International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print); 2222-5234 (Online)
Website: https://www.innspub.net
Email contact: info@innspub.net
Vol. 27, Issue: 2, p. 270-279, 2025

RESEARCH PAPER OPEN ACCESS

Physico-chemical characterization of soils in two peri-urban lowlands: Implications for the sustainability of rice cultivation in Korhogo (northern Côte d'Ivoire)

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Key words: Inland valleys, Rice cultivation, Soil fertility, Sustainable land management, Physico-chemical properties

DOI: https://dx.doi.org/10.12692/ijb/27.2.270-279 Published: August 25, 2025

ABSTRACT

In a context of heavy dependence on rice cultivation and intensifying land pressures in Ivorian peri-urban areas, this study analyzes the physico-chemical properties of two lowlands (Logokaha and Natio) located on the outskirts of Korhogo. The aim is to identify edaphic constraints likely to limit rice-growing productivity, and to propose sustainable management options. The methodology is based on stratified sampling according to longitudinal (upstream, median, downstream) and transverse (center, hydromorphic zones) topographical units. Samples were subjected to granulometric and chemical analysis, assessing texture, pH, nitrogen, phosphorus, potassium, organic matter and cation exchange capacity (CEC). The results reveal considerable textural variability between sites and topographical units. The soils of Logokaha, with their silty-clay texture, offer better rice-growing potential than those of Natio, which are sandier. Chemically, both lowlands have moderate acidity but marked deficits in total nitrogen, assimilable phosphorus and organic matter. CEC is generally low, reflecting limited fertility. In addition, some areas show high sodium levels, representing a risk of structural degradation, especially in hydromorphic conditions. We recommend boosting fertility with organic inputs (compost, manure) and targeted mineral fertilizers. Acidity correction and optimized water management should complement these interventions to sustainably improve the productivity and agroecological resilience of the lowlands studied.

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INTRODUCTION

In West Africa, lowland areas are strategic agroecological spaces for rice production, particularly during the dry season. In Côte d'Ivoire, rice cultivation in lowlands is undergoing significant development, particularly around large urban areas such as Korhogo, in the north of the country. These peri-urban ecosystems are increasingly in demand due to population growth and food demand, intensifying pressure on the soil. However, sustainable use of these environments requires in-depth knowledge of their soil characteristics and their capacity to store organic carbon, an essential element for soil fertility and combating climate change (Liniger, 2011 ; Koné *et al.*, 2022). Lowland soils generally have particular physico-chemical properties, linked to their hydromorphy, fine texture, high acidity and high organic matter content. These conditions often favor good short-term agricultural productivity, but the sustainability of this fertility depends on the management of cultivation practices. In Korhogo, where arable land is gradually being taken over by urbanization, Peri-urban rice growing is becoming a subsistence solution for many households (Kanaté, 2022). However, scientific data on soil quality and organic carbon stocks in these lowlands remain scarce, making any sustainable management strategy difficult. The question is therefore: what are the physico-chemical properties of Korhogo's peri-urban lowland soils, and to what extent do they constitute effective organic carbon reservoirs? In other words, is current rice-growing on an ecologically sustainable basis, or does it run the risk of depleting soil fertility reserves in the medium term? A better understanding of soil characteristics will enable us to propose farming practices that promote the resilience of rice-growing systems. We hypothesize that Korhogo's peri-urban lowlands have significant organic carbon stocks due to their hydromorphy and organic matter accumulation, but that this richness is threatened by unsustainable intensive cropping practices. Thus, a rigorous soil assessment will help inform technical and policy choices for sustainable urban agriculture. The general aim of this study is therefore to characterize the physicochemical properties of soils and assess organic carbon stocks in two peri-urban lowlands of Korhogo, in order to analyze the implications for the sustainability of rice cultivation. Specifically, the aim will be to: (i) determine the physical and chemical characteristics of soils and estimate organic carbon stocks in the different topographical sections of two peri-urban lowlands in the town of Korhogo in northern Côte d'Ivoire, in order to propose guidelines for sustainable rice growing based on the conservation of soil resources.

