FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 5, May, 2025, pp 164 - 170
DOI: https://doi.org/10.33003/fjs-2025-0905-3482

SOIL DEGRADATION AND NUTRIENT DYNAMICS IN SOILS UNDER CONTINUOUS RICE PRODUCTION IN SEASONAL WETLAND ECOSYSTEMS OF ANAMBRA STATE, NIGERIA

***[1]Okafor, Maduabuchi J., [2]Nweke, Ikechukwu A. and [2]Nsoanya, Leonard N.**

[1]Department of Soil Science and Land Resources Management, Nnamdi Azikiwe University, Awka, Nigeria
[2]Department of Soil Science, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.

*Corresponding authors' email: buchi.okafor86@gmail.com Phone: +2347032532603

ABSTRACT

This study assessed soil degradation and nutrient dynamics in seasonal wetland ecosystems under continuous rice cultivation in Atani and Odekpe, Anambra State, Nigeria. Soil samples were collected from rice fields and adjacent ≥ 5-year fallow (control) soils at two depths (0-15cm and 15-30 cm), and analyzed for selected soil physicochemical properties. Results showed high bulk density in the rice field (2.01 Mg/m^3 at Atani), reduced organic carbon (1.07% at 15 – 30 cm in Odekpe), and high cadmium levels (0.38 mg/kg at 15-30 cm in Odekpe rice field). The soils showed moderate acidity across locations with pH values ranging from 5,45 to 6.00. The soil degradation index (SDI), computed as the weighted sum of normalized scores for eight degradation-sensitive parameters, ranged from 0.231 (Odekpe control at 15-30 cm depth) to 0.438 (Odekpe control at 0-15 cm depth). Rice fields showed inconsistent SDI values with depth, while control soils consistently had lower degradation at 15-30 cm depth. The findings showed that long-term rice cultivation, through agrochemicals use and tillage, significantly alters soil properties and increases degradation.

Keywords: Agrochemicals, Nutrient dynamics, Rice farming, Soil degradation, Wetland ecosystems

INTRODUCTION

Soil degradation and nutrient depletion have always been critical global environmental concerns. There is no difference in seasonal wetland soils of Anambra state, where intensive rice production is practiced (Okafor *et al.,* 2024). In Nigeria, wetland ecosystems play a pivotal role in food production (Sharma and Naik, 2024), particularly through rice cultivation (Lawler, 2001). Anambra State is known for its extensive temporary wetlands, especially at lowlands and across the plains of Niger and Omambala river which support continuous rice production (Agulue *et al.*, 2020), which has significantly impacted soil quality, stability (Nweke *et al.*, 2023), and nutrient dynamics (Zou *et al.*, 2024). Continuous cropping and high-yield expectations have escalated the use of agrochemicals, which have the potential to pollute underground water, which in many cases finds its way to domestic water use through boreholes (Mujahid *et al*., 2024). Research suggests that intensive agricultural practices, if unchecked, can lead to severe soil degradation (Bedolla-Rivera *et al.,* 2023), reduction in fertility, and consequent decline in crop yield (Haque *et al.,* 2023).

In wetland rice farming systems, particularly those in Anambra State, agrochemicals are often used without regulation, causing an imbalance in nutrient availability and disrupting soil health (Zhou *et al.*, 2024). Studies reveal that frequent and irregular application of fertilizers and pesticides in rice production often leads to the build-up of toxic residues (Shah *et al.,* 2024), soil acidity (Sharma *et al.*, 2022), and reduced microbial activity (Ezeokoli *et al.*, 2021), thereby threatening the sustainability of agricultural soils. Meanwhile, poor soil resource management practices, combined with the impacts of deforestation, have led to the gradual formation of savanna-like conditions where forested wetlands once thrived (Mandah *et al.,* 2024). Deforestation not only contributes to biodiversity loss but also alters the microclimate and reduces the organic matter critical for maintaining soil structure and fertility.

In Anambra State, there is a lack of dedicated soil monitoring and nutrient management frameworks, posing long-term risks to soil and environmental health and soil productivity. This, therefore, highlights the need to understand the dynamics of soil nutrients and soil degradation under continuous rice production, especially in temporary wetland ecosystems in Anambra State, where ecological stability is already fragile. Such insights are essential for making informed decisions on sustainable soil management that support both high productivity and environmental conservation.

This study therefore, aims to assess soil degradation and nutrient dynamics in soils under continuous rice cultivation in Anambra's wetlands; the specific objectives were to evaluate the effects of continuous rice production on selected soil physicochemical properties; investigate the impact of agrochemical usage on cadmium and zinc content of the study areas, and evaluate certain soil degradation indices in the temporary wetland areas of Anambra state.

