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Influence of Repeated Agrochemical Inputs on Nutrient Availability and Heavy Metal Status of Lowland Soils of Ifite-Ogwari Anambra State Nigeria

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ABSTRACT: This study evaluated the influence of repeated agrochemical inputs on nutrient availability and heavy metal status of lowland soils in Ifite-Ogwari, Anambra State. Composite soil samples were collected from agrochemical-treated fields (AGI) and adjacent fallow soils (control) at two depths (0–15 cm and 15–30 cm). Standard laboratory analyses were conducted to determine texture, bulk density, pH, organic carbon (OC), total nitrogen (TN), exchangeable bases, effective cation exchange capacity (ECEC), available phosphorus (Av.P), and concentrations of arsenic (As) and lead (Pb). Results showed significant reductions ($p \leq 0.05$) in OC, TN, Ca^{2+}, and Av.P under AGI soils compared with controls, indicating fertility depletion. Soil pH remained acidic across sites, but AGI soils recorded slightly higher values. Heavy metals exhibited contrasting trends; arsenic (As) was significantly higher in AGI soils at 15 – 30 cm depth, while Pb concentrations showed no significant difference ($p \leq 0.05$) between AGI and control soils nor across depths. Correlation analysis revealed that arsenic (As) was strongly correlated with soil texture (silt, clay) and pH, whereas Pb correlated with exchangeable bases (Na^{+}, Mg^{2+}, Ca^{2+}). Although As and Pb levels remained below international safety limits, the observed build-up under continuous inputs highlights the risk of long-term accumulation. The findings demonstrate that repeated agrochemical use compromises soil fertility and promotes gradual heavy metal enrichment, underscoring the need for integrated soil fertility management and reduced dependence on chemical inputs in lowland rice systems.

KEYWORDS: Lowlands, Soils, Fertility, Agrochemicals, Heavy metals

INTRODUCTION

Agrochemicals are widely applied to sustain rice production in wetland ecosystems, yet their repeated use can alter soil chemical properties, disrupt nutrient cycling, and influence the behavior of potentially toxic elements. Nitrogen-based fertilizers accelerate soil acidification and deplete exchangeable bases (Tadesse *et al.,* 2024), while herbicides such as glyphosate compete with phosphate for sorption sites, reducing available phosphorus (Chavez-Otiz *et al.,* 2022). Persistent pesticides like imidacloprid further raise concerns about cumulative impacts on soil fertility

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(Smolander *et al.,* 2025). In lowland rice systems, fluctuating redox conditions regulate dynamics, particularly arsenic (As) and lead (Pb), which can mobilize into soil solutions and pose risks to food safety (Cheraghi *et al*., 2025). While studies from Asia document As accumulation in rice soils, African paddy soils remain underexplored despite increasing dependence on agrochemical inputs (Mlangeni *et al.,* 2023).

In southeastern Nigeria, earlier research has shown soil acidification, organic carbon decline, and nutrient depletion under continuous rice cultivation, with some emphasis on Cd and Zn in Atani and Odekpe wetlands, and fertility contrasts between rice and fallow wetlands in Ifite-Ogwari and Omor (Okafor *et al*., 2025a; Okafor *et al*., 2025b). However, the influence of repeated agrochemical regimes on nutrient availability and status, particularly As and Pb, in Ifite-Ogwari lowland soils remains unaddressed. Given evidence of heavy metals in local water sources, there is a need to link agrochemical-driven soil changes with potential environmental risks. This study therefore evaluated nutrient availability and heavy metal status in rice soils of Ifite-Ogwari under repeated agrochemical inputs, compared with adjacent fallow soils.

