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LATERAL VARIATION IN SOIL FERTILITY ALONG A DIAGONAL TOPOSEQUENCE ON THE UNIVERSITY OF SAN PEDRO FARM

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ABSTRACT

Efficient management of agricultural land in tropical regions requires a precise understanding of the spatial variability of soil fertility and, by extension, that resulting from topography. The aim of this study, conducted at the University of San Pedro (USP) teaching farm, is to assess the suitability of the site's soils for cultivation with a view to establishing a teaching farm. To carry out this work, we conducted three surveys along a diagonal across an area measuring 100 m × 200 m, from the summit to the valley floor, combined with physico-chemical analyses of the samples collected. The results show that the topographical position reveals a marked morphopedo-logical difference along the transect. The profiles at the summit and midway down the slope exhibit characteristics typical of active ferralitic pedogenesis, with a sandy-clay texture and a lumpy, lamellar structure. In contrast, the lowland profile is characteristic of a gley horizon, indicating a process of gleyification through iron reduction and prolonged water saturation. The soil water pH increases moderately, reflecting a lateral redistribution of exchangeable bases towards the lower elevations. Organic matter shows a gradual decline, with the ratio falling from 13.93 to 7.92, indicating very rapid mineralisation of organic matter. CEC is moderate, but increases towards the lower positions, indicating an enrichment in clay. The peak in iron content confirms the diagnosis of gleyification established by morphological analysis. Overall, all these results effectively demonstrate that topographical position is a significant factor in the spatial variability of soil fertility.

Keywords: Soil Fertility, Toposequence, Ferralsols, Argilluvialization, San Pedro

1 INTRODUCTION

Ferrallitic soils are characterised by low organic matter content, a fragile structure and severe degradation, although they play an important role in agricultural production (FAO, 2024). In the context of intensification, poor farming practices are now one of the main causes of soil degradation worldwide (Lal, 2015). They accelerate soil depletion, the deterioration of soil structure and the exhaustion of nutrients, thereby compromising soil productivity (Chimi et al., 2025) . To ensure the sustainable productivity of these soils, monitoring of their physico-chemical characteristics is

essential in order to identify their limitations and adapt farming techniques (Sparks, 2025). The variability of soil properties is closely linked to their topographical location. Furthermore, the concept of a toposequence enables the analysis of characteristic soil variations along a gradient extending from the summit down the slope (Phillips, 2021; Schaetzl & Anderson, 2021). These variations directly affect soil fertility. However, the lateral variation in fertility remains poorly documented in tropical environments. It is within this context that our study, entitled [title], is situated; its objective is to assess the suitability of the soils at the site dedicated to the University of San Pedro's teaching farm.

2 METHODOLOGY

2.1 Study site

The educational farm is situated within the University of San Pedro (Figure 1). It comprises orchards of cocoa, cashew, coffee and rubber trees, as well as rice paddies. The soils are desaturated ferralitic soils, dominated by clay. It is situated at the coordinates 4°47.446' north atitude and 6°41.558' west longitude**.**