MATERIALS AND METHODS

Study sites

The study was conducted in the Korhogo region of northern Côte d'Ivoire, between 9°20' and 10°10' north latitude and 5°20' and 6°10' west longitude. The region belongs to the SudanoGuinean climatic zone, characterized by a rainy season from May to October and a dry season from November to April. Average annual rainfall is between 1,200 and 1,400 mm, with an average temperature of around 27°C (Alphonse *et al.*, 2020). Two peri-urban lowlands were selected for this study: Logokaha and Natio, located near Korhogo city center.

These sites (Fig. 1) were chosen for their representativeness in terms of cropping intensity, accessibility and agricultural pressure exerted by peri-urban rice cultivation.

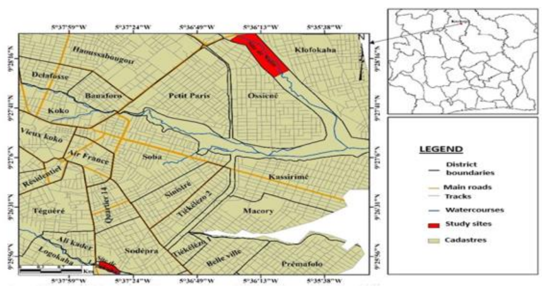
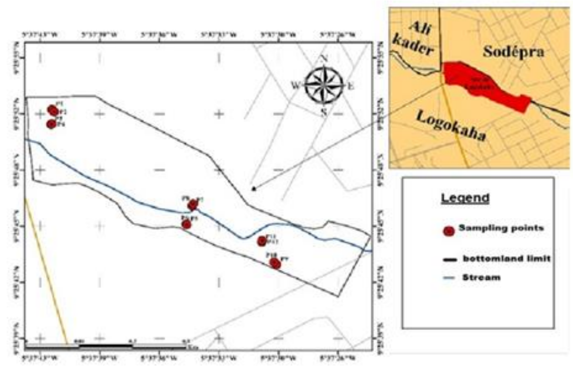


Fig. 1. Representative map of study sites

Soil sampling for physico-chemical analysis

Two representative sites were selected for this study: Logokaha and Natio (Fig. 1). Soil sampling was carried out according to a stratified strategy (Fig. 2A and 2B) at depth, targeting two standard horizons (0-20 cm and 20-40 cm), with the aim of highlighting the vertical variability of edaphic characteristics. Transverse transects were laid out along three longitudinal segments representative of each lowland, so as to cover the diversity of topographical microenvironments, from hydromorphic peripheral zones to the central zone.



A: Sampling device in Natio lowland, B: Sampling device in Logokaha lowland

Fig. 2. Sampling devices in the Natio and Logokaha lowlands

At each site, samples were taken at using an Edelman auger, a tool adapted to hydromorphic soils that causes little disturbance to soil structure. Samples from each depth of each sampling level were homogenized in the field to form a composite sample, ensuring adequate vertical representativeness. Each composite sample was then packaged in a clean plastic bag, accurately labeled and transported to the laboratory under conditions that ensured physico-chemical stability. In all, six composite samples were taken from each site, making a total of twelve samples for the two lowlands studied.

Laboratory physico-chemical soil analyses

In the laboratory, the samples were prepared and sieved to 2 mm, allowing isolation of the fine soil fraction for physico-chemical analysis. Granulometric analysis was carried out using the classic Robinson pipette method described by Gee and Bauder (1986). Organic carbon content was determined using the Walkley and Black method (Nelson and Sommers, 1982).

Total nitrogen was determined using the Kjeldahl method (Bremner, 1996), involving acid digestion of nitrogenous matter, followed by distillation and titration of the ammonia released. This approach makes it possible to assess the overall reserve of organic and inorganic nitrogen available to plants. Exchangeable bases, namely calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^{+}), were extracted using an ammonium acetate solution buffered to pH 7.0. Ca^{2+} and Mg^{2+} cations were quantified by atomic absorption spectrometry, while potassium was measured by flame emission spectrometry. These analyses characterize the soil's cation exchange capacity and chemical fertility potential. Soil pH was measured with an electronic pH meter, using a soil-water suspension prepared in a mass ratio of 1/2.

Agronomic interpretation and decision-making based on physico-chemical soil analyses

The agronomic interpretation of the soil analysis results from this study is based on a comparison of the observed nutrient levels with recognized critical thresholds for rice cultivation (Becker and Johnson, 1999). These thresholds represent the minimum concentrations necessary for the proper development of rice (*Oryza sativa* L.), below which nutritional deficiencies appear. Their value varies according to soil type, cropping method and agro-ecological conditions (Dobermann and Fairhurst, 2000).