MATERIALS AND METHODS

Study Areas

The study was carried out in continuous rice production lowland fields and adjacent 5-year-old fallow grasslands (control) in Atani, Ogbaru Local Government Area, and Odekpe, Anambra West Local Government Area, both in Anambra State. The study areas in Atani were located within 6° 0' 21.38" N, 6° 0' 21.65" N and 6° 45' 50.86" E; 6° 45' 51.42" E (Rice field); 6° 0' 17.56" N, 6° 0' 18.03" N and 6° 45' 50.87" E; 6° 45' 51.71" E (control). The study areas at Odekpe were located within 6° 30' 8.27" N, 6° 30' 8.39" N and 6° 41' 18.24" E; 6° 41' 18.62" E (Rice fields); 6° 30' 7.91" N, 6° 30' 8.21" N and 6° 41' 17.46" E, 6° 41' 17.92" E (control). Atani has an annual mean temperature of 27° C and annual mean rainfall of 1331mm, while Odekpe has a mean annual temperature of 26° C and annual mean rainfall of 1544mm. The study areas are usually saturated, stretching to late January, when a few patches of marshes, unlike the total submergence that is witnessed from late February till October. The areas have long become a derived savanna.

Soil sampling

Soils were randomly sampled in the rice fields, composited and replicated four (4 ×) times in each of active rice farms, as well as active fallow farms (5 years fallow) which served as control, and at two depths (0 – 15 cm and 15 -30 cm), making a total of thirty-six (36) disturbed soil samples. The disturbed soils were sampled with a soil auger and hand trowel. Undisturbed soil samples (36) were collected with a core (5cm diameter × 10cm height), with the help of a plastic head hammer at two depths as well (0 – 15, 15 – 30 cm). The undisturbed soils were carefully airdried, sieved with 2mm sieved, and properly labeled before being taken to the laboratory for analysis.

Laboratory Analysis

The physicochemical properties that were analyzed in the laboratory were, particle size distribution (Percentage sand, silt and clay), bulk density (BD), moisture content (MC), soil structural stability index (SSSI), pH, total nitrogen (TN), electrical conductivity (EC), organic carbon (OC), exchangeable acidity (Al^{3+} and H^+), exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+) effective cation exchange capacity (ECEC), available phosphorus (Av. P), selected heavy metals (Zn, Cd).

Particle size was determined using Bouyoucos method, as modified by Andres *et al*. (2014).

Bulk density was determined by the core method (Grossman and Reinsch, 2002).

$$Bulk\ density\ (BD) = \frac{\text{oven dry weight of soil}}{\text{Volume}} \quad (1)$$

Soil pH, 1:2.5 (aqueous suspension) soil, and distilled water were determined using a high-precision pH meter, as described by Thomas (1994).

Organic carbon was determined by the modified Walkley–Black wet digestion/oxidation method described by Nelson and Sommers (1996).

Total nitrogen was determined by the Micro Kjeldahl digestion method, as described by Allen (1989).

Exchangeable acidity (Al^{3+} and H^+) was determined titrimetrically as described by (Tan, 1998; Hesse, 1971).

Exchangeable bases (Ca, Mg, K, and Na) were extracted in neutral normal ammonium acetate (1N-NH_4OA_c); Calcium and Magnesium were determined by Atomic Absorption Spectrophotometer, while Potassium and Sodium were determined using a flame photometer, as described by (Schollenberger and Simon, 1945).

Effective cation exchange capacity was determined by the summation of Exchangeable bases and Exchangeable acidity.

Available phosphorus was determined using the Bray (I) method (Bray and Kurtz, 1945).

Selected heavy metals (Zn and Cd) were determined by double acid—nitric acid (HNO3) and Perchloric acid (HClO4) methods. The extracts were subjected to an atomic absorption Spectropotometer (AAS), using an appropriate hollow cathode lamp/wavelength (Watson and Isaac, 1990; Wright and Stuczynski, 1996).

Soil Degradation Index

Soil degradation index (SDI) was computed using the Weighted Average Method:

SDI = Σ (Normalized parameter score × Weight of parameter) …. (2)

SDI was evaluated and compared between the Rice field and the control sites at two depths for the two locations studied, on a scale of 0 – 1, 0 meaning less degradation, and 1 meaning high degradation.

Statistical Analysis

Data collected from the study were subjected to Analysis of variance (ANOVA) to determine the variation in soils of the rice field and control, as well as soil depths studied. Significant differences in the variations were determined using the least significant difference (LSD) at $p \leq 0.05$. The statistical package used was Excel 2021.