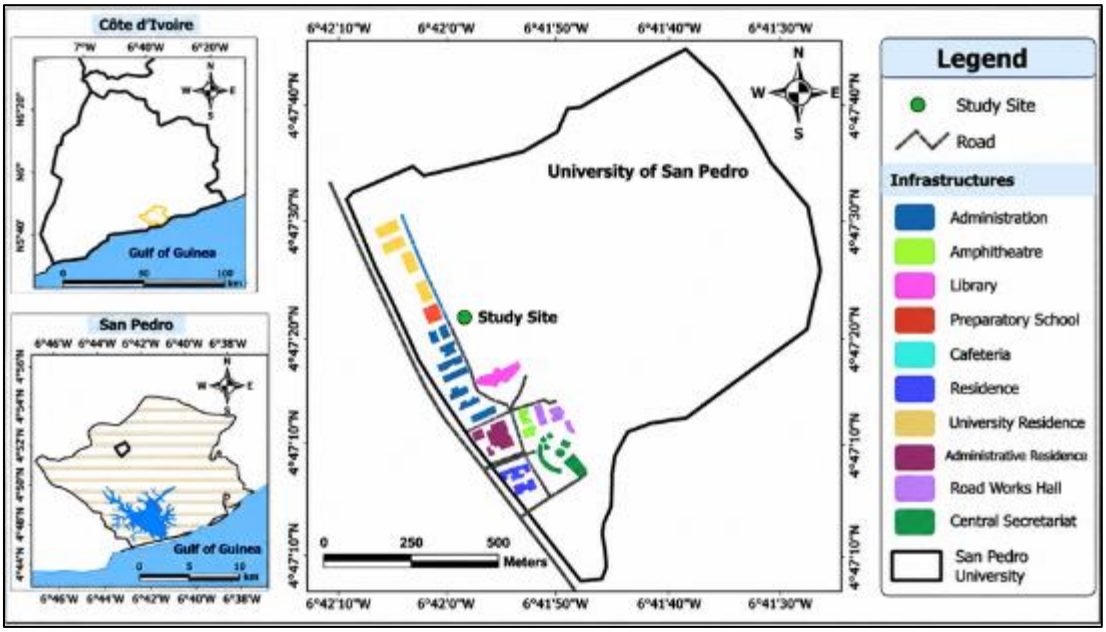


Figure 1: Location of the study site (Ouattara et al., 2024)

2.2 Technical equipment

These include:

- GPS, for geolocation;
- plastic bags, for packaging soil samples;
- Munsell colour system, for determining soil colours;
- soil scientist's knife, for delineating soil horizons;
- pick and spade, for digging soil profiles.

2.3 Survey grid

As part of this study, a 100 m × 200 m survey area was selected to investigate the spatial variability of soils at a local scale (Figure 2). The layout is based on a 100 m main transect serving as a reference, supplemented by three perpendicular secondary transects oriented north–south. Three soil pits were excavated along the diagonal, positioned at the summit, mid-slope and foot of the slope respectively, covering the entire toposequence. Five samples were collected, three from the surface horizons and two from between the pits.