The soil fertility of the lowlands studied was assessed by comparing the analytical results with the standard granulometric and chemical reference scales for rice cultivation.

Normative values for interpreting and deciding on the physico-chemical characteristics of the soil for optimal fertilization in rice cultivation

Tables 1 and 2 shows the granulometric and chemical interpretation scales for ricegrowing soils in the lowlands studied.

Table 1. Granulometric interpretation scale

Soil texture	Clay (%)	Silt (%)	Sand (%)	Suitability for rice cultivation
Silty-clay	20-35	30-50	20-40	Very favorable: good water retention, stable structure
Silty-clay	25-40	30-50	20-35	Very favorable: balanced, ideal for flooding
Silty	< 20	> 60	< 20	Acceptable: risk of capping, low cohesion for flooding
Sandy-silty	15	25-40	45-60	Unfavorable: poor water retention
Sandy	< 10	< 20	> 70	Unfavorable: high percolation, poor water management

Source: Bouman *et al.* (2007)

Table 2. Soil chemistry interpretation scale for rice cultivation

Parameter	Critical threshold	Remarks	References
Total nitrogen (Nt)	0.2 - 0.5 %	Low if < 0.2	Fageria (2007); Dobermann and Fairhurst (2000)
Phosphorus (P)	7 - 10 ppm	Probable deficiency if < 7 ppm	Fageria (2007); Dobermann and Fairhurst (2000)
Potassium (K)	175 - 200 ppm	Recommended intake if < 175 ppm	Fageria (2007); Dobermann and Fairhurst (2000)
Carbon (C org)	1.5 - 2.0 %	Low fertility if < 1%.	Dobermann and Fairhurst (2000)
Organic matter (OM)	2 - 3.5 %	Good fertility above 2%.	Brady and Weil (2017)
pH (H_2O)	5.5 - 6.5	Optimal for rice cultivation	FAO (2003); Breemen and Moormann (1978)
CEC	≥ 10 cmol(+)/kg	Affects nutrient availability	Fageria (2007); Brady and Weil (2017)
Calcium (Ca^{2+})	≥ 2000 ppm	Rarely limiting	Fageria (2007); Dobermann and Fairhurst (2000)
Magnesium (Mg^{2+})	≥ 120 ppm	Recommended intake if < 120 ppm	Fageria (2007); Dobermann and Fairhurst (2000)
Sodium (Na)	0.3 - 0.7	Deficiency if < 10 ppm	Fageria (2007); Bado *et al.* (2018)
Zinc (Zn)	≥ 1 ppm	Highly sensitive in rice cultivation	Dobermann and Fairhurst (2000); Alloway (2008)
Iron (Fe)	≥ 4 ppm	Frequent deficiency in calcareous soils	Dobermann and Fairhurst (2000); Alloway (2008)

Statistical analysis

An analysis of variance (ANOVA) was performed using XLSTAT software, version 2019, to determine the mean distribution of nutrients in the studied lowland soils according to longitudinal topographic units. Means were separated at the 5% significance level.

RESULTS

Analysis of physical characteristics of lowland soils

Table 3 below shows the granulometric characteristics and textural classes of the Natio and Logokaha lowlands. In the lowlands studied, analysis of the granulometric characteristics shows that the distribution of fractions varies according to longitudinal (upstream, median, downstream) and transverse (hydromorphic zone-ZH and center of lowland-CBF) topographical positions, reflecting the pedogenetic and hydrological processes in place.

Analysis of this table shows a predominance of silty textures in both lowlands. However, sandyclayey-silty and clayey-silty textures are observed respectively in the Logokaha lowland upstream in the hydromorphic zone and in the Natio lowland in the median at the center of the lowland.

Analysis of chemical characteristics of lowland soils

Comparative pH analysis of Logokaha and Natio soils according to topographical units

The pH values presented indicate edaphic conditions that are generally suitable for rice cultivation in the two lowlands studied. Nevertheless, the soils located upstream and in the hydromorphic zones of the median and center of the Logokaha lowland show pH values between 6 and 6.1, slightly closer to neutrality, compared with those of Natio, where the pH values recorded upstream and in the center of the median and downstream are more acidic, around 5.5. On the other hand, the hydromorphic zones in the median and downstream parts of Natio have pH levels similar to those observed in Logokaha in the center and in the hydromorphic zone. Overall, the pH levels measured in the various lowland sections remain compatible with the agronomic requirements of rice, although the Logokaha site appears to offer a slightly more favorable environment for this crop (Fig. 3).