MATERIAL AND METHODS

Study area

The study was conducted in Faculty of Agriculture (Annex), Nnamdi Azikiwe University, Ifite-Ogwari, Anambra State, southeastern Nigeria, which lies between 6°14′28″– 6°14′51″N, and 7°06′46″– 7°06′47″E). The area falls within the tropical savanna zone, characterized by a bimodal rainfall regime, with mean annual rainfall of 1520 – 2020 mm, and mean annual temperature of 27 – 28 °C. The soils are predominantly clay-loam and support extensive rice cultivation under seasonal wetland conditions, alongside yam, cassava, maize, and vegetables. Farming systems are input-intensive, relying heavily on mineral fertilizers, herbicides, and pesticides.

Experimental Design and Soil sampling

Two land-use types were selected, a rice fields with a minimum of four years of continuous agrochemical application, and adjacent fallow fields (≥3 years) used previously for yam cultivation, which served as controls. In each land-use type, soil samples were collected at two depths (0–15 cm and 15–30 cm) using an auger, with three replicates per depth. Composite samples were prepared from random sub-samples within each plot to account for spatial variability. Samples were air-dried, gently crushed, and sieved through a 2-mm mesh for analysis.

Laboratory Analyses

Particle size was determined using Bouyoucos method. pH was determined by measuring in a 1:2.5 soil-to-water suspension using a calibrated glass electrode pH meter. Organic carbon (OC) was determined by the Walkley–Black wet oxidation method with external heating modification to improve accuracy in tropical soils. Total nitrogen (TN) was determined by the Kjeldahl digestion–distillation method. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) was extracted with 1 M ammonium acetate (pH 7.0). Calcium and magnesium were measured with an atomic absorption spectrophotometer (AAS), while Na^{+} were quantified using a flame photometer. Exchangeable acidity (Al^{3+} + H^{+}) was determined by titration following extraction with 1 M KCl. Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases and exchangeable acidity. Available phosphorus (Av.P) was extracted by the Bray I method and determined colorimetrically using a spectrophotometer. Arsenic (As) and lead (Pb) were determined using aqua regia digestion (HCl–HNO_3, 3:1) followed by analysis with an atomic absorption spectrophotometer (AAS, PerkinElmer Analyst 400).

Statistical Analysis

Data were subjected to two-way analysis of variance (ANOVA) to evaluate the effects of land use (AGI vs control) and depth (0 -15, 15 - 30 cm) on soil properties and heavy metal concentrations. Significant differences among means were separated using the Least Significant Difference (LSD) test at $p \leq 0.05$. Statistical analyses were conducted using R software (version 4.3.1).

RESULTS AND DISCUSSION

Studied soil physicochemical properties

Physicochemical properties of the studied soils were shown in Table 1. Agrochemical input (AGI) soils had more clay (39.1 % - 45.1 %) than control soils (33.7 % - 38.4 %). Bulk density (BD) ranged from 1.28 – 1.36 Mg/m^3, with slightly higher values in control soils. Soil pH was acidic across both soils (AGI and control); ranged from 5.12 – 5.41, with AGI soils having slightly higher values. Organic carbon (OC) and total nitrogen (TN) were consistently lower in AGI soils (1.01 – 1.11 % OC; 0.09 % TN) than in the control (1.55 – 1.90 % OC; 0.13 – 0.16 %). Calcium (Ca) and magnesium (Mg) were reduced in AGI soils (2.27 – 2.67 cmol/kg Ca^{2+}; 1.20 – 1.47 cmol/kg Mg^{2+}) relative to the control soils (3.30 – 4.80 cmol/kg Ca^{2+}; 2.03 – 2.27 cmol/kg Mg^{2+}). Sodium (Na) values were low in both land uses (0.09 – 0.15 cmol/kg). effective cation exchange capacity (ECEC) was lower in AGI soils (4.79 – 5.34 cmol/kg) than in control soils (6.51 – 8.81 cmol/kg). Available phosphorus (Av. P) was lower in AGI soils (3.39 – 3.63 mg/kg) than in control soils (6.22 – 10.4 mg/kg).

