Celebes Agricultural 5(1): 25 - 41 August (2024)

Research Article

Quantifying Nutrient Ratios as Soil Fertility and Health Indicators across a Hydrosequence Transect in North Musi Rawas, South Sumatra

Kuantifikasi Rasio Hara sebagai Indikator Kesuburan dan Kesehatan Tanah Sepanjang Transek Hidrosekuen di Musi Rawas Utara, Sumatra Selatan

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Recived: December 2024
Accepted: December 2024
Published: December 2024

p-ISSN: 2723-7974
e-ISSN: 2723-7966
doi: 10.52045/jca.v5i1.795

Website:
https://ojs.untika.ac.id/index.php/faperta

Abstract: Since the modern soil assessment focus is currently moving towards "soil health", it is important to align the Basic Cation Saturation Ratio/BCSR of soil fertility evaluation with this term, yet no research conducted its application in tandem with CNP stoichiometries, nor vice versa. This study evaluated soil nutrient ratios across a hydrosequence transect in North Musi Rawas Regency, the lowland area of eastern Sumatra using Basic Cation Saturation Ratio/BCSR and CNP stoichiometries as potential soil health indicators. By integrating international and national/Indonesian BCSR framework and globally recognized CNP stoichiometry criteria, this study found that all soils experienced cation deficiencies, particularly in the upper soil depth (0–30 cm), alongside low phosphorus (P) and potassium (K) availabilities and their imbalances with C and N in deeper layers (30–60 cm). Cation ratios were observed to decline closer to the Merang River but increased with sampling depth. Additionally, wetter, gleyed soils exhibited greater cation imbalances while maintaining relatively balanced CNP stoichiometries. This study proposes an integrated multi-proxy approach combining BCSR and CNP stoichiometries as a cost-effective method for assessing soil fertility and health by addressing nutrient imbalances.

Keywords: BCSR, CNP stoichiometry, hydrosequence, soil fertility, soil health

Abstrak: Penilaian tanah modern saat ini semakin berfokus pada studi "kesehatan tanah," dimana penting untuk menyelaraskan evaluasi kesuburan tanah menggunakan rasio kejenuhan kation basa (BCSR) dengan konsep ini. Namun, belum ada penelitian yang mengaplikasikan BCSR secara bersamaan dengan stoikiometri CNP, maupun sebaliknya. Penelitian ini mengevaluasi rasio hara tanah di sepanjang transek hidrosekuen di wilayah Kabupaten Musi Rawas Utara, dataran rendah Sumatra bagian timur, dengan menggunakan BCSR dan stoikiometri CNP sebagai indikator potensial kesehatan tanah. Dengan mengintegrasikan kerangka BCSR internasional dan nasional/Indonesia serta kriteria stoikiometri CNP yang diakui secara global. Penelitian ini menemukan ketidakseimbangan kation basa pada keseluruhan tanah yang diteliti, terutama pada lapisan tanah atas (0–30 cm), ketersediaan fosfor (P) dan kalium (K) yang rendah dan ketidakseimbangannya dengan karbon (C) dan nitrogen (N) pada lapisan tanah yang lebih dalam (30–60 cm). Rasio kation cenderung menurun semakin dekat jarak dari Sungai Merang, tetapi meningkat seiring dengan kedalaman pengambilan contoh. Selain itu, tanah yang lebih basah dan berglei menunjukkan ketidakseimbangan kation yang lebih besar, meskipun memiliki stoikiometri CNP yang relatif seimbang. Penelitian ini mengusulkan pendekatan multi-proksi terintegrasi dengan menggabungkan BCSR dan stoikiometri CNP sebagai metode yang hemat biaya untuk menilai kesuburan dan kesehatan tanah dengan mengatasi ketidakseimbangan hara tanah.