Table 3. Soil granulometric and textural variability as a function of topographic differentiation in the Logokaha and Natio lowlands

Topographic segments		Granulometric composition (%)			Texture
		Sand	Silt	Clay	
			Logokaha		
Upstream	hydro	48.3	23.7	28.0	Sandy-clay-silt
	CBF	44.5	25.5	30.0	Silty
Median	Hydro	40.14	51.86	8.0	Silty
	CBF	31.05	44.95	24.0	Silty
Downstrea m	Hydro	37.55	48.45	14.0	Silty
	CBF	33.62	42.38	24.0	Silty
			Natio		
Upstream	hydro	41.18	35.82	23.0	Silty
	CBF	33.05	43.95	23.0	Silty
Median	Hydro	30.3	49.70	20.0	Silty
	CBF	32.05	40.95	27.0	Silty-clay
Downstrea m	Hydro	31.6	46.4	22.0	Silty
	CBF	38.12	35.88	26.0	Silty

Hydro: hydromorphic zone; CBF: center of the lowland

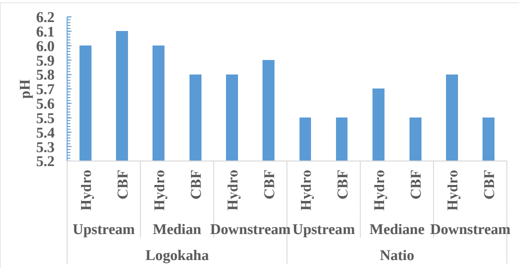


Fig. 3. Illustrates the variation in pH values in Logokaha and Natio lowland soils as a function of topographical differentiation

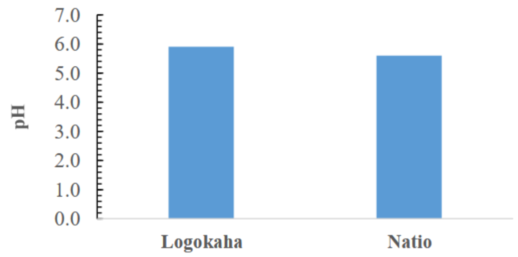


Fig. 4. Average pH values in Logokaha and Natio lowlands

Evaluation of average pH values in Logokaha and Natio lowland soils

Fig. 4 shows the average pH values of Logokaha and Natio lowland soils. The average pH values measured in the Logokaha and Natio lowlands are relatively close, at 5.9 and 5.6 respectively.

Variation in nutrient content in Logokaha lowland soils according to longitudinal and transverse topographical units

Analysis of the table (Table 4) reveals organic carbon and organic matter levels well below the critical thresholds, with values around half the permitted standards (<15 g/kg for carbon and <20 g/kg for organic matter). A similar trend is observed for total nitrogen, whose concentrations remain below agronomic requirements. However, the C/N ratio is within the range considered normal, reflecting a relatively balanced organic dynamic. C/N ratios above the norm were found mainly upstream, on all transects, as well as in the middle and downstream positions. Phosphorus levels are generally low, particularly downstream where they become very marginal. Concentrations of exchangeable cations are also very low throughout the lowland, with the notable exception of sodium (Na^+), whose levels appear excessively high on all sections. Finally, the cation exchange capacity (CEC) shows normal values (≥ 10 meq/100 g), while the iron (Fe) and zinc (Zn) contents far exceed the usual thresholds.