The higher clay content observed in AGI soils could have been as a result of continuous cultivation which affect aggregation, as well as exposing clay materials within the depths to the near surface soils, and this could indicate greater potential for nutrient and agrochemical adsorption. Bulk density falls within the range typical for cultivated wetland soils (Reddy *et al.,* 2013), where puddling and repeated tillage contribute to moderate compaction. The consistency acidic soil pH reflected the long-term use of ammonium-based fertilizers, which enhances soil acidification. The reduction of organic carbon and total nitrogen in AGI soils could be as a result of continuous cultivation which may have depleted organic matter content (Lopez-Vincent *et al.,* 2020). The lower exchangeable bases and ECEC in AGI soils than in control soils could have been acidification caused by continuous use of ammonium-based fertilizers and other agrochemicals which has the ability to exacerbate cation losses (Sabina *et al.,* 2025). The substantial lower Available phosphorus in AGI soils despite fertilizer inputs, may have been as a result of strong fixation in clay-rich soils or competition with herbicides such as glyphosate for sorption sites; similar observation has been reported in tropical wetland systems where agrochemical residues interact with mineral phases to immobilize phosphorus (Yasir *et al.,* 2025).

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Table 1. Physicochemical properties of lowland soils in Ifite-Ogwari

Land use	Depth (cm)	Sand	Silt (gkg^{-1})	Clay	TC	BD (Mg/m^3)	pH	OC (%)	TN	Ex.A	Ca^{2+}	Mg^{2+} (Cmol/kg)	Na^+	ECEC	Av.P (mg/kg)
AGI	0-15	31.6	29.3	39.1	CL	1.30	5.41	1.11	0.09	1.23	2.27	1.20	0.09	4.79	3.63
	15-30	29.6	25.3	45.1	C	1.28	5.38	1.01	0.09	1.07	2.67	1.47	0.13	5.34	3.39
Control	0-15	50.3	16	33.7	SCL	1.36	5.12	1.90	0.16	1.60	4.80	2.27	0.14	8.81	10.4
	15-30	46.3	15.3	38.4	SL	1.34	5.23	1.55	0.13	1.03	3.30	2.03	0.15	6.51	6.22

Key: AGI = Agrochemical input, BD = bulk density, TC = Textural class, OC = organic carbon, TN = total nitrogen, Ex. A = Exchangeable acidity, ECEC = effective cation exchange, Av. P = available phosphorus, CL = clay loam, C = clay, SCL = sandy clay loam, SL = silty loam, Ctr = control

Variation of Selected Soil Properties across Soils and depths

Variations of soil properties across sites and two soil depths were shown in Table 2. Sand content was significantly ($p \leq 0.05$) higher in the control soils (46.3 – 50.3 %) compared with agrochemical input (AGI) soils (29.6 – 31.6 %), while silt was significantly higher in AGI soils (25.3–29.3 %). Clay showed significant difference only at 15–30 cm depth, with AGI soils recording higher values (45.1 %) than control (38.4 g %). Bulk density differed significantly ($p \leq 0.05$) between sites and depths, with slightly higher values in control soils (1.34 –1.36 Mg/m^3) than in AGI soils (1.28–1.30 Mg/m^3). Soil pH was significantly ($p \leq 0.05$) higher in AGI soils (5.38–5.41) relative to controls (5.12–5.23). Organic carbon (OC) and total nitrogen (TN) were significantly ($p \leq 0.05$) higher in control soils (1.55–1.90% OC; 0.13–0.16% TN) compared with AGI soils (1.01–1.11 % OC; 0.09 % TN). Exchangeable acidity (Ex. A) showed significant difference ($p \leq 0.05$) at control soils, with 0 –15 cm soil depth (1.60 cmol/kg) higher than 15-30 cm (1.03 cmol/kg). Calcium (Ca^{2+}) was significantly ($p \leq 0.05$) depleted in AGI soils (2.27 –2.67 cmol/kg) compared with control soils (3.30 – 4.80 cmol/kg). Magnesium (Mg^{2+}), and sodium (Na^+) did not differ significantly across depths, but Av. P was significantly ($p \leq 0.05$) higher in control soils (10.4 mg/kg) relative to AGI soils (3.63 mg/kg) at 0 – 15 cm depth only.

