the farm level (Zhang et al., 2023).

The Av.P was high in the soils under red and green pepper cultivation, but was excessive in the fluted pumpkin and the tomato cultivated soils, which might be due to the applications of phosphate fertilizers and the addition of organic manure, respectively.

These high and excess Av.P content is remarkable, given the high P fixation potential in Ultisols (Mora et al., 2017). Annabi et al. (2011) reported that during the vegetable growing seasons, the soil receives a higher amount of Av.P, which comes mainly from phosphate fertilizers. Considering the critical functions of P in plant nutrition, the Av.P in these studied soils appears to be a great potential for vegetable crop productivity. However, given the low P bioavailability in agricultural soils due to reactions such as soil adsorption, immobilization, or precipitation, the high accumulation of P in these soils could be related to low P-acquisition and utilization efficiency (Dixon et al., 2020). Excess Av.P could negatively impact soil by contributing to soil acidity and making soil nutrients inaccessible for plant use (Sharpley et al., 2000). Therefore, it would be beneficial to evaluate the P-use efficiency (PUE) of the vegetable crops. Phophorus-use efficiency is the sum of P-acquisition efficiency and P-utilization efficiency (Dixon et al., 2020). These determinations and the management strategies to improve P cycling lie outside the structured framework of our quantitative research. Despite limitations, the discovery of high accumulation of Av.P in these soils requires further studies, which would translate into economic benefits in the form of lower input costs and higher crop yields through the application of site-specific P requirements for crops.

The concentration of H^+ was generally higher than that of Al^{3+}, indicating the contribution of H^+ to the soil pH. The concentrations of exchangeable bases in the soils are low. Tomašić et al. (2013) reported that low exchangeable bases could be due to the parent material from which the soil was formed. In heavily weathered Ultisols of the humid tropics, exchangeable base cations are often deficient. This could be attributed to severe leaching, erosion and runoff due to the heavy rainfall contributing to nutrient losses (Okebalama et al., 2022). Furthermore, continuous cultivation has been reported to result in a reduction in exchangeable bases, OC and total N contents and ECEC (Ernest and Mbah, 2016). The higher Na^+ and K^+ contents in the red pepper and tomato cultivated soils could be due to increased recycling and bioavailability of added poultry manure, as evidenced by their corresponding OM contents. Similarly, the relatively higher ECEC in these soils was influenced by the higher contents of colloidal particles (OM and clay), which contribute to the negative charges of the soil particles that adsorb and retain plant nutrient cations. In this case, the higher Na^+, K^+ and H+ contents in these soils contributed to their higher ECEC, even though the ECEC of the soils was generally low. The significantly lower nutrient reserve in the other soils suggests that nutrient uptake of the plants (fluted pumpkin and green pepper) exceeded addition.

This result implies that continuous cultivation of fluted pumpkin or green pepper during the growing season would require frequent applications of base forming fertilizers either in the form of inorganic or organic, or both. Due to their low content in the soils, the major primary nutrients N and K should be applied frequently together with the secondary plant nutrients such as Ca and Mg. Given the sandy texture of the soils, a combination of organic and inorganic fertilizers would likely improve the soil structure and reduce nutrient losses. In addition, fertilizer application methods should aim to increase fertilizer use efficiency and minimize P fixation and leaching or volatilization of N.

CONCLUSIONS AND RECOMMENDATIONS

The studied soils are generally coarse textured and have similar infiltration and permeability characteristics, suggesting better drainage but slower water infiltration capacity. The soils were moderately to slightly acid and had moderately high organic matter and high accumulation of available P, while N and exchangeable base content, including cation exchange capacity, was low. Nevertheless, the fertility status of the soils under red pepper and tomato vegetable crops was better than that under green pepper and fluted pumpkin crops due to the higher of organic matter and exchangeable base cation content, and higher percent aggregate stability. The potential of the soils for improved vegetable production lies in favourable pH, and high SOC and available P reserves, while N and K are the main potentially limiting nutrients in the soils. Considering the better soil structure and greater nutrient reserves, which better predict nutrient availability for sustained vegetable production, the fertility status was better in the red pepper and the tomato cultivated soils that the fluted pumpkin and the green pepper cultivated soils.

The discovery of a high accumulation of available P in the soils calls for further investigation. Sustainable vegetable cultivation on these soils would therefore require further assessment of the P use efficiency due to the supposedly low P-uptake by the vegetable plants. Furthermore, the low N retention due to N losses requires strategic N management aimed at synchronizing N availability with crop needs and maintaining high crop productivity with minimal N input. While appropriate fertilizer application methods are necessary to increase fertilizer use efficiency and minimize nutrient losses, integrated use of organic and inorganic fertilizers and other beneficial soil fertility measures such as mulching and crop rotation are strongly recommended as strategies to increase nutrient content and improve soil structure, especially in the fluted pumpkin and the green pepper cultivated soils.