Kata kunci: BCSR, hidrosekuen, kesehatan tanah, kesuburan tanah, stoikiometri CNP

Citation:
Pulunggono HB, Adiani DR, Nurazizah LL, Chahyahusna A, Iskandar. 2024. Quantifying Nutrient Ratios as Soil Fertility and Health Indicators across a Hydrosequence Transect in North Musi Rawas, South Sumatra. *Celebes Agricultural*. 5(1):25-41. doi: 10.52045/jca.v5i1.795

INTRODUCTION

Sustainable agriculture is inextricably linked to soil fertility and health (Fausak et al. 2024; Hou 2023a; Lehmann et al. 2020; Sofo et al. 2022). According to FAO (FAO 2024), soil fertility refers to the ability of soil to sustain plant growth by supplying essential nutrients and maintaining optimal chemical, physical, and biological properties. Naturally infertile or degraded soils limit crop growth due to nutrient deficiencies. Contrastingly, excessive nutrient application in other regions cause pollution, biodiversity loss, and environmental degradation. These imbalances could threaten food security and exacerbate climate change, which highlight the urgent need for sustainable soil management to ensure environmental, economic, and social resilience (FAO 2023; Hou 2023b). In order to enhance agricultural productivity and sustain food security, managing soil nutrients are their keystone indicators (Reytar et al. 2014; Roy et al. 2006).

From a classical soil fertility point of view, the first step in soil nutrients management is conducted by evaluating the magnitude of each nutrient against some critical thresholds or sufficiency levels. However, other approaches named basic cation saturation ratio/BCSR and CNP stoichiometry, more focused on assessing imbalances of nutrient in soils by calculating their exchangeable and total ratios, respectively. The first method can be interpreted either excessive amount or dominance of one cation can suppress the activity of others (Koppitke and Menzies 2007; McLean 1977). Without further identification, this antagonism, consequently, can be devastating for the deficient ones and generally for the plants, since the drawbacks can be in forms of potential leaching from soil systems and failures in plant uptakes, respectively (Xie et al. 2021; Yang et al. 2024). Moreover, as represented by their names, the second method applying ratio to total carbon (C), nitrogen (N), and phosphorus (P), accordingly, as proxies for (1) interpreting the state of biological progress in organic material, or generally called as microbial decomposition and (2) limiting factors for plant growth and development (Horwarth 2007; Smith and Collin 2007; Swift 1979).

Conversely to widespread and well recognized CNP stoichiometries in agricultural communities and scholars, BCSR have undergone limited recognition among academics and universities during past decades (Chaganti & Culman 2017; Koppitke and Menzies 2007). Nevertheless, current research have unveiled unnecessary dichotomization and biased perspectives against cation ratios (Culman et al. 2021). Brock et al (2020, 2021) reported that BCSR have been applied extensively among farmers and private laboratories for improving subtropic soil health for decades, yet no research conducted its application in tandem with CNP stoichiometries, nor vice versa. Furthermore, similar research on tropical soils remains underexplored and separately conducted (Anda 2012; Pulunggono et al. 2022, 2024; Sabudu et al. 2021; Souza et al. 2016).

Since the modern soil assessment focus is currently moving towards "soil health" (Hubanks et al. 2018), it is important to align nutrient assessment of classical soil fertility evaluation with this term. Kibblewhite et al (2008) defined soil health as "the multifunctional capacity of soil to deliver a range of different ecosystem functions and services." As a dynamic proxy of soil quality, soil health recognizes the critical functioning of biotic soil components, which extends beyond the classical goals of agriculture-related soil maintenance and farmer communities (Hou 2023a; Lehmann et al. 2020; Smith et al. 2021). Linking with ecosystem services (Rinot et al. 2019), its primary consideration is of soils as finite and living resources (Doran 2002; Doran et al. 1999; Lal 2016). Despite the growing interest on studying its indicators both in tropical and subtropical soils (Hou 2023a; Bhaduri et al. 2022; Riwandi and Handajaningsih 2011), research discussing the coupling evaluation of nutrient ratios and stoichiometries for improving soil health, which portrays crucial roles in revealing nutritional imbalances and limitations in soils, unfortunately, are less documented.