RESULTS AND DISCUSSION

Selected soil properties

The physicochemical properties of the studied soils are presented in Table 1a. The soils were predominantly silty clay across the studied soil, except at the rice field in Atani, which was silty loam, and clayey-loam at the topsoil of the control soil in Atani. Bulk density was highest (2.01 Mg/m^3) at 0 – 15 cm depth at Atani rice field, which could have been caused by compaction from farm machinery (Oduma *et al.*, 2018); bulk density was higher in the studied soils than what a healthy seasonal wetland soil would be (0.9 – 1.30 Mg/m^3) (Idris *et al*., 2019). pH was moderately acidic across the studied soil, ranging from 5.45 (at the control soil in Atani) to 6.00 (at the control soil in Odekpe). The pH values could have been because of the hydromorphic nature of the soils and the prolonged history of use of inorganic fertilizers and agrochemicals in the soils (Grybos *et al.*, 2009; Osinuga *et al.*, 2023). Organic carbon was higher at the rice fields than in the control soils, although the highest organic carbon was recorded at 0 – 15 cm soil depth in the control soil of Odekpe (2.22 %). The highest organic carbon in the topsoil of the control soil may have been caused by the accumulation of organic matter as a result of the hydromorphic nature of the soils (Steinmuller and Chambers, 2019). Aluminum was moderate across soils, ranging from 0.09 Cmol/kg to 1.11 Cmol/kg; hydrogen was also moderate across soils. The pH levels of the soils would have influenced moderate levels of Aluminum and hydrogen in the soil. Calcium levels were low across soils except at the rice field, 0-15 cm depth (5.53 Cmol/kg) and at the control soil, 0-15 cm depth (5.28 Cmol/kg), all in Odekpe. The low calcium level would have been because of the acidification of those soils, as reflected in the pH. Magnesium levels in the soils were low to moderate, with control soil having the highest value of magnesium (3.03 Cmol/kg) at 0-15 cm soil depth in Odekpe, whereas the lowest value of magnesium (1.21 Cmol/kg) was at the rice field, 0/15 cm depth in Atani. Potassium was low across the studied soil, ranging from 0.24 Cmol/kg to 0.43 Cmol/kg. Sodium levels were generally lower, although it was higher at rice fields in both Atani (0.18 Cmol/kg) and Odekpe (0.22 Cmol/kg), more than in control soils in Atani (0.10 Cmol/kg) and Odekpe (0.17 Cmol/kg). The higher values of sodium concentration in the studied rice fields would have been caused by inorganic fertilizers and other chemical inputs (Mohammed *et al.*, 2024). Effective cation exchange capacity was low across soils except at the control soil, 15 – 30 cm depth (10.2 Cmol/kg) in Odekpe, which was moderate. Available phosphorus was low across soils except in Odekpe, at the rice field, 0-15 cm soil (12.8 mg/kg), and at the control, 0-15 cm soil (12.1 mg/kg), which were moderate. The low phosphorus across soils would have been a reflection of the fixation of phosphorus by aluminum in acidic soils (Mesele *et al.*, 2024). Cadmium concentration was within safe limits except at the rice field, 15 – 30 cm depth (0.38 mg/kg) in Odekpe, which was slightly above the FAO safe limit (WHO/FAO, 2001). The high cadmium recorded in the rice field must have been caused by inorganic fertilization and pesticide application (Grant and Sheppard, 2008; Khatun *et al.*, 2022). Zinc concentrations were low across the studied soils, although it appears to be more in rice fields than in the control soils. The interaction and the mean significant difference of the studied soil properties are presented in Table 1b.

Table 1a: Physicochemical properties of the studied soil

Location	Land use	Depth (cm)	Sand	Silt (gkg^{-1})	Clay	TC	BD (Mg/m^3)	pH	OC (%)	Al^{3+}	H^+	Ca^{2+}	Mg^{2+} (Cmol/kg)	K^+	Na^+	ECEC	Av.P	Cd (mg/kg)	Zn
Atani	Rice Field	0-15	271	571	158	SL	2.01	5.55	1.18	0.82	0.48	2.45	1.21	0.26	0.13	5.35	2.44	0.01	0.44
		15-30	275	570	155	SL	1.82	5.61	1.22	0.72	0.57	3.50	1.55	0.26	0.18	6.78	3.31	0.15	0.33
	Control	0-15	260	359	381	CL	1.65	5.54	1.84	1.11	0.58	3.14	2.43	0.24	0.10	7.60	7.03	0.02	0.18
		15-30	128	423	449	SC	1.70	5.45	0.93	0.73	0.50	2.01	1.76	0.24	0.12	5.36	1.57	0.02	0.48
Odekpe	Rice Field	0-15	89	403	508	SC	1.29	5.60	2.17	0.18	0.83	5.53	2.53	0.43	0.22	9.72	12.8	0.09	0.42
		15-30	54	448	498	SC	1.88	5.80	1.07	0.09	0.75	3.18	1.78	0.28	0.19	6.27	5.22	0.38	0.52
	Control	0-15	38	356	606	SC	1.39	6.00	2.22	0.19	1.05	5.28	3.03	0.42	0.23	10.2	12.1	0.12	0.45
		15-30	17	400	583	SC	1.63	5.78	1.57	0.14	0.85	3.43	1.78	0.24	0.17	6.61	6.15	0.05	0.44

TC= textural class, BD = bulk density, OC = Organic carbon, SL = Silty Loam, CL = Clay Loam, SC = Silty Clay, Al = Aluminum, H = Hydrogen, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, ECEC = Effective Cation Exchange Capacity, Av.P = Available Phosphorus, Cd = Cadmium, Zn = Zinc