Overall, site-specific fertilizer recommendations for the different vegetable crops would make more economic sense, and frequent fertilizer applications would be necessary to improve soil health and maintain soil productivity.

REFERENCES

Akamigbo, F. O. R. and Asadu, C. L. A. 1982. Influence of parent materials on the soils of southestern Nigeria. East Afr. Agric. For. J., 48(1-4): 81-91.

Akinrinde, E. A., Adepoju, A. A. and Adeyemo, A. J. 2013. The impact of inorganic fertilizer on soil fertility and crop yield in southwestern Nigeria. J. Sustain. Agric., 37(7): 777-790.

Akpoveta, O. V., Osakwe, S. A., Okoh, B. E. and Otuya, B. O. 2010. Physicochemical characteristics and levels of some heavy metals in soils around metal scrap dumps in some parts of Delta State, Nigeria. J. Appl. Sci. Environ. Manag., 14(4): 57-60.

Akubue, I. O. and Ugwuoke, C. C. 2016. Hydrological and sediment yield characteristics of Nsukka area, Southeastern Nigeria. In IOP Conference Series: IOP Publishing, Earth Environ. Sci., 49(1): 012068.

Amede, T. 2003. Opportunities and Challenges in Reversing Land degradation: The Regional Experience. In T. Amede (Editor), Natural resource degradation and environmental concerns in the Amhara National Regional State: Impact on Food Security. Ethiop. Soils Sci. Soc., 3: 173-183.

Annabi, M., Le Bissonnais, Y., Le Villio, P. M. and Houota, S. 2011. Improvement of soil aggregate stability by repeated applications of organic amendments to a cultivated silty loam soil. Agric. Ecosyst. Environ., 144: 382-389.

Asadu, C. L. A., Ekwo, A. U. and Udigwe, T. K. 2001. Soil characteriatics around lake opi in eastern Nigeria and land use recommendations. Agro-Science, 2(1): 76-89.

Bhardwaj, P., Sharma, R. K., Chauhan, A., Ranjan, A., Rajput, V. D., Minkina, T., Mandzhieva, S. S., Mina, U., Wadhwa, S., Bobde, P. and Tripathi, A. 2022. Assessment of heavy metal distribution and health risk of vegetable crops grown on soils amended with municipal solid waste compost for sustainable urban agriculture, Water, 15(2): 228.

Bulluck, L. R., Brosius, M., Evanylo, G. K. and Ristaino, J. B. 2002. Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. Appl. Soil Ecol., (19): 147-160.

Celik, I., Gunal, H., Budak, M. and Akpinar, C. 2010. Effects of long term organic and mineral fertilizers on bulk density and penetration resistance in semi-arid Mediterranean soil conditions. Geoderma, 160(2): 236-243.

Cezary, K., Elżbieta, M., Bernard, G., Dorota, Ł. and Paulina, M. 2016. Conversion of soil pH 1:2.5 KCl and 1:2.5 H_2O to 1:5 H_2O: Conclusions for soil management, environmental monitoring, and international soil databases. Pol. J. Environ. Stud., 25(2): 647-653.

Congreves, K. A. and Van Eerd, L. L. 2015. Nitrogen cycling and management in intensive horticultural systems. Nutr. Cycl. Agroecosys., 102: 299-318.

Dixon, M., Simonne, E., Obreza, T. and Liu, G. 2020. Crop response to low phosphorus bioavailability with a focus on tomato. Agronomy, 10(5): 617.

Doran, J. W. 2002. Soil health and global sustainability: translating science into practice. Agric. Ecosyst. Environ., 88: 119-127.

Ernest, C. I. and Mbah, C. N. 2016. Impact of continuous cultivation on soil properties of Imo state southeastern Nigeria. Агрохімія і ґрунтознавство, 85: 47-53.

Esu, I. E. 1991. Detailed soil survey of NIHORT farm at Bunkure, Kano State, Nigeria, Institute for Agricultural Research, Ahmadu University, Zaria, Nigeria, 32 pp.

Ezeaku, P. I. and Iwuanyanwu, F. C. 2013. Degradation rates of soil chemical fertility as influenced by topography in Southern Nigeria. IOSR J. Environ. Sci. Toxocol. Food Technol., 6: 39-49.