This study evaluated nutrient ratios across a hydrosequence transect in the lowland area of eastern Sumatra using BCSR and CNP stoichiometries as soil health indicators. We assumed that despite the differences in soil type, the nutrient ratio variation in soils at our transect was governed by depth. The tropical lowland areas were periodically inundated during the rainy season and experienced shallow to deep water tables during the dry season. These dynamics control reduction and oxidation degrees within soil solum, which consequently, generated varying magnitudes of organic material decompositions and cation mobilities. Besides standing as soil fertility assessment, this study also served as a forum for discussing the incorporation of nutrient ratios as an alternative indicator for evaluating soil health.

MATERIALS AND METHODS

Study Site and Sampling Strategy

The study transect is situated on a lowland area of eastern Sumatra, North Musi Rawas Regency, South Sumatera Province. The study area is located on riverine sedimentary regions serving as a backswamp for the Merung River with elevation under 50 masl, as shown in Figure 1. The soil types in the areas are primarily comprised of inceptisol that developed from sedimented, quaternary felsic tuffs and pumices from the Kasai formation (Suwarna et al. 1992) in two contrasting moisture regimes. An aquic regime of inceptisols with a constant shallow water table (endoaquept) expressing gley soils were dominantly found in the depression areas, while drier and infertile inceptisols with udic regime (dystrudept) occupied relatively elevated and deep-water table areas. Moreover, inceptisols with histic epipedon were observed scattering on the periodically inundated areas. On the other hand, scattered epiaquepts displaying mottlings were also found in the transitional region from wet to dry areas experiencing periodical flooding and inundation (Pulunggono et al. 2019).

A hydrosequence transect served as the primary sampling framework (Figure 1) intersected contour lines perpendicular to the Merung river and represented multi-hydrological conditions. Seven sampling points were established along this transect, consisting of six fertility and single profile samplings. Approximately 500 g of soil samples were compositely collected at two depth intervals (0-30 cm and 30-60 cm). The profile samples that were taken from different soil horizons, were then calculated using weighted averages to match the depth intervals for soil fertility coring.