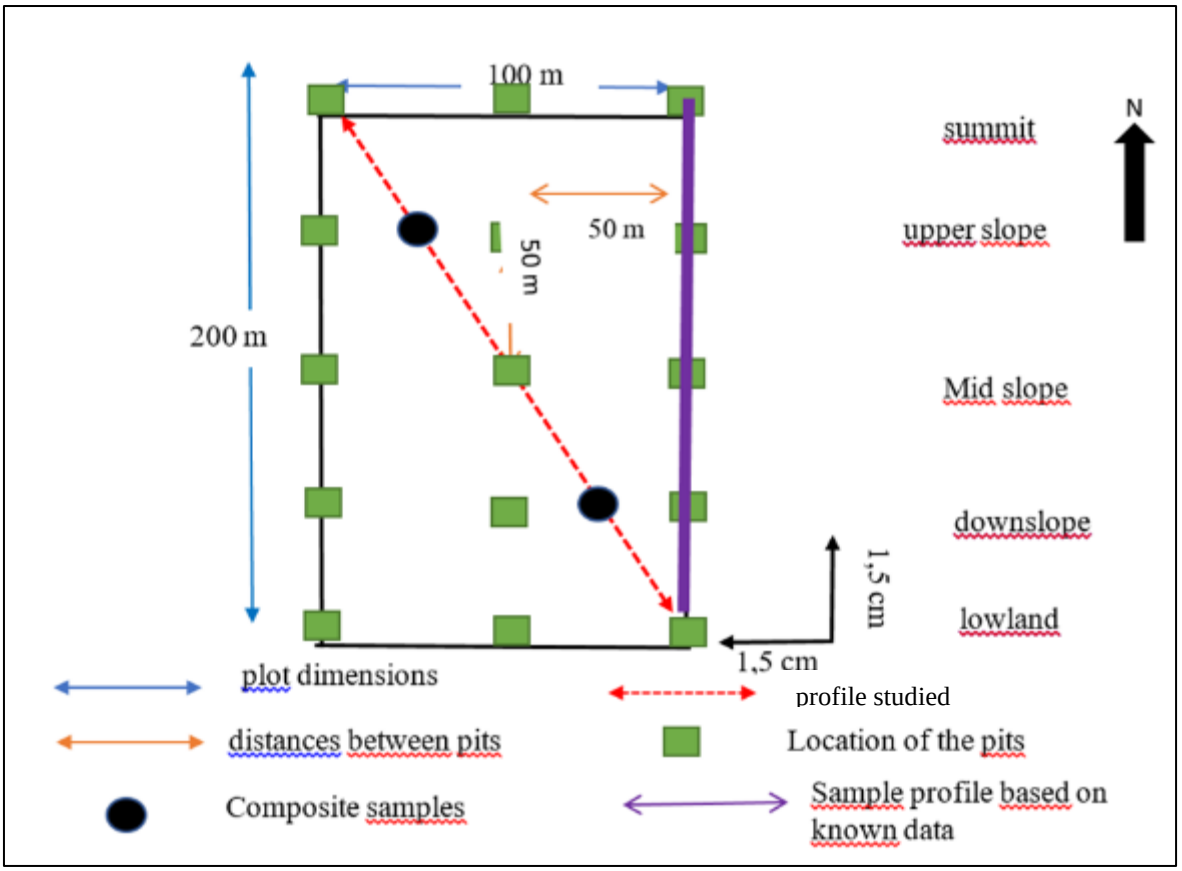


Figure 2: Diagram of the experimental setup

2.4 Excavation of the soil pits

Each station corresponds to the location of a soil pit, the geographical coordinates of which were recorded on a description sheet. The dimensions of each soil pit were marked out using stakes, string and a tape measure. All soil pits were dug by hand using a pickaxe and a spade, to the following dimensions: 1.20 m deep, 0.8 m wide and 1 m long. The soil pits were oriented so that the face to be observed was exposed to natural light, in order to ensure favourable conditions for morphological description. The excavated material was carefully removed to the side opposite the observation face to avoid any visual obstruction. Our study focused specifically on the path running diagonally across the plot, thus constituting a representative toposequence allowing us to observe soil variations linked to topographical positions..

2.5 Description of soil profiles

The soil description was carried out in accordance with the morphopedological parameters established for the assessment of agricultural soils (Abdulkadir et al., 2025). These parameters are recognised as key indicators of soil physical quality in tropical regions (Baize & Jabiol., 2011). The description was carried out by horizon, from the bottom upwards. For soil classification, we used the CPCS system (Aubert., 1965). The colour of the horizons was determined using the Munsell colour system (Munsell., 1998). The texture of the horizons was assessed using the empirical tactile method (Delaunois et al., 2013). Once the description was complete, samples were taken for physico-chemical laboratory analysis.

2.6 Laboratory analyses

The physico-chemical analyses were carried out at the ICRAF (International Centre for Research in Agroforestry) soil laboratory in Sinématiali, in accordance with current standardised protocols. soil pH (soil-to-solution ratio 1:2.5, standard NF ISO 10390), organic matter using the Walkley-Black method (1934), total nitrogen (Nt) using the Kjeldahl method, available phosphorus (Pass) using the Bray & Kurtz method (1945) adapted for tropical acidic soils, cation exchange capacity (CEC) using the ammonium acetate method (pH 7) and exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) by atomic absorption spectrophotometry.