Table 1b: Interaction of Physicochemical properties of the studied soil

Location	Land use	Depth (cm)	Sand	Silt (gkg^{-1})	Clay	BD (Mg/m^3)	pH	OC (%)	Al^{3+}	H^+	Ca^{2+}	Mg^{2+} (Cmol/kg)	K^+	Na^+	ECEC	Av.P	Cd (mg/kg)	Zn
Atani	Rice Field	0-15	271	571	158	2.01	5.55	1.18	0.82	0.48	2.45	1.21	0.26	0.13	5.35	2.44	0.01	0.44
		15-30	275	570	155	1.82	5.61	1.22	0.72	0.57	3.50	1.55	0.26	0.18	6.78	3.31	0.15	0.33
		LSD (0.05)	NS	NS	NS	NS	NS	NS	0.09	NS	0.54	NS	NS	0.03	0.91	NS	0.03	NS
	Control	0-15	260	359	381	1.65	5.54	1.84	1.11	0.58	3.14	2.43	0.24	0.10	7.60	7.03	0.02	0.18
		15-30	128	423	449	1.70	5.45	0.93	0.73	0.50	2.01	1.76	0.24	0.12	5.36	1.57	0.02	0.48
		LSD (0.05)	92.2	NS	NS	NS	NS	0.44	0.09	NS	0.54	0.49	NS	NS	0.91	2.36	NS	0.11
	Rice Field	0-15	271	571	158	2.01	5.55	1.18	0.82	0.48	2.45	1.21	0.26	0.13	5.35	2.44	0.01	0.44
		Control	260	359	381	1.65	5.54	1.84	1.11	0.58	3.14	2.43	0.24	0.10	7.60	7.03	0.02	0.18
		LSD (0.05)	NS	67.9	84.5	0.26	NS	0.44	0.09	0.09	0.54	0.49	NS	0.03	0.91	2.36	NS	0.11
	Rice Field	15-30	275	570	155	1.82	5.61	1.22	0.72	0.57	3.50	1.55	0.26	0.18	6.78	3.31	0.15	0.33
		Control	128	423	449	1.70	5.45	0.93	0.73	0.50	2.01	1.76	0.24	0.12	5.36	1.57	0.02	0.48
		LSD (0.05)	92.2	67.9	84.5	NS	NS	NS	NS	NS	0.54	NS	NS	0.03	0.91	NS	0.03	0.11
Odekpe	Rice Field	0-15	89	403	508	1.29	5.60	2.17	0.18	0.83	5.53	2.53	0.43	0.22	9.72	12.8	0.09	0.42
		15-30	54	448	498	1.88	5.80	1.07	0.09	0.75	3.18	1.78	0.28	0.19	6.27	5.22	0.38	0.52
		LSD (0.05)	NS	NS	NS	0.20	NS	0.29	NS	NS	1.13	0.48	0.09	NS	1.60	3.13	0.13	NS
	Control	0-15	38	356	606	1.39	6.00	2.22	0.19	1.05	5.28	3.03	0.42	0.23	10.2	12.1	0.12	0.45
		15-30	17	400	583	1.63	5.78	1.57	0.14	0.85	3.43	1.78	0.24	0.17	6.61	6.15	0.05	0.44
		LSD (0.05)	NS	NS	NS	0.20	NS	0.29	NS	0.21	1.13	0.48	0.09	0.03	1.60	3.13	NS	NS
	Rice Field	0-15	89	403	508	1.29	5.60	2.17	0.18	0.83	5.53	2.53	0.43	0.22	9.72	12.8	0.09	0.42
		Control	38	356	606	1.39	6.00	2.22	0.19	1.05	5.28	3.03	0.42	0.23	10.2	12.1	0.12	0.45
		LSD (0.05)	35.5	NS	27.7	NS	0.26	NS	NS	NS	NS	0.48	NS	NS	NS	NS	NS	NS
	Rice Field	15-30	54	448	498	1.88	5.80	1.07	0.09	0.75	3.18	1.78	0.28	0.19	6.27	5.22	0.38	0.52
		Control	17	400	583	1.63	5.78	1.57	0.14	0.85	3.43	1.78	0.24	0.17	6.61	6.15	0.05	0.44
		LSD (0.05)	35.5	46.6	27.7	0.20	NS	0.29	NS	NS	NS	NS	NS	NS	NS	NS	0.13	NS

TC= textural class, BD = bulk density, MC = moisture content, OC = Organic carbon, SSSI = soil structural stability index, SL = Silty Loam, CL = Clay Loam, SC = Silty Clay, Al = Aluminum, H = Hydrogen, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, ECEC = Effective Cation Exchange Capacity, Av.P = Available Phosphorus, Cd = Cadmium, Zn = Zinc