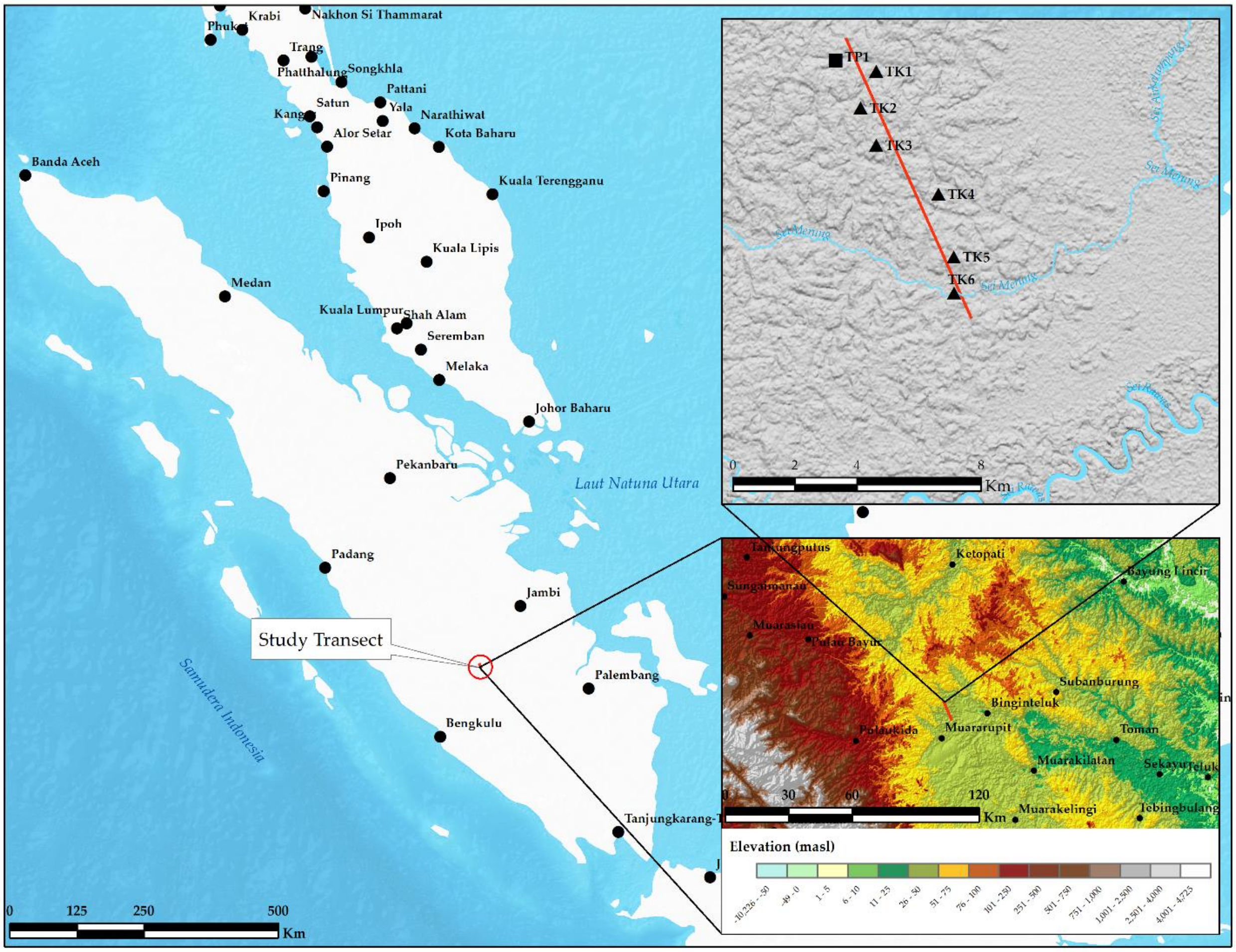

Figure 1. Map depicting this study's hydrosequence transect and its surrounding areas. Black square and triangles indicated profile and fertility observation points, respectively.

Laboratory Determinations and Calculations

Laboratory analysis was carried out at the Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University. Explicitly, seven parameters of soil physical and chemical properties were determined, including cation exchange capacity/CEC (1 N NH_4Ac extracted at pH 7), base saturation/BS; total P and K (HCl 25%), organic C (Walkley and Black), exchangeable bases and acids (1 N NH_4OAc pH 7; KCl 25%; respectively), and fine earth fraction (pipette method). Effective CEC (CEC_{ef}) was calculated as sum of all exchangeable cations (bases+acids) and expressed as me/100g soils. Furthermore, the saturation of base and acid cations were calculated as percentages by dividing the cation value to CEC_{ef}. BCSR-related nutrient ratios (exchangeable bases) were calculated as me/100 g ratio, meanwhile CNP stoichiometries (total C, N, and P) were calculated as percent ratio.

Soil Fertility and Health Assessments

Soil fertility assessment was conducted using a multi-metric approach the Basic Cation Saturation Ratio (BCSR) method based on the criteria of internationally recognized Baker and

Amacher (1981) and Indonesian standards using median value of medium level (PPT 1983; Eviati et al 2023). We also included BCSR ideal ranges using Indonesian standards by cross-calculated minimum and maximum values of medium level of exchangeable base saturations to medium CEC, which resulting probable range of accepted ideal saturation Ca (25–60%), Mg (4.5–12%), K (1.5–3%), and Na (0.1-4%) (Eviati et al 2023) and Albrecht standards (Albrecht 1975): Ca (60–75%), Mg (10–20%), K (2–5%), and Na (0.5-5%). Furthermore, the CNP ratio was assessed according to various internationally accepted criteria. Only C:N ratio was found on the national/Indonesian parameter (Eviati et al 2023).

RESULTS AND DISCUSSION

General Characteristics of Studied Soils

Overall soil properties (Table 1) suggested all studied soils across the hydrosequence transect possessed low fertility, regardless of their types and depths. This poor fertility can be denoted by tuffs and pumices with tuffaceous sandstone intercalations of Kasai formation that may contain high Si (felsic) and sand contents (Suwarna et al. 1992). Early geological and soil research in Bukit Barisan volcanic mountains (Mohr 1944; van Bemmelen 1949) as cited by Tan (2008) indicated felsitic, liparitic/rhyolitic, and dacitic to andesitic materials were likely to be erupted during quaternary periods. The sedimentary origin at riverine areas indicated an extensive cation leaching during both alluvial deposition of parent materials and soil development processes. Most soils were categorized as sandy soils, represented by high sand and low clay contents. It can be seen that the sand contents were gradually decreased along with the close proximities from the Merung river (Figure 1; Table 1). This condition indicated that the continuous deposition of relatively finer materials was undergone later, more periodic, and closer to the river than the coarser materials. Whereas, medium particles like silt, showed a fluctuated trend, with the highest content found adjacent to the river.