3 RESULTS

3.1 Morpho-pedological characteristics of the toposequence

3.1.1 Top profile

3.1.1.1 It comprises three (3) horizons (Figure 3)

- Horizon H1 (0–30 cm), humus-rich, slightly dark, dry, ochre in colour (10YR/4), with few coarse particles (10%) and the presence of a few millimetre- to centimetre-long roots oriented sub-horizontally; slightly cohesive, very porous, with a distinct transition, a sandy-clay texture and a lumpy structure. Type A horizon.
- -Horizon H2 (30–60 cm), low in humus, fresh, ochre in colour (10 YR/6), coarse particles not very abundant (30 per cent), rare roots with a sub-horizontal orientation, porous, cohesive, irregular in size, distinct transition, sandy-clay texture, lamellar structure. Type B horizon
- -Horizon H3 (60–120 cm), no humus, very fresh, very ochre in colour (10YR/8), abundant coarse particles 45%), no roots, slightly porous, very cohesive, sandy-clay texture. Type C

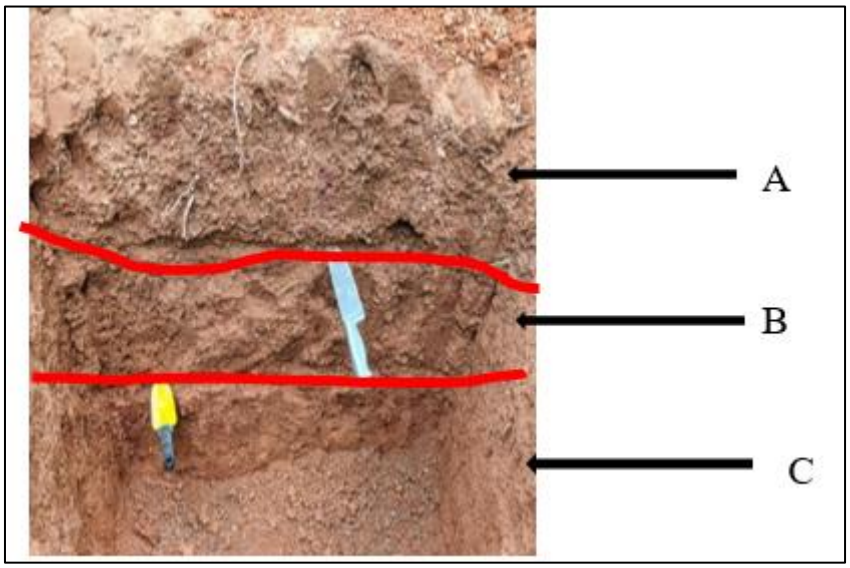


Figure 3: Soil profile 1 at the summit.

3.1.2 Mi versant profile

It comprises three (3) horizons (Figure 4):

- Horizon H1 (0–28 cm), humus-rich, dry, light ochre in colour (4YR/4), with few coarse particles (5%), abundance of centimetre- to millimetre-sized roots with a sub-horizontal orientation, porous, irregular in size, poorly cohesive, distinct transition, sandy-clay texture, distinct transition, lumpy structure, presence of root galleries. This horizon is of type A
- Horizon H2 (28–66 cm), low in humus, fresh, ochre in colour (5YR/6), coarse particles not very abundant (20%), rare roots with a sub-horizontal orientation, irregular size, poorly cohesive, porous, distinct transition, sandy-clay texture, lamellar structure. Type B horizon
- Horizon H3 (66–120 cm), no humus, very fresh, very ochre in colour (5YR/6), few gravelly particles, no roots, poorly cohesive, not very porous, sandy-clay texture, lamellar structure, Type C horizon