Atani rice field (between 0 -15 cm and 15-30 cm depth): Sand content remained similar between depths (271 gkg^{-1} at 0-15 cm and 275 gkg^{-1} at 15-30 cm). Silt and clay content also did not show any significant difference ($p \leq 0.05$). bulk density was slightly lower at 15 – 30 cm (1.82Mg/m^3) compared to 2.01 Mg/m^3 at 0 – 15 cm, but the difference was not significant. The minimal texture variation suggests similar depositional history and limited pedogenic differentiation at depth. Soil pH increased slightly at 15 – 30 cm (5.61 compared to 5.55), although with no significant difference ($p \leq 0.05$), possibly due to reduced leaching of basic cations at depth. Ca^{2+} was significantly higher ($p \leq 0.05$) at 15 – 30 cm (3.50 Cmol/kg) compared to 2.45 Cmol/kg at 0-15 cm. ECEC increased with depth and showed a significant difference (6.78 Cmol/kg) at 15 – 30 cm, likely due to the accumulation of clay minerals at depth. Available phosphorus increased from 2.44 $mgkg^{-1}$ at 0-15 cm to 3.31 $mgkg^{-1}$ at 15 -30 cm, though no significant difference. Cadmium (Cd) was significantly higher at 15-30cm (0.15 $mgkg^{-1}$), indicating potential accumulation from agrochemicals leaching downwards.

Atani control soil (between 0-15cm and 15-30cm depth): Sand content was significantly lower at 15 – 30cm (128 gkg^{-1}). The decline suggests an eluviation-illuviation process where finer particles accumulate at depth. Soil pH remained similar at both depths. Organic carbon decreased significantly at 15-30cm (0.93 %), suggesting organic matter depletion at depth due to limited biological activity. ECEC was significantly lower at 15-30cm (5.36 Cmol/kg), indicating reduced nutrient retention capacity, likely due to decreased organic matter. Available phosphorus was significantly lower at 15-30 cm (1.57 mg/kg), indicating leaching. Cd remained similar at both depths (0.02 mg/kg), showing minimal mobility in the control soils.

0-15 cm depth in Atani (between rice fields and control soil): The rice field had significantly higher silt content (571 gkg^{-1}) than the control (359 gkg^{-1}) but significantly lower clay content (158 gkg^{-1}). Bulk density was significantly higher in rice fields (2.01 Mg/m^3), indicating compaction from continuous cropping as well as machinery activities. Organic carbon was significantly lower in rice fields (1.18 %) than in control soil (1.84 %), showing organic matter depletion from continuous cropping.

Soil degradation Index

Parameter that was considered in their order of degradation capability seasonal floodplains were cadmium (Cd), organic carbon (OC), pH, zinc (Zn), available phosphorus (Av.P), potassium (K), calcium (Ca), and magnesium (Mg). The average weighting of these properties which must be equal to 1, was presented in Table 2.

Table 2: Average weight of soil properties in this study

Soil properties	Cd	OC	pH	Zn	Av.P	K	Ca	Mg
Average weight	0.25	0.20	0.15	0.15	0.10	0.06	0.05	0.04

Cd = cadmium, OC = organic carbon, Zn = zinc, Av.p = available phosphorus, K = potassium, Ca = calcium, Mg = magnesium

Soil parameters that were considered for SDI, were given normalized scores, which was presented in Table 3. Normal score apportioned was on a scale of 0 – 1 based on the distance of their analytical values or concentrations from the optimal range (WHO/FAO, 2001; Zondo, 2021).

Table 3: Normalized score for soil parameters considered for SDI

Location	Land use	Soil depth (cm)	pH	OC	Ca	Mg	K	Av.P	Cd	Zn
Atani	Rice field	0-15	0.74	0.30	0.49	0.40	0.33	0.08	0.01	0.009
		15-30	0.75	0.31	0.70	0.52	0.33	0.11	0.21	0.007
	Control	0-15	0.74	0.46	0.63	0.81	0.30	0.23	0.03	0.004
		15-30	0.73	0.23	0.40	0.59	0.30	0.05	0.03	0.011
Odekpe	Rice field	0-15	0.75	0.54	1.00	0.84	0.54	0.43	0.13	0.009
		15-30	0.77	0.27	0.64	0.59	0.35	0.17	0.54	0.011
	Control	0-15	0.80	0.56	1.00	1.00	0.53	0.40	0.17	0.01
		15-30	0.77	0.39	0.69	0.59	0.30	0.21	0.07	0.01

OC = organic carbon, Ca = calcium, Mg = magnesium, K = potassium, Av.P = available potassium, Cd = cadmium, Zn = zinc.

SDI of the seasonal wetland soils at two locations (Atani and Odekpe), two land uses (Rice field, Control soil), and two soil depths (0-15 cm and 15-30cm), are represented in Figure 1. Higher SDI indicates greater soil degradation.