Due to its low clay content, CEC of most of the studied soils and depths, including TP1, TK1, TK3, TK4, and TK5 were considered as low statuses. Moreover, soils at TK2 exhibited very low to low CEC at 0-30 and 30-60 cm, respectively. TK6 exhibited moderate CEC at 0-30 cm and low CEC at its lower depth. This moderate status was highly influenced by high organic C content that accumulated as histic epipedon within 18 to 30 cm of upper soil surfaces, which contrastingly have dramatic decreases at its lower depth. BS at all observation points at both depths were considerably low, correlating with the low levels of base cations. These were also attributed partially to the acidic to very acidic soil pH and high saturation of acid cations (H and Al). The total K and P levels at the research location were also categorized as low to very low, especially at lower depth. It could be influenced by the combination of low levels of organic materials, low apatite and alkali feldspar as P and K sources, respectively, high K mobility, and high sand contents located at tropical region that experiencing high rainfall (2699 mm/year), recorded at the nearest site (Pulunggono et al. 2019), which consequently led to an extensive nutrient leaching and deficiencies (Fujii 2014; Juo and Franzluebbers 2003; Marschner and Rengel 2023; Tan 2008).

Table 1. Chemical and physical properties of soils at studied transect

Depth	pH		Org-C	Total N	Total P	Total K	Exchangeable Bases				Exchangeable Acids		CEC_{ef}	CEC	BS	Fine Earth Fraction			Texture Class
	H_2O	KCl					Ca	Mg	K	Na	Al	H				Sand	Silt	Clay	
cm			--------- % ---------		------- mg/kg -------		-- me/100g --									-------------------- % --------------------			
TP1, Typic Endoaquept, Rolling (8-15%), 40 masl																			
0-30	5.05	4.48	1.75	0.13			0.26	0.06	0.05	0.05	1.90	0.18	2.50	6.34	7.64	69.72	15.28	15.00	Sandy loam
30-60	5.27	4.71	0.39	0.13			0.34	0.07	0.04	0.12	2.11	0.33	3.01	8.65	6.53	47.75	11.95	40.30	Sandy clay
TK1, Typic Dystrudept, Rolling (8-15%), 39 masl																			
0-30	4.51	4.01	2.82	0.12	56.02	48.17	0.27	0.13	0.10	0.07	2.89	0.34	3.80	8.81	6.59	54.73	14.67	30.60	Sandy clay loam
30-60	4.71	4.18	1.22	0.11	34.14	21.65	0.23	0.08	0.05	0.07	2.14	0.26	2.83	5.25	8.05	52.47	12.28	35.25	Sandy clay
TK2, Typic Endoaquept, Rolling (8-15%), 44 masl																			
0-30	4.62	4.12	1.20	0.11	25.24	20.51	0.10	0.05	0.05	0.05	2.24	0.23	2.72	4.72	5.19	65.68	15.90	18.42	Sandy loam
30-60	4.90	4.24	0.23	0.13	4.14	20.82	0.49	0.26	0.20	0.10	2.27	0.24	3.56	9.25	11.37	55.44	12.60	31.96	Sandy clay loam
TK3, Typic Endoaquept, Rolling (8-15%), 35 masl																			
0-30	4.55	4.04	2.63	0.14	38.00	37.99	0.30	0.12	0.09	0.07	4.06	0.30	4.94	13.49	4.35	39.57	19.82	40.61	Clay
30-60	4.76	4.16	0.41	0.11	12.47	28.99	0.22	0.06	0.06	0.06	2.69	0.33	3.42	12.06	3.26	52.53	14.06	33.41	Sandy clay loam
TK4, Typic Dystrudept, Rolling (8-15%), 41 masl																			
0-30	4.48	3.98	2.89	0.19	40.35	38.44	0.14	0.13	0.08	0.05	3.54	0.11	4.05	12.98	3.11	37.30	18.03	44.67	Clay
30-60	4.78	4.24	0.78	0.15	22.88	27.04	0.13	0.07	0.05	0.07	2.81	0.13	3.26	9.42	3.35	46.37	11.75	41.88	Sandy clay
TK5, Typic Dystrudept, Rolling (8-15%), 36 masl																			
0-30	4.75	4.18	2.25	0.11	43.05	35.93	0.14	0.12	0.13	0.06	2.45	0.12	3.02	9.75	4.59	49.42	15.17	35.41	Sandy clay
30-60	4.91	4.24	0.69	0.10	34.47	31.08	0.21	0.07	0.05	0.06	1.40	0.37	2.16	6.80	5.80	48.60	9.58	41.83	Sandy clay
TK6, Histic Humaquepts, Flat-Undulating (0-8%), 39 masl																			
0-30	4.53	4.03	8.82	0.10	81.68	52.12	0.15	0.12	0.11	0.07	4.33	0.32	5.10	22.79	1.95	30.62	34.30	35.08	Clay loam
30-60	4.55	4.02	0.52	0.11	19.07	25.70	0.12	0.04	0.03	0.04	2.67	0.33	3.23	9.76	2.29	40.97	22.50	36.53	Clay loam