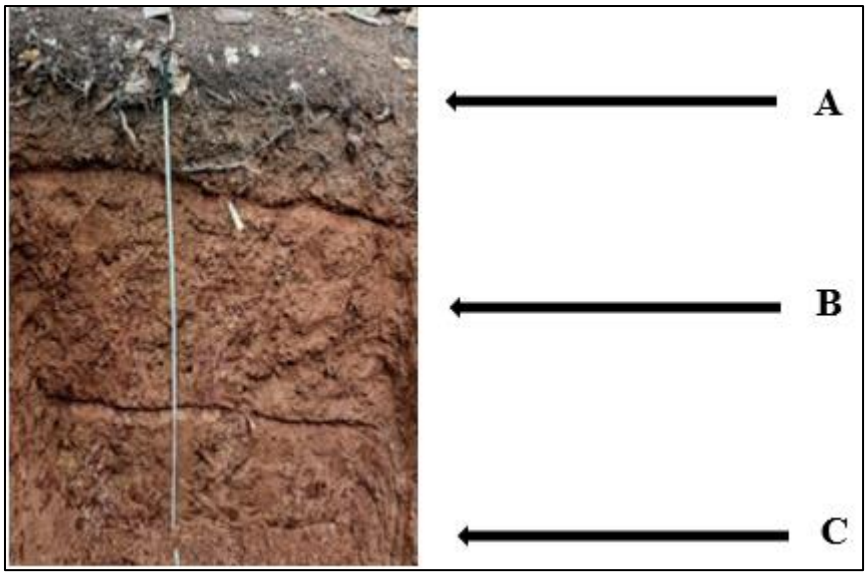


Figure 4: Soil profile 2 at the mid-slope

3.1.3 Bas-fond profile

It comprises three (3) horizons (Figure 5):

- Horizon H1 (0–14 cm): very moist, abundant sub-horizontal millimetre-sized roots, ochre in colour (5YR/8), humus-rich, no coarse particles, distinct transition, very cohesive, clayey texture, massive structure. Type A horizon
- Horizon H2 (14–29 cm): very moist, low in humus, dark (3YR/2), no coarse particles, very cohesive, few millimetre-sized roots with a sub-horizontal orientation, distinct transition, clayey texture, massive structure. Type B horizon
- H3 horizons (29–45 cm), wet, grey in colour (10Y/6), no coarse particles, no roots, very cohesive, clayey texture, massive structure. Gley-type horizon

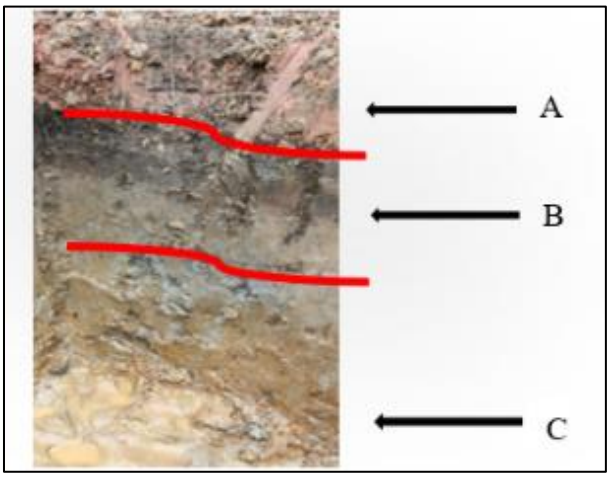


Figure 5: Soil profile 3 in the shallows

3.1.4 Particle size characteristics

The particle size analysis of the soil samples shows a gradual variation in textural composition along the toposequence (Table I). The clay content increases steadily from the summit (52.16 per cent) to the valley floor (68.55 per cent). Meanwhile, the sand fraction shows an overall downward trend, from 31.27 per cent at the summit to 19.61 per cent at the valley floor, with a slight increase at the lower slope (32.10 per cent). The silt content varies less regularly, reaching its maximum at the HV (18.57 per cent) and its minimum at the BV (10.41 per cent). The grain-size composition indicates that this is a sandy-clay soil.

Table 1: Particle size characteristics

Soil type	Sand (%)	Clay (%)	Silt (%)
S	31,27	52,16	16,57
MV	31,42	51,41	17,17
BF	19,61	68,55	11,84

S = Summit; MV = Mid-slope;; BF = Low-lying area

3.1.5 Chemical parameters of the soils

The results in Table II show an increase in pH from the summit to the base, indicating decreasing acidity; organic matter and total nitrogen follow the opposite trend, with higher contents at the summit (Corg = 1.52 per cent; N = 0.109 per cent) and decreasing towards the base. The C/N ratio decreases gradually from 13.93 at the top to 7.92 at the bottom. Calcium (Ca) largely dominates the exchangeable complex throughout the toposequence but drops at the bottom (1466.02), whilst magnesium increases (733.03 at the bottom). The CEC increases slightly from the summit downwards, reflecting a gradual enrichment in clays and organic matter. As for iron, its concentration decreases from the summit down the slope, indicating ferric mobility**.**