FAO (Food and Agricultural Organization of the United Nations). 2013. The State of Food and Agriculture 2013: Rome: FAO. Retrieved from: http://www.fao.org/3/i3300e.pdf

FAO (Food and Agricultural Organization of the United Nations). 2017. The future of food and agriculture: Trends and challenges. Rome: FAO.

Goulding, K., Jarvis, S. and Whitmore, A. 2008. Optimizing nutrient management for farm systems. Philos. Trans. R. Soc. A, 363: 667-680.

GPS Coordinates Mobile Application. 2023. Version 5.10. Google play store.

Harris, D. C. 2010. Quantitative chemical analysis (8th ed.). W.H. Freeman and Company.

Hobbs, P. R. 2007. Conservation agriculture: what is it and why is it important for future sustainable food production?. J. Agric. Sci., 145(2): 127.

Jackson, L. E., Ramirez, I., Yokota, R., Fennimore, S. A., Koike, S. T., Henderson, D. M., Chaney, W. E., Calderon, F. J. and Klonsky, K. 2004. On-farm assessment of organic matter and tillage management on vegetable yield, soil, weeds, pests, and economics in California. Agric. Ecosyst. Environ., 103: 443-463.

Kemper, W. D. and Rosenau, R. C. 1986. Aggregate stability and size distribution. In A. Klute (Editor), Methods of soil analysis. Part 1. Agronomy Monograph 9. Second Edition, Madison, Wisconsin, p. 425-442.

Kinyangi, J. 2007. Soil health and soil quality: A review.

Knowler, D. and Bradshaw, B. 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food policy, 32(1): 25-48.

Kyriacou, M. C. and Rouphael, Y. 2018. Towards a new definition of quality for fresh fruits and vegetables. Sci. Hortic., 234: 463-469.

Mandal, U. K., Mal, S., Naiya, A. K., Ghosh, A., Nayak, D. B., Digar, S., Bhutia, R. N., Lama, T., Burman, D., Mahanta, K. and Sarangi, S. 2023. Nano-urea for Vegetable Cultivation in Coastal West Bengal. J. Indian Soc. Coastal Agric. Res., 41(1): 9-16.

Matus, F. J. 2021. Fine silt and clay content is the main factor defining maximal C and N accumulations in soils: a meta-analysis. Sci. Rep., 11(1): 6438.

Mitchell, D. 2008. A note on rising food prices. Washington, DC: World Bank.

Mora, E., Toro, M., Flores, E. and López-Hernández, D. 2017. Plant growth promoting abilities of phosphate solubilizing bacteria native from a high P-sorbing Ultisol. Ann. Adv. Agric. Sci., 1: 1-10.

Musa, J. J. and Gupa, Y. U. 2016. An overview of methods used in the determination of soil hydraulic conductivity. Al-Hikmah J. Pure Appl. Sci., 7: 22-30.

Nimmo, J. R. 2004. Porosity and pore size distribution. In D. Hillel (Editor), Encyclopedia of Soils in the Enviroment, London, Elsevier, 3: 295-303.

Norris, C. E. and Congreves, K. A. 2018. Alternative management practices improve soil health indices in intensive vegetable cropping systems: a review. Front. Environ. Sci., 6: 50.

NRCS (National Resources Conservation Service). 2001. Soil Quality Test Kit Guide. USDA Natural Resources Conservation Service, Washington, DC.

Nwachukwu, O. I., Olim, D. M., Afu, S. M., Akpa, E. A. and Adie, P. I. 2021. Comparative effects of organic amendments on heavy metals adsorption in soil and their chemical properties. Asian J. Appl. Sci., 9(1): 59-65.

Ocheli, A., Ogbe, O. B. and Aigbadon, G. O. 2021. Geology and geotechnical investigations of part of the Anambra Basin, Southeastern Nigeria: Implication for gully erosion hazards. Environ. Syst. Res., 10: 1-16.

Okebalama, C. B., Ibezim, C. O., Ugwu, V. U. and Marschner, B. 2020. Effects of amending an Ultisol with bambara groundnut seed residue on soil fertility, microbial nutrient cycling and yield of cucumber. Biol. Agric. Hortic., 36(4): 249-266.

Okebalama, C. B., Igwe, C. A. and Onunwa, A. O. 2022. Enumeration of carbon and nitrogen contents of water-stable aggregates in layers of topsoils from cultivated and adjacent bush-fallow loamy soils. Agro-Science, 21(1): 103-13.

Okorie, B. O., Asadu, C. L. A., Tariq, M., Ahmed, I. and Umeugokwe, C. P. 2021. Influence of slope and management practices on top-soils fertility status of compound farms in Nsukka campus. Medicon Agric. Environ. Sci., 2.1: 25-33.