The significant textural differences between AGI and control soils suggest that long-term cultivation may be linked with increased clay and silt aggregation, consistent with findings that cultivation practices alter soil particle distribution and structure (Wang *et al.,* 2024). Lower bulk density in AGI soils indicated puddling and tillage effects typical of rice fields, whereas fallow soils had slightly denser structures. Organic carbon and nitrogen were significantly reduced in AGI soils compared with controls, highlighting continuous cultivation and agrochemical-driven declines in soil organic matter. This agrees with (Goud *et al.,* 2022), who reported enhanced decomposition and fertility loss under intensive management. The depletion of Ca^{2+} in AGI soils indicates leaching under acidic conditions exacerbated by fertilizer inputs, consistent with (Guan *et al.,* 2025). The consistently lower Av. P in AGI soils, despite fertilization, likely reflects fixation in clay-rich soils and competitive sorption with herbicides such as glyphosate (Reda *et al.,* 2025).

Table 2. Variation of soil properties across studied sites and soil depths

Sites	Depth (cm)	Sand	Silt (gkg^{-1})	Clay	BD (Mg/m^3)	pH	OC (%)	TN (%)	Ex.A	Ca^{2+}	Mg^{2+} (Cmol/kg)	Na^+	Av.P (mg/kg)
AGI	0-15	31.6	29.3	39.1	1.30	5.41	1.11	0.09	1.23	2.27	1.20	0.09	3.63
	15-30	29.6	25.3	45.1	1.28	5.38	1.01	0.09	1.07	2.67	1.47	0.13	3.39
	LSD (p<0.05)	**NS**	**NS**	**5.65**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Ctr	0-15	50.3	16	33.7	1.36	5.12	1.90	0.16	1.60	4.80	2.27	0.14	10.4
	15-30	46.3	15.3	38.4	1.34	5.23	1.55	0.13	1.03	3.30	2.03	0.15	6.22
	LSD (p<0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.51**	**NS**	**NS**	**NS**	**NS**
Depth (cm)	**Sites**												
0-15	AGI	31.6	29.3	39.1	1.30	5.41	1.11	0.09	1.23	2.27	1.20	0.09	3.63
	Ctr	50.3	16.0	33.7	1.36	5.12	1.90	0.16	1.60	4.80	2.27	0.14	10.4
	LSD (p<0.05)	**9.48**	**5.80**	**NS**	**0.04**	**0.15**	**0.76**	**0.07**	**NS**	**1.86**	**0.86**	**NS**	**6.40**
15-30	AGI	29.6	25.3	45.1	1.28	5.38	1.01	0.09	1.07	2.67	1.47	0.13	3.39
	Ctr	46.3	15.3	38.4	1.34	5.23	1.55	0.13	1.03	3.30	2.03	0.15	6.22
	LSD (p<0.05)	**9.48**	**5.80**	**5.65**	**0.04**	**0.15**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Key: AGI = Agrochemical input, BD = bulk density, TC = Textural class, OC = organic carbon, TN = total nitrogen, Ex. A = Exchangeable acidity, ECEC = effective cation exchange, Av. P = available phosphorus, CL = clay loam, C = clay, SCL = sandy clay loam, SL = silty loam, Ctr = control, NS = not significant

Heavy Metal Concentration in the Studied Soils

Heavy metal concentration of soils across two studied depths were shown in figure 1, and 2. Figure 1 showed arsenic (As) concentration in soils under agrochemical input (AGI) and control (Ctr). Arsenic levels were higher in AGI soils (0.16 mg/kg) at both depths, compared with control

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soils (0.04 mg/kg at 0-15 cm; 0.01 mg/kg at 15-30 cm). Figure 2, showed lead (Pb) concentration across soils and depths. In 0-15cm depth, Pb was higher in AGI soil (0.22 mg/kg) than in control soil (0.14 mg/kg). At 15 – 30 cm depth, the trend reversed, with control soil (0.19 mg/kg) exceeding AGI soil (0.16 mg/kg).