Table 2: Soil chemical parameters

Topographical position	S	MV	BF
pH eau	5,54	5,58	6
Cog (%)	1,52	1	0,76
N (%)	0,109	0,11	0,096
C/N	13,93	9,09	7,92
K(mg/kg)	169,6	182,56	153,84
CEC (cmol/kg)	21,2	21,6	22,1
Pass (mg/kg)	6,1	6,1	6.68
Ca (mg/kg)	1651,4	1660,7	1466
Mg (mg/kg)	670,7	658,5	733
Fe (mg/kg)	130,9	112,6	144,8

S = Summit; MV = Mid-slope;; BF = Low-lying area

3.1.6 Lateral variation in physical and chemical parameters along the toposequence

The results in Table III show slightly acidic pH values (5.4–6.0). The diagonal toposequence exhibits slightly higher values at the HV and BF, suggesting slightly less pronounced acidity. The BF is identical for both transects, with a pH of 6.00. The CEC increases from the upper slope in both cases. Unlike the BF, toposequence 1 exhibits a CEC of 24.13 cmolc/kg, significantly higher than that of the diagonal at 22.13 cmolc/kg. The iron content shows a marked difference on the upper slope; the diagonal contains 40 per cent more iron (129.92 versus 92.42 mg/kg). The C/N ratio of toposequence 1 is higher on the upper slope (11.83 versus 10.14). The diagonal is more homogeneous across the entire slope. These two C/N ratios converge towards lower values at the BF.

Table 3: Lateral variation in physico-chemical parameters along the toposequence

Paramters	S	MV	BF
pHeau	5,43 **5,54**	5,8 **5,84**	5,9 **6**
Cor (%)	1,12 **1,42**	1,06 **1**	0,74 **0,76**
N(%)	0,11 **0,12**	0,11 **0,11**	0,09 **0,1**

C/N(%)	10,14 **11,83**	9,85 **9,09**	7,72 **7,92**
Pass (mg/kg)	6,23 **7,11**	6,18 **6,18**	7,81 **7,81**
CEC (cmolc/kg)	19,75 **20,17**	21,63 **21,63**	24,13 **22,13**
K(mg/kg)	172 **169,95**	172,56 **182,56**	155,83 **153,84**
Ca(mg/kg)	1765 **1653,42**	1666,7 **1660,70**	1456 **1466**
Mg(mg/kg)	420 **660,69**	658,29 **658,49**	733 **733,03**
Fe(mg/kg)	92,42 **129,92**	110,55 **112,55**	147,8 **144,8**

S = Summit; MV = Mid-slope;; BF = Low-lying area

Topsequence1 perpendicular to the baseline in black and diagonal toposequence in bold

4 DISCUSSION

4.1 Morpho-pedological characterisations of the profiles studied

The three profiles reveal a gradual morphological and pedological differentiation, linked to topographical position and the water regime. This gradual differentiation from the summit down to the foot of the slope is consistent with the concept of 'catena' formulated by Milne (1935), which describes the lateral evolution of pedological properties along a slope under the influence of drainage and material transport. Furthermore, this lateral evolution constitutes a response to the gradients in drainage, moisture and the supply of fine-grained material characteristic of toposequences in the humid tropical zone of Côte d'Ivoire (Adechina et al., 2025). At the summit, the profile exhibits a classic A-B-C sequence of ferrallitic soils on granitic to gneissic substrates in a humid tropical environment (Brady & Weil, 2017; Schaetzl & Anderson, 2021). The mid-slope profile shows animal burrows in horizon A, indicating active edaphic fauna, probably termites and earthworms, whose development is favoured by slightly higher moisture levels. The absence of coarse particles in H3 and the silty-clay texture suggest a more advanced stage of pedogenesis, in accordance with d'Adegbite et al. (2019), in West African toposequences, where lower slope positions exhibited increased biological activity. Furthermore, the presence of a grey-coloured gley horizon indicates prolonged waterlogging and intense reducing conditions. This gleyification process involves the reduction of iron oxides by anaerobic bacteria under conditions of prolonged waterlogging (Brady & Weil, 2017; Koné et al., 2014).