In Atani, the SDI for the rice field was 0.264 at 0-15 cm depth, and 0.316 at 15-30 cm depth, while the control soils showed higher degradation at 0-15 cm depth (0.317), but lower SDI at 15-30 cm depth (0.231). In Odekpe, rice field had SDI of 0.413 at 0-15cm, and 0.40 at 15-30cm depth, both of which were slightly lower than the control's SDI at 15 cm depth (0.438), but much higher than the 15-30 cm depth (0.206). Control soils at both Atani and Odekpe maintained a consistent pattern of less SDI at the 15-30 cm depth, while rice fields at both locations showed inconsistent SDI. The higher SDI values at control soils in 0-15 cm depth may have been caused by surface level disturbances (Wang *et al.*, 2024). In contrast, the inconsistent SDI at rice fields may have been caused by tillage operations, fertilizer, and agrochemical use (Nath *et al.,* 2023).

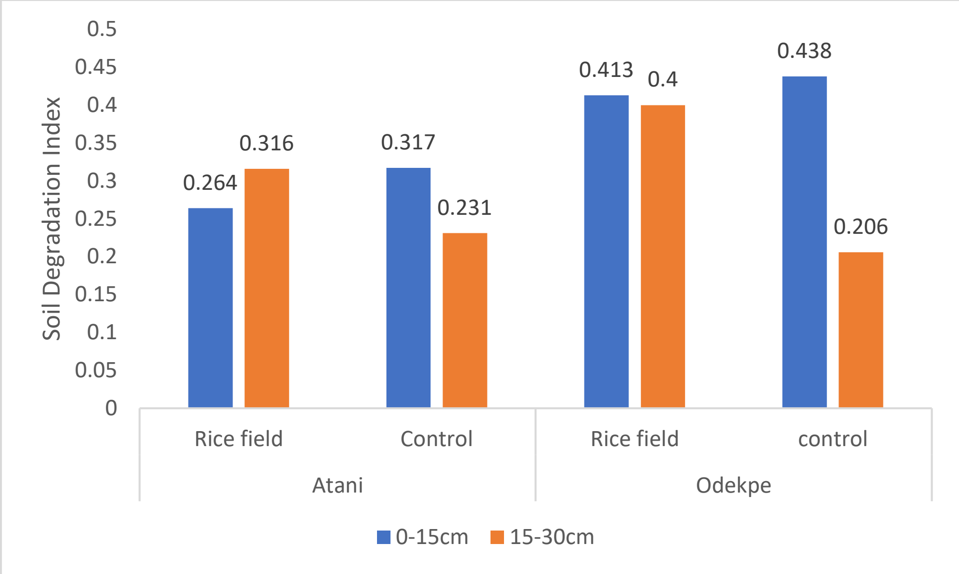

Figure 1: Soil degradation Index of the studied soils at two soil depths

CONCLUSION

From the study, it was shown that continuous rice farming impacted soil quality, increasing bulk density and reducing organic carbon, particularly in the 0-15 cm soil depth. Bulk density in rice fields was as high as 2.01 Mg/m^3 (Atani, 0-15 cm), and organic carbon was lower in rice fields compared to control soils. Cadmium concentration remained within safe limits in most studied soils, except in Odekpe rice field at 15 – 30 cm depth (0.38mg/kg). zinc was generally low, but higher in the rice field than control soils. Soil degradation index (SDI) values were higher in rice fields (0.413 in Odekpe, 0-15 cm) than in control soils, particularly at 0-15 cm, indicating more intense degradation. Control soils consistently showed lower SDI at 15-30 cm depth (0.231 in Atani, 0.206 in Odekpe), reflecting protection from soil surface disturbance and better subsurface resilience. In contrast, rice fields showed an inconsistent SDI pattern.

REFERENCES

Agulue E., Okoye N., Oji S. I., Nwocha K. F. (2020). Assessment of land use and land cover changes and its implications to flooding along Omambala flood plain, Anambra state. *International Journal of Geography and Geology*. Vol. 9(1): 71 – 83. https://doi.org/10.18488/journal.10.2020.91.71.83

Allen, S.E., 1989. Chemical Analysis of Ecological Materials. Blackwell Scientific Publications, Oxford. *Blackwell Scientific Publication 2nd edition.* 209 -311.

Andres N. B, Ana V. S, Leonardo P., Dborah T., Daniel B., Raquel M., Andriana G. (2014). Soil texture analysis using a hydrometer: modification of the Bouyoucos method. *Ciencia Investigacion Agraria*. 41 (2): 263 – 271.

Bedolla-Rivera H. I., Negrete-Rodriguez M. X., Gamez-Vazquez F. P., Alvarez-Bernal D., Conde-Barajas E. (2023). Analyzing the impact of intensive agriculture on soil quality: a systemic review and global meta-analysis of quality indexes. *Agronomy*. Vol. 13(8), 2166. https://doi.org/10.3390/agronomy13082166

Bray, R. H., and Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59, 39–45.