Table 4. Nutrient levels in Logokaha lowland soils by longitudinal and transverse topographic segments

Soil parameters	Lowland topographic segments						Standard
	Upstream		Median		Downstream		
	Hydro	CBF	Hydro	CBF	Hydro	CBF	
Corg (g.kg-1)	5.6	5.5	4.9	4.6	3.5	5.2	15 - 20
OM (g.kg-1)	9.65	9.48	8.45	7.93	6.03	8.97	20 - 35
Nt (g.kg-1)	0.5	0.5	0.4	0.4	0.3	0.5	2 - 5
C/N	11.2	11.0	12.25	11.5	11.67	10.4	10 - 12
Pass (mg.kg-1)	4.4	3.8	4.4	3.4	2.9	2.8	7 - 10
K^+ (cmol.kg-1)	0.12	0.15	0.12	0.1	0.11	0.1	0.4 - 0.5
Ca^{2+} (cmol.kg-1)	13.00	16.00	1.55	3.59	1.77	1.15	≥ 20
Mg^{2+} (Cmol.kg-1)	0.62	1.38	0.62	1.38	1.15	0.61	≥ 10
Na^+ (cmol.kg-1)	2.04	3.77	2.04	3.77	3.01	2.04	0.3 - 0.7
CEC (cmol.kg-1)	26.00	32.00	26.00	32.00	14	22	≥ 10
TSB (%)	60.69	66.56	60.69	66.56	41.34	28.92	36-50
Fe (ppm)	116.7	113.4	118.30	120.10	120.1	121.3	≥ 4
Zn (ppm)	291.9	291.9	352.61	427.61	68.6	66.4	≥ 1

Table 5. Average nutrient content of Logokaha lowland soils by longitudinal topographic segment

Longitudinal segments	Logokaha			Pr > F
	Upstream	Median	Downstream	
Corg (g.kg-1)	5.55 ±0.07a	4.75 ±0.21a	4.35 ±1.20a	0.354
Nt (g.kg-1)	0.50± 0.00a	0.40 ±0.00a	0.40 ±0.14a	0.465
C/N	11.10 ±0.14a	11.87 ±0.53a	11.03 ±0.89a	0.416
OM (g.kg-1)	9.60±0.31a	8.19±0.26a	7.5±0.21a	0.454
Pass (mg.kg-1)	4.10±0.42a	3.90 ±0.71a	2.85 ±0.07a	0.144
K^+ (cmol.kg-1)	0.14±0.01a	0.11±0.12a	0.10±0.1a	0.482
Mg^{2+} (cmol.kg-1)	1.00±0.12a	1.00±0.1a	0.88±0.11a	0.455
Ca^{2+} (cmol.kg-1)	1.45±0.14a	2.57±0.13a	1.46±0.1a	0.452
Na^+ (cmol.kg-1)	2.90 ±0.15a	2.90±0.11a	2.52±0.14a	0.465
CEC (cmol.kg-1)	29.00 ±4.24a	18.00 ±5.65a	21.00 ±7.07a	0.288
TSB (%)	63.62 ±4.15a	35.11 ±8.82a	25.732±004b	0.015
Fe (ppm)	115.05±1.34	119.02±1.53	120.7±1.67	0.465
Zn (ppm)	291.9± 91.6	390.11±95.2	67.05±25.1	0.015

Table 6. Nutrient levels in Natio lowland soils by longitudinal and transverse topographic segments

Soil parameters	Lowland topographic segments						Standard
	Upstream		Median		Downstream		
	Hydro	CBF	Hydro	CBF	Hydro	CBF	
Corg (g.kg-1)	4.1	4.1	3.5	3.8	4.8	4	15 - 20
OM (g.kg-1)	7.052	7.052	6.02	6.536	8.256	6.88	20 - 35
Nt (g.kg-1)	0.3	0.3	0.3	0.3	0.4	0.4	2 - 5
C/N	13.67	13.67	11.67	12.67	12.00	10.00	10 - 12
Pass (mg.kg-1)	2.8	2.8	1.4	1.8	2.3	2.1	7 - 10
K^+ (cmol.kg-1)	0.1	0.1	0.09	0.09	0.11	0.1	0.4 - 0.5
CEC (cmol.kg-1)	18	18	21	19	18	23	≥ 20
Ca^{2+} (cmol.kg-1)	1.24	1.87	0.82	1.87	2.34	1.07	≥ 10
Mg^{2+} (Cmol.kg-1)	0.44	0.89	2.34	0.44	0.70	2.10	0.3 - 0.7
Na^+ (cmol.kg-1)	2.21	2.41	3.78	2.21	2.12	3.70	≥ 10
TSB (%)	21.61	28.68	33.06	23.74	28.68	29.85	36-50
Fe (ppm)	125.2	135.6	103	96	108.5	100.4	≥ 4
Zn (ppm)	63.2	63.2	63.2	63.2	63.2	63.2	≥ 1