Integrating BCSR and CNP Stoichiometries as Soil Nutrient Ratio Assessments for Soil Health

Based on Table 2, Figures 2 and 3, all studied soils experienced cation imbalances at their entire depths according to Indonesian national BCSR-adapted criteria (Eviati et al. 2023; PPT 1983), as observed by deficient ratios in all cations. However, using international criteria (Baker and Amacher 1981), several soils including TP1, TK3, TK5, and TK6 exhibited balanced Ca:Mg ratios, while all observation points were deficient in Ca:K and Mg:K ratios. Typic endoaquept showed relatively similar cation ratios among 0-60 cm depths. Whereas, histic humaquept exhibited striking differences among both depths (Figure 2).

All cation ratios seemingly decreased along with the proximity to the Merang river (Figure 3), but increased with the deepening of the sampling depth (Figure 2). The spatial trend was likely more pronounced at the upper (0-30 cm) compared to a more fluctuating pattern at the lower depth (30-60 cm; Figure 3). Based on Albrecht and national standard (PPT 1983; Eviati et al. 2023; Figure 4), our studied soils apparently had low Ca, Mg and K, while had sufficient amount of Na. The cation imbalances were more pronounced at typic endoaquept compared to drier typic dystrudept (Figure 5).

Overall condition indicated an imbalance of cation concentrations in the studied soil since more restrictive criteria must be enforced at the humid tropic region, especially at the studied transect. In this sandy-dominated area, the potential of cation leachings are larger due to high precipitation (Pulunggono et al. 2019; Tan 2008). Balancing Ca to other nutrients or increasing its saturation according to ideal saturation as the primary BCSR approach would benefit the structural integrity of soils in the long term since Ca can act as a bridging agent of clay particles as well as mediating soil organic matter stabilisation (Dou et al. 2024; Rowley et al. 2018; Wan et al. 2021). However, in sandy soils with very low clay content (e.g., quartzipsamment), implementing BCSR or cation saturation ratios without addressing CEC problems through organic matter amelioration could introduce high production costs for farmers (Chaem-Ngern et al. 2020; Culman et al. 2021; Pulunggono et al. 2024; Santos et al. 2022).