4.2 Changes in grain size distribution along the toposequence

A gradual accumulation of clay is observed from the summit (52.16 per cent) towards the lower reaches (68.55 per cent), accompanied by an overall decrease in the sandy fraction. This redistribution of fine particles along the slope is governed by several pedogenic processes closely linked to topography (Khomo et al., 2011; Conforti et al., 2020). Lateral leaching of clay particles causes them to migrate from higher elevations to low-lying areas where they are deposited. This process is particularly active in ferrallitic soils of humid tropical zones, where heavy rainfall generates significant lateral water flows (Dabin & Maignien, 1979). This phenomenon of grain-size sorting by runoff is typical of ferrallitic landscapes in West Africa (Dabin & Maignien, 1979).

4.3 Physico-chemical parameters of the soil

The increase in pH from the summit (5.54) towards the lowlands (6.00) reflects a decrease in acidity towards the lower elevations. This gradient is explained by the accumulation of basic cations (Ca^{2+}, Mg^{2+}) in the lowlands via lateral transfer of soil solutions draining from the upstream slopes (Adechina et al., 2025; Koné et al., 2014). The semi-waterlogged conditions in the lowlands, by slowing down aerobic nitrification and the production of free organic acids, help to maintain a relatively higher pH. These results are also consistent with those reported by Bouadou et al. (2023) in the lowlands of central-western Côte d'Ivoire. The C/N ratio decreases steadily from 13.93 at the summit to 7.92 in the lowlands—a characteristic of humus undergoing progressive mineralisation (Chamayou & Legros, 1989; Bhatt et al., 2019). CEC is also influenced by organic matter, whose negative charges—which vary with pH—contribute to cation

retention. The slight decrease in organic matter towards the lowlands is offset by the increase in clay content, thereby maintaining an overall increasing trend in CEC (Koné et al., 2014)

4.4 Comparison of the fertility of the toposequence under study with that of the data from transect T1, which is perpendicular to the baseline

The comparison reveals spatial heterogeneity in the farm's soil fertility that cannot be captured by a single axis of observation. This finding is consistent with the concept of multidirectional toposequence developed by Phillips (2021), which emphasises that variability soil characteristics of a landscape cannot be fully characterised by a single transect. The two transects converge on identical pH values at the lowest point (6.00), confirming that the accumulation of bases at lower elevations is a homogeneous process independent of the direction of the transect. By contrast, significant differences are observed at the summit in terms of iron content, which is 129.92 mg/kg compared with 92.42 mg/kg for T1, representing a 40 per cent difference. The C/N ratio is higher at the summit, at 11.83 compared with 10.14 for T1. However, the two transects converge towards similar values in the shallows (7.72–7.92), confirming the homogenisation of organic mineralisation processes in the lower reaches, regardless of the observation axis (Szott et al., 1999; Manlay et al., 1998). The CEC in the shallow water zone is higher for T2 (24.13 cmolc/kg) than for T1 (22.13 cmolc/kg). This difference reflects a slightly more intense accumulation of clay, determined by the micro-relief configuration and the preferential orientation of water flows.

5 CONCLUSION

This study has revealed that the soils investigated along the toposequence are of a moderately desaturated ferrallitic nature, with morphopedological differentiation resulting from the site's topography. The pH is acidic; the soils are loosely compacted, rich in humus and have a sandy-clay texture. Organic matter and phosphorus content remain relatively low across the entire transect. Exchangeable aluminium levels represent a constraint for crops due to soil toxicity. CEC increases towards lower elevations with the gradual enrichment in clay. A comparison of the two transects revealed spatial heterogeneity in soil fertility. Overall, this study demonstrates that topographical position is a key determinant of the spatial variability of soil fertility. The results obtained have direct agronomic implications: they enable effective guidance on cropping practices and erosion control measures tailored to specific topographical units.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

Authors must disclose any financial or non-financial conflicts of interest

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