Average distribution of nutrients in Logokaha lowland soils according to longitudinal topographic units

Analysis of nutrient content (Table 5) in Logokaha lowland soils, according to longitudinal segments, reveals low concentrations of organic carbon, organic matter (OM) and total nitrogen (Nt)from upstream to downstream. The C/N ratio, although homogeneous between sections, remains within the critical range. All exchangeable cations are below agronomic thresholds, with the exception of sodium, whose levels, although significantly elevated, remain statistically identical between transects. On the other hand, base saturation rate (BST), iron (Fe) and zinc (Zn) exceed critical thresholds, with significant variations between segments.

Variation of nutrient contents in Natio lowland soils according to longitudinal and transverse topographic units

Table 6 shows nutrient levels in Natio lowland soils according to longitudinal and transverse topographic segments analytical Table 6 analysis of Natio lowland soils according to longitudinal and transverse segments shows organic carbon, organic matter and total nitrogen levels below more than half the critical thresholds on both longitudinal and transverse transects. The C/N ratio remains within critical norms, although it is slightly higher upstream in the hydromorphic zone and in the center of the lowland (CBF), while it reaches the lower limit (10) downstream in the central zone. Assimilable phosphorus and exchangeable cations remain below normative thresholds. CEC is close to reference values, with a slight excess downstream. Iron levels are lowest in the median, while zinc levels are consistently high across all transects.

Table 7. Average nutrient levels in Natio lowland soils by longitudinal topographic segment

Longitudinal segments	Upstream	Median	Downstream	Pr > F
Corg ($g.kg^{-1}$)	4.1±0.00a	3.65±0.21a	4.4±0.56a	0.2439
MO ($g.kg^{-1}$)	7.57±0.45a	7.27±0.41a	7.05±0.4a	0.454
Nt ($g.kg^{-1}$)	0.4±0.6	0.35±0.50	0.31±0.45	0.439
C/N	13.67±0.10a	12.17±0.707a	11±1.414a	0.1319
Pass ($mg.kg^{-1}$)	2.8±0.00a	1.6±0.28b	2.2±0.14ab	0.0165
K^+ ($cmol.kg^{-1}$)	0.11±0.48	0.09±0.50	0.11±0.60	0.2439
Mg^{2+} ($cmol.kg^{-1}$)	0.66±0.44	1.39±0.56	1.40±0.51	0.2439
Ca^{2+} ($cmol.kg^{-1}$)	1.55±0.11	1.34±0.74	1.70±0.81	0.2439
Na^+ ($cmol.kg^{-1}$)	2.31±0.12	3.05±0.17	2.91±0.10	0.2439
CEC ($cmol.kg^{-1}$)	18±0.00a	20±1.414a	20.5±3.535a	0.5539
TSB (%)	25.14±4.998a	28.40±6.590a	29.26±0.830a	0.6958
Fe (ppm)	130.4±35.13	99.50±32.13	104.45±33.10	0.429
Zn (ppm)	63.20±20.31	63.25±20.15	64.2±20.12	0.439

Average distribution of nutrients in Natio lowland soils according to longitudinal topographic units

Analysis of Table 7 according to Natio's longitudinal segments reveals that the majority of chemical parameters measured show no statistically significant differences, with the exception of phosphorus, whose levels vary significantly along the longitudinal transect (Pr > F = 0.016). The C/N ratio remains within normative limits from upstream to downstream. Total nitrogen, organic carbon and organic matter levels are well below their critical thresholds, as are exchangeable cations. CEC values are compliant in the median and downstream, but insufficient upstream. SST remains below the critical threshold, with a minimum observed upstream. Iron and zinc levels are well above critical standards, although iron has its lowest value in the median.