Ezeokoli O. T., Nuaila V. N. A., Obieze C. C., Muetanene B. A., Fraga I., Tesinde M. N., Ndayiragije A., Coutinho J., Melo A. M. P., Adeleke R. A., Ribeiro-Barros A. I., Fangueiro D. (2021). Assessing the impact of rice cultivation on off-season period on dynamics of soil enzyme activities and bacterial communities in two agro-ecological regions of Mozambique. *Agronomy*. 11(4), 694. https://doi.org/10.3390/agronomy11040694

Grant C. A., and Sheppard S. C. (2008). Fertilizer impacts on cadmium availability in agricultural soils and crops. Human and Ecological Risk Assessment. 14 (2): 210-228

Grossman, R.B., Reinsch, T.G., 2002. Bulk density and linear extensibility. In: Methods of Soil Analysis: Part 4 Physical Methods, 5.4. Dane, J.H., Topp, G.C. (Eds.). SSSA Book Series 5. *Soil Science Society of America*. Madison,Wisconsin, USA. pp. 201-225. DOI: https://doi.org/10.2136/sssabookser5.4.c9

Grybos M., Davranche M., Gruau G., Petitjean P., and Pedrot M. (2009). Increasing pH drives organic matter solubilization from wetland soils under reducing conditions. Geoderma, 154(1-2): 13 -19. https://doi.org/10.1016/j.geoderma.2009.09.001Get rights and content

Haque M. A., Kabir M. E., Akhter S., Hoque M. F., Sarker B. C., Anik M. A., Ahmed A., Pranto S., Sima A. S., Lima F., Jahiruddin M., Hossain M. B., Haque M. E., Satter M. A., William R. (2023). Crop Nutrient Limitations in Intensified Cropping Sequences on the Ganges Delta Coastal Floodplains. *Journal of Soil Sci and Plant Nutr* 23, 1996–2006. https://doi.org/10.1007/s42729-023-01154-1

Hesse, P.R. (1971). Soil Chemical Analysis, Chemical Publishing Co., New York. Pp.120-309.

Idris S., Lawal H. M., Maiyaki, Mahmud A. T, and Adamu M. (2019). Influence of various land use systems on selected soil productivity parameters of wetland soils. FUDMA Journal of Sciences. 3(2): 295-301.

Khatun J., Intekhab A., and Dhak D. (2022). Effect of uncontrolled fertilization and heavy metal toxicity associated with arsenic, lead and cadmium, and possible remediation. Toxicology, 477, 153274.

Lawler, S. P. (2001). Rice Fields as Temporary Wetlands: A Review. *Israel Journal of Zoology*, 47(4), 513–528. https://doi.org/10.1560/X7K3-9JG8-MH2J-XGX1

Mandah V. P., Tematio P., Onana A. A., Fiaboe K. K. M., Arthur E., Giweta M. H., Ndango R., Silatsa F. B. T., Voulemo D. D. I., Biloa J. B., Nguemezi C., Masso C. (2024). Variability of soil organic carbon and nutrient content across land uses and agriculturally induced land use changes in the forest-savnna transition zone of Cameroon. *Geoderma Regional.* Vol. 37, e00808. https://doi.org/10.1016/j.geodrs.2024.e00808

Mesele S. A., Ajiboye G. A., and Talbot J. (2024). Edaphic factors modulating pgosphorus availability in lowland rice systems in Nigeria. Communications in Soil Science and Plant Analysis. 55(19): 2935-2952. https://doi.org/10.1080/00103624.2024.2379593

Mohammed S. E., Aderibigbe D. O., Saeed M. D., Neland S. M., Musa A., and Ayanda O. S. (2024). Seasonal quality and statistical assessement of physicochemical properties and base saturation of Hadejia-Nguru wetland soils, Northwest/Eastern Nigeria. Water practice and Technology, 19 (3): 761.

Mujahid, S. N., Bala, M. U., Isyaku, A. M., Abba, M., Sani, S., Aliyu, H., Muhammad, A., Jamilu, Y., Shafiu, S., & Umar, M. Y. (2024). Evaluation of specific heavy metals in drinking water consumed in Yar'akwa quarters, Na'ibawa, Tarauni LGA, Kano State, Nigeria. *Fudma journal of sciences*, *8*(3), 208 - 213. https://doi.org/10.33003/fjs-2024-0803-2470

Nath, A., Bhuyan, P., Gogoi, N., and Deka, P. (2023). Pesticides and chemical fertilizers: Role in soil degradation, groundwater contamination, and human health. Xonobiotics in Urban Ecosystems, Springer Nature. Pp 131 -160. https://doi.org/10.1007/978-3-031-35775-6_7

Nelson D. W., Sommers L. E (1996). Total carbon, total organic carbon, and organic matter. In 'Methods of soil analysis. Part 3: Chemical methods. *Agronomy Monograph No. 9. (Ed. DL Sparks)* pp. 961–1010. DOI: https://doi.org/10.2136/sssabookser5.3.c34

Nweke I., Ijeh A., Okafor J., Ngonadi E., Igili D. (2023). Aggregation status of four Nigerian soil classes tested under different water soaking times. *Danish Scientific Journal.* No. 72, 3 – 13. y https://doi.org/10.5281/zenodo.7997208

Oduma O., Oluka S. I., and Eze P. C. (2018). Effect of soil physical properties on the performance of agricultural field machineries in the tropical region of Nigeria. CIGR Journal. Open access, 20 (1): 25.