Table 2. Assessment of soil fertility status based on the BCSR method

Observation Point	Depth (cm)	Ca:Mg	Int	Nat	Ca:K	Int	Nat	Mg:K	Int	Nat
			Status			Status			Status	
TP1 (TE)	0-30	4.33:1	B	D	5.2:1	D	D	1.29:1	D	D
	30-60	4.86:1	B	D	5.2:1	D	D	1.75:1	D	D
TK1 (TD)	0-30	2.08:1	D	D	2.7:1	D	D	1.3:1	D	D
	30-60	2.88:1	D	D	4.6:1	D	D	1.6:1	D	D
TK2 (TE)	0-30	2:1	D	D	2:1	D	D	1:1	D	D
	30-60	1.88:1	D	D	2.45:1	D	D	1.3:1	D	D
TK3 (TE)	0-30	2.5:1	D	D	3.33:1	D	D	1.33:1	D	D
	30-60	3.67:1	B	D	3.67:1	D	D	1:1	D	D
TK4 (TD)	0-30	1.08:1	D	D	1.75:1	D	D	1.63:1	D	D
	30-60	1.86:1	D	D	2.6:1	D	D	1.4:1	D	D
TK5 (TD)	0-30	1.17:1	D	D	1.08:1	D	D	0.92:1	D	D

Observation Point	Depth (cm)	Ca:Mg	Int	Nat	Ca:K	Int	Nat	Mg:K	Int	Nat
			Status			Status			Status	
	30-60	3:1	B	D	4.2:1	D	D	1.4:1	D	D
TK6 (HH)	0-30	1.25:1	D	D	1.36:1	D	D	1.09:1	D	D
	30-60	3:1	B	D	4:1	D	D	1.33:1	D	D

Notes: D (*Deficient*); B (*Balanced*); E(*Excessive*). Int (international standard); Nat (national standard). TE, TD, HH : *Typic Endoaquept, Typic Dystrudept, Histic Humaquept*, respectively