DISCUSSION

Granulometric analysis of Logokaha and Natio lowland soils reveals a wide range of textures depending on topographic position, both longitudinally (upstream, median, downstream) and transversely (hydromorphic zone, center of lowland). This diversity reflects the pedogenetic and hydrological dynamics specific to tropical lowlands (Boulet, 1978; Bonneau, 2001). The predominance of silty textures reveals a clear influence of settling processes in a saturated environment, stimulating the accumulation of fine particles in hydromorphic zones, which are advantageous for rice cultivation thanks to their good water retention capacity (Godwin, 1992). However, a sandy-clay-loam texture observed upstream at Logokaha reflects recent contributions of coarser particles linked to a slope and runoff context (Mabasa, 2019). At Natio, a silty-clay texture in the center reflects sedimentary stability and slow hydric functioning, favoring differentiation by leaching and clay migration (Bravard and Righi, 1991).

pH levels measured in both lowlands fluctuate between 5.5 and 7, a favorable range for rice cultivation (Bouman *et al.*, 2007). Soils upstream and in the hydromorphic zone of the median have pH values closer to neutrality, reflecting better drainage or sedimentary inputs rich in exchangeable bases (Brady and Weil, 2017). Downstream, pH levels are lower. The Logokaha lowland has a slightly higher average pH (5.9) than Natio (5.6). This moderate variation influences the availability of nutrients, particularly phosphorus, which is often limited in slightly acidic soils (Sanchez, 1982), making Logokaha a site with a slight agronomic advantage.

Soils in the Logokaha lowlands have low chemical fertility, with organic carbon (Corg), organic matter (OM) and total nitrogen (Nt) contents below half the critical thresholds (<15 g/kg for Corg, <20 g/kg for OM). This deficit suggests advanced organic matter degradation or low input, probably linked to intensive farming practices or low organic restitution (Yoro, 2000). The C/N ratio remains within norms, indicating balanced decomposition, although locally higher ratios suggest an accumulation of poorly decomposed organic matter upstream and in hydromorphic zones, possibly due to more pronounced hydromorphy (Baize and Ducommun, 2008). Assimilable phosphorus is highly deficient, particularly downstream, due to its low mobility in tropical soils and its fixation on iron oxides (Dabin, 1970). Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+) are also very low, revealing a marked chemical poverty. On the other hand, sodium (Na^+) is abnormally high, posing a risk of sodization, with its negative effects on soil structure (clay dispersion, compaction) (Landon, 1991). Normal cation exchange capacity (CEC) (≥10 meq/100g) indicates a mineralogy beneficial to soil fertility. However, iron (Fe) and zinc (Zn) levels are high, and can be toxic under acidic or reducing conditions (Baize and Ducommun, 2008). These observations underline a generalized chemical poverty throughout the lowland, with local specificities depending on hydric topography. Recommended management includes regular organic fertilization, sodium management via calcium amendments, soluble phosphorus and improved drainage.

In the Natio lowland, chemical parameters show no significant longitudinal differences, except for phosphorus, whose levels vary (Pr > F = 0.0165), reflecting distinct hydrological and sedimentary dynamics. The C/N ratio is stable and meets current normative criteria. However, levels of total nitrogen, organic carbon and organic matter are below critical thresholds, indicating low overall fertility (Sempéré *et al.*, 2000). CEC varies according to topography: sufficient in the median and downstream areas, but insufficient upstream, limiting nutrient retention. Base saturation rate (BSR) is low, particularly upstream, suggesting a more pronounced acidity (Landon, 1991).

Iron and zinc levels exceed critical standards, posing a phytotoxic risk, especially under fluctuating hydromorphic conditions (Mench *et al.*, 2009). Transversely, the hydromorphic zone retains more water and soluble elements, while the center of the lowland accumulates more organic matter, albeit low overall. Targeted management requires organic amendments, reasoned fertilization and adapted water strategies.

CONCLUSION

The integrated soil analysis of the Logokaha and Natio rice-growing lowlands revealed a pedological diversity influenced by topographical position and water conditions. This heterogeneity reveals several major constraints to the sustainability of rice production and the environmental enhancement of these ecosystems. In physical terms, the main constraints are textural heterogeneity, local soil compaction and low permeability in certain areas. By limiting water and air exchanges in the soil, these factors compromise plant rooting and, depending on the topography, can accentuate waterlogging or erosion phenomena. Chemical constraints are dominated by low overall fertility. Soils are very poor in organic matter, organic carbon, total nitrogen, assimilable phosphorus and exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}). Added to this are high sodium levels in some areas, posing a risk of sodication, as well as a punctual excess of micronutrients (iron, zinc) that can become phytotoxic. Despite an overall sufficient cation exchange capacity, these widespread deficiencies affect crop nutrition and limit yield potential. Moreover, leaching dynamics in hydromorphic zones call for careful management to avoid nutrient losses.

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