Okafor M. J., Chidozie E. I. (2016). Impact of different soil amendments on crude oil-polluted soil and performance of maize Agrokhimiya i gruntoznavstvo. VIP. 85. - P. 19-27. http://nbuv.gov.ua/UJRN/ agrohimigrn_2016_85_5

Okafor M. J., Nnabuihe E. C., Madueke C. O., Egboka T. N., Apalowo O. A., Nwaiwu C. J., Ernest C. I., Ezeonu C. J. (2024). Assessment of carbon and nitrogen stock in soils of cassava and rice farms in the derived savanna of Anambra state, southeastern Nigeria. *Agriculture, Food and Natural Resource Journal.* Vol. 3(1): 14 -23. https://www.doi.org/10.5281/zenodo.13697979

Osinuga O. A., Aduloju A. B., and Oyegoke C. O. (2023). Impact of agrochemical application on soil quality indicators and trace elements levels of wetlands under different uses. Journal of trace elements and minerals. Vol. 5, 100090. https://doi.org/10.1016/j.jtemin.2023.100090

Pieri C (1992). Fertility of soils: A future for farming in the West African savannah. *Springer Series in Physical Environment. (Springer-Verlag: Berlin).* DOI: https://doi.org/10.1007/978-3-642-84320-4

Schollenberger, C. J., and Simon, R. H. (1945). Determination of exchange capacity and exchangeable bases in soil-ammonium acetate method. Soil Science, 59(1), 13–24.

Shah S. S., Dam J. V., Singh A., Kumar S., Kumar S., Bundela D. S., Ritsema C. (2024). Impact of irrigation, fertilizer, and pesticide management practices on groundwater and soil health in the rice-wheat cropping system: a comparison of conventional, resource conservation technologies and conservation agriculture. *Research Square*. https://doi.org/10.21203/rs.3.rs-4151237/v1.

Sharma L.K., Naik R. (2024). Wetland Ecosystems. *Springer, Singapore*. pp. 3 – 32. https://doi.org/10.1007/978-981-97-5069-6_1

Sharma, U.C., Datta, M., Sharma, V. (2022). Land Use and Management. In: Soils in the Hindu Kush Himalayas. Geography of the Physical Environment. *Springer, Cham.* pp. 295 – 462. https://doi.org/10.1007/978-3-031-11458-8_7

Steinmuller H. E. and Chambers L. G. (2019). Characterization of coastal wetland soil organic matter: Implications for wetland submergence. Science of the total environment, 677: 648 – 659. https://doi.org/10.1016/j.scitotenv.2019.04.405

Thomas, M.F., 1994. Geomorphology in the Tropics: A Study of Weathering and Denudation in Low Latitudes. John Wiley, New York.

Wang, C., Zhang, G., and Chen, S. (2024). Soil surface roughness of sloping croplands affected by land degradation degree and residual of incorporated straw. Geoderma, 444: 116872. https://doi.org/10.1016/j.geoderma.2024.116872

Watson, M. E., and Isaac, R. A. (1990). Analytical instruments for soil and plant analysis. In R. L. Westerman (Ed.), Soil Testing and Plant Analysis. Soil Science Society of America, Madison, WI. 3rd ed., pp. 691–740

WHO/FAO. Codex alimentarius commission. Food additives and contaminants. Food Standards Programme, ALINORM 10/12A. Joint FAO/WHO; 2001. Available: https://doi.org/10.13140/RG.2.1.4910.2560

Wright, R. J., and Stuczynski, T. I. (1996). Atomic absorption and flame emission spectrometry. In D. L. Sparks (Ed.), Methods of Soil Analysis, Part 3, Chemical Methods. Soil Science Society of America, Madison, WI. SSSA Book Series No. 5, pp. 65–90

Zhou W., Li M., Achal V. (2024). A comprehensive review on environmental and human health impacts of chemical pesticides usage. *Emerging Contaminants.* Vol. 11(1), 100410. https://doi.org/10.1016/j.emcon.2024.100410

Zondo S. (2021). Maximum residue limits (MRLs) of heavy metals in agricukltural soil, irrigation water and crops. Research and Technology Bulletin. Pp. 2.

Zou, Y., Tang, X., Cui, L, Li H., Zhao X., Zhai X., Li J., Wang J., Wang R., Li W. (2024). Analysis of coupled wetland soil–plant ecological stoichiometric characteristics of carbon, nitrogen, and phosphorus under different disturbance intensities. Plant Soil. https://doi.org/10.1007/s11104-024-07031-9