The higher Arsenic (As) level in AGI soil suggested that repeated agrochemical applications contribute to As concentration, either through inputs containing As impurities or through mobilization under lowland redox conditions (Elumalai *et al.,* 2025). Although As remained below permissible limits, the significant difference ($p \leq 0.05$) between AGI and control soils indicates a gradual build-up. Surface accumulation of Pb in AGI soils may be attributed to pesticide residues and atmospheric deposition (Zhang *et al.,* 2025; Kumar *et al.,* 2025).

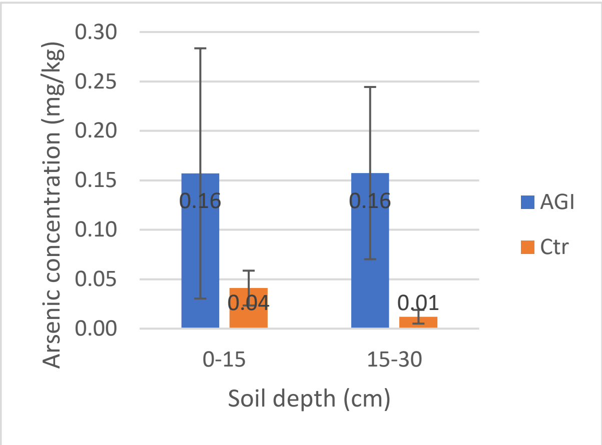

Fig. 1: Arsenic level in studied soils

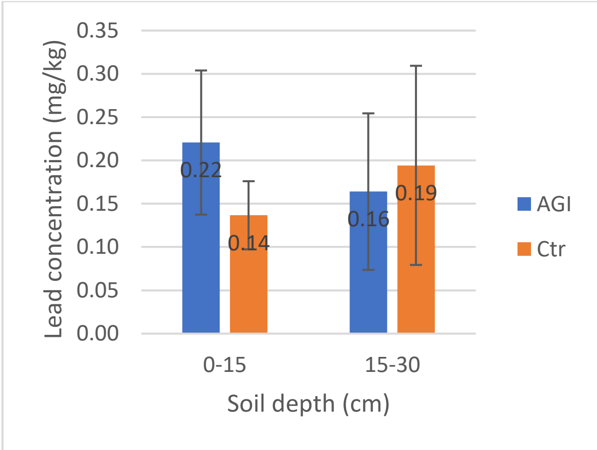

Fig. 2: Lead level in studied soils

Relationship between studied soil properties and heavy metals

The correlation among soil physicochemical properties and heavy metals was shown in Figure 3. Arsenic (As) was strongly and positively correlated with silt (r =0.97), pH (r = 0.88), and clay (r = 0.67), but negatively correlated with sand (r = -0.95), bulk density (r = -0.90), organic carbon (r = -0.87), total nitrogen (r = -0.87), and exchangeable Mg^{2+} (r = -0.91). Lead on the other hand showed strong positive correlations with Na^{+} (r = 0.87) and Mg^{2+} (r = 0.58), and moderate positive correlations with Ca^{2+} (r = 0.46) and ECEC (r = 0.44). Conversely, Pb correlated negatively with silt (r = -0.60) and pH (r = -0.45).

The positive relationship of arsenic (As) with silt and pH indicated that As mobility and retention are influenced by fine-textured soils and surface charge dynamics, consistent with earlier studies that As-adsorption increases with pH in tropical wetland soils (Srivastava *et al.,* 2021). The negative relationship of As with organic carbon and nitrogen could imply that soils with higher fertility and organic matter immobilizes less As, possibly due to microbial reduction and enhanced mobilization under redox-active conditions (Suda *et al.,* 2023). The negative correlation of Pb with pH and silt indicated higher availability of Pb in more acidic soils, consistent with Pb solubility behaviour in low-pH soils (Feszterova *et al.,* 2024; Kicinska *et al.,* 2021).