Olsen, S. R. and Sommers, L. E. 1982. Phosphorus. In A. L. Page, R. H. Miller, and D. R. Keeney (Editors), Methods of Soil Analysis, Part 2, American Society of Agronomy, p. 403-430.

Onyekwelu, J. C., Eze, E. C. and Ezemenari, K. U. 2010. Impact of land use changes on vegetation cover in Nsukka, Enugu State, Nigeria. J. Environ. Sci. Technol., 3(4): 225-236.

Oshunsanya, S. (Editor). 2019. Soil pH for nutrient availability and crop performance. BoD–Books on Demand.

Patnaik, L., Raut, D., Behera, L., Nayak, A., Misha, S. and Swain, S. 2013. Physico-chemical and heavy metal characterization of soil from industrial belt of Cuttack, Orissa. Asian J. Exp. Biol. Sci., 4(2): 219-225.

Phil-Eze, P. O., 2004. The Vegetation of the Nsukka Plateau: Empirical Analysis of Forms and Patterns. In J. C. Nwafor et al. (Editors), Geographical Report of the University of Nigeria, p. 128-146.

Rouphael, Y., Kyriacou, M. C., Petropoulos, S. A., De Pascale, S. and Colla, G. 2018. Improving vegetable quality in controlled environments. Sci. Hortic., 234: 275-289.

Saketu, H., and Gezahagn, K. 2020. Measurement of soil particle size distribution using hydrometer analysis. Am. Eurasian J. Agric. Environ. Sci., 20(4): 243-254.

Sharpley, A., Foy, B. and Withers, P. 2000. Practical and innovative measures for the control of agricultural phosphorus losses to water: An overview. J. Environ. Qual., 29: 1-9.

Slavin, J. L. and Lloyd, B. 2012. Health benefits of fruits and vegetables. Adv. Nutr., 3, 506-516.

Soil Survey Staff. 2009. Soil survey field and laboratory methods manual. Soil survey investigations Report No. 51, Version 1.0. R. Burt (Editor). U.S. Department of Agriculture, Natural Resources Conservation Service.

Tautua, A., Bamidele, M. W., Onigbinde, A. O. and Ere, D. 2014. Assessment of some heavy metals and physicochemical properties in surface soils of municipal open waste dumpsite in Yenagoa, Nigeria. Afr. J. Environ. Sci. Technol., 8(1): 41-47.

Tomašić, M., Zgorelec, T., Jurišić, A. and Kisić, I. 2013. Cation Exchange Capacity of Dominant Soil Types in the Republic of Croatia. Eur. J. Cent. Agric., 14(3): 937-951.

Umeugokwe, C. P, Ajoagu, G. M. and Asadu, C. L. A. 2022. Characterization, classification and suitability evaluation of soils on three geological formations in Nsukka Area of Enugu State for pepper production. Niger. J. Soil Sci., 32(2): 95-104.

UNN (University of Nigeria) Meteorological Station. 2010. Weather data report. Nsukka, Enugu State.

USDA National Resources Conservation Service. 2008. Soil quality indicators: Aggregate stability. nrcs. usda. gov.

Wen, S. and Ke, Y. 2022. Method validation for determination of exchangeable acidity in soils. Sci. J. Technol., (4)10.

Wei, W., Yan, Y., Cao, J., Christie, P., Zhang. F. and Fan, M. 2016. Effects of combined application of organic amendments and fertilizers on crop yield and soil organic matter: An integrated analysis of long-term experiments. Agric. Ecosyst. Environ., 225: 86-92.

WHO (World Health Organisation). 2003. Fruit and vegetable promotion initiative: A Meeting Report. Geneva.

Willekens, K., Vandecasteele, B. and De Neve, S. 2014. Limited short-term effect of compost and reduced tillage on N dynamics in a vegetable cropping system. Sci. Hortic., 178: 79-86.

Zhang, F., Ma, X., Gao, X., Cao, H., Liu, F., Wang, J., Guo, G., Liang, T., Wang, Y., Chen, X. and Wang, X., 2023. Innovative nitrogen management strategy reduced N_2O emission while maintaining high pepper yield in subtropical condition. Agric. Ecosyst. Environ., 354: 108565.

Zhang, Y., Wei, G., Luan, H., Tang, J., Li, R., Li, M., Zhang, H. and Huang, S. 2022. Effects of a decade of organic fertilizer substitution on vegetable yield and soil phosphorus pools, phosphate activities, and the microbial community in a greenhouse vegetable production system. J. Integr. Agric., 21(7): 2119-2133.

Zublena, J. P. 1997. Nutrient removal by crops in North Carolina. North Carolina Extension Service. Soil Facts Pub. AG, p. 439-446.