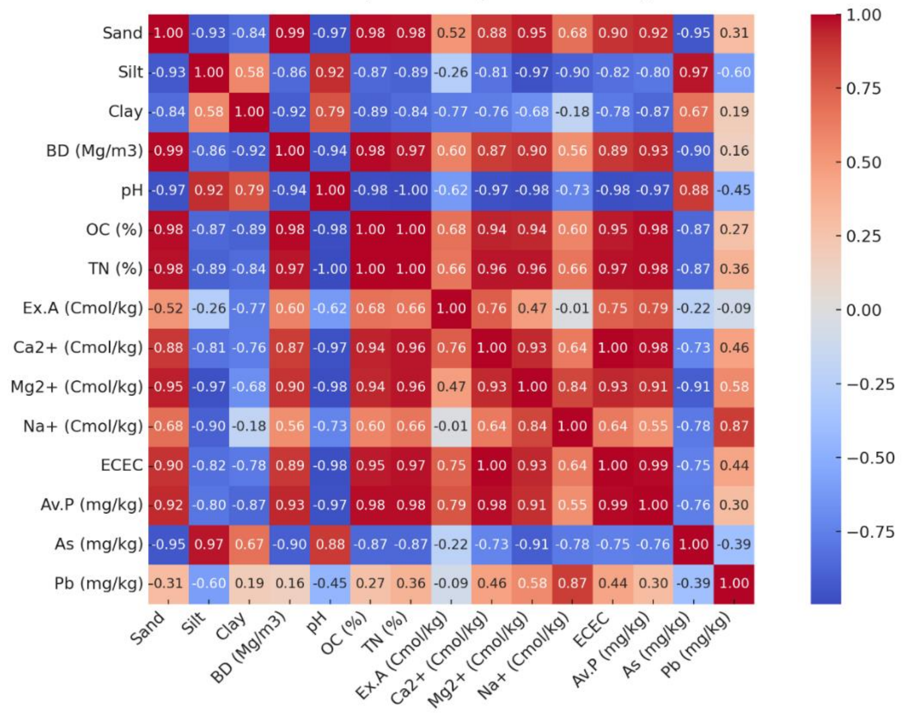

Fig. 3: Correlation of studied soil properties with heavy metals

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CONCLUSION AND RECOMMENDATION

This study showed that repeated agrochemical inputs in Ifite-Ogwari lowland soils significantly reduced soil organic carbon, total nitrogen, exchangeable Ca^{2+}, and available phosphorus, while increasing soil acidity relative to control soils. Variations across sites and depths showed that control soils maintained higher fertility and nutrient reserves. Studied heavy metals behaved differently; arsenic (As) was significantly higher in agrochemical input (AGI) soils at subsurface depth (15 – 30 cm), while lead (Pb) remained low and showed no significant difference ($p \leq 0.05$) across land uses. Correlation analysis further showed that As was strongly influenced by soil texture (silt, clay) and pH, whereas Pb was associated with exchangeable bases (Na^{+}, Mg^{2+}, Ca^{2+}), although heavy metal concentrations remained below FAO/WHO permissible limits in agricultural soils, the trends in the result predicts a gradual build-up under continuous inputs.

Farmers in Ifite-Ogwari and similar lowland communities should adopt simple, affordable practices to restore soil fertility and reduce contamination risks, such as incorporating organic amendments like farmyard manure, compost, and crop residues to replenish organic matter and nitrogen; applying lime or wood ash to buffer soil acidity and improve nutrient availability; rotating rice with legumes to naturally enhance nitrogen and soil structure; and reducing excessive reliance on agrochemicals by practicing integrated weed and pest management. Also, community-led soil monitoring, supported by extension agents, can help track nutrient status and heavy metals at minimal cost, ensuring sustainable rice production while protecting soil health.

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