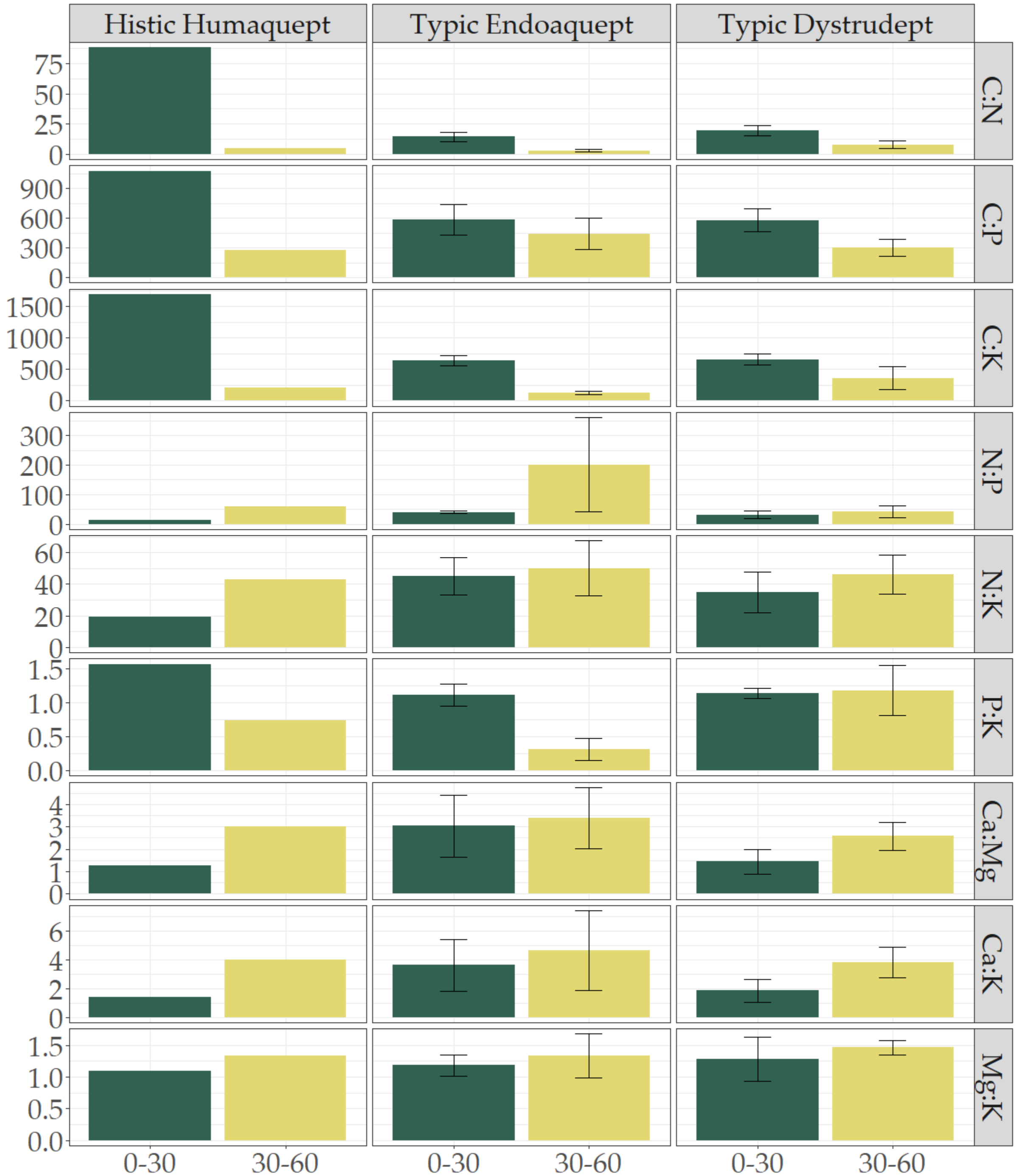

Figure 2. Nutrient ratios (CNR stoichiometries and cation ratios) grouped by sampling depths (0-30 and 30-60 cm) and soil types

Figure 3. Nutrient ratios (CNR stoichiometries and cation ratios) in each observation point grouped by sampling depths (0-30 and 30-60 cm)

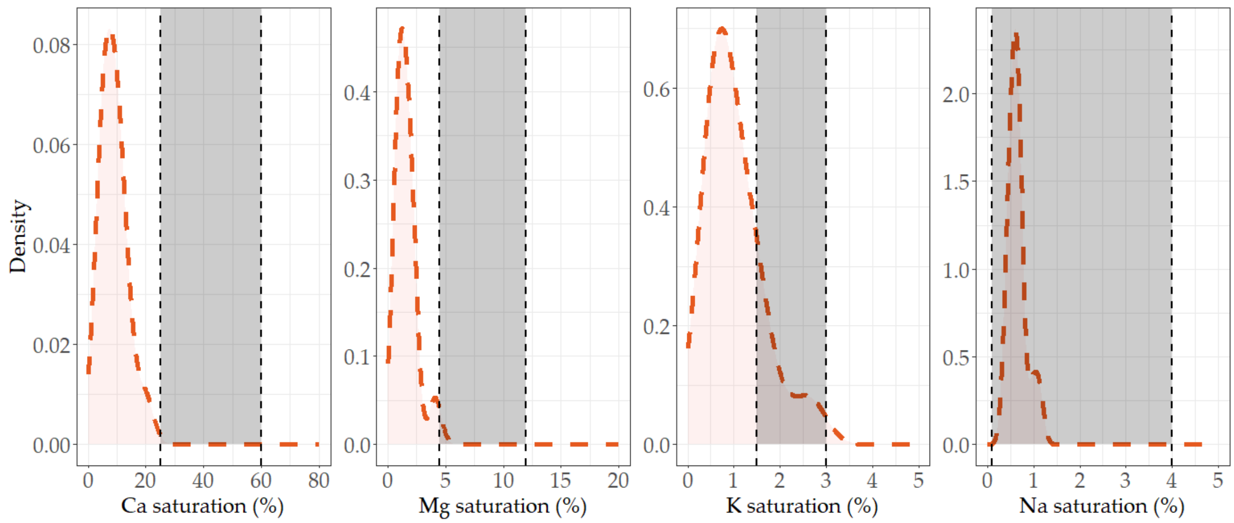

Figure 4. Distributions of Ca, Mg, K, and Na saturations with BCSR ideal ranges are denoted by black shaded areas and vertical dashed lines, representing Indonesian standards: Ca (25–60%), Mg (4.5–12%), K (1.5–3%), and Na (0.1-4%) at upper subfigures; and Albrecht standards: Ca (60–75%), Mg (10–20%), K (2–5%), and Na (0.5-5%) at lower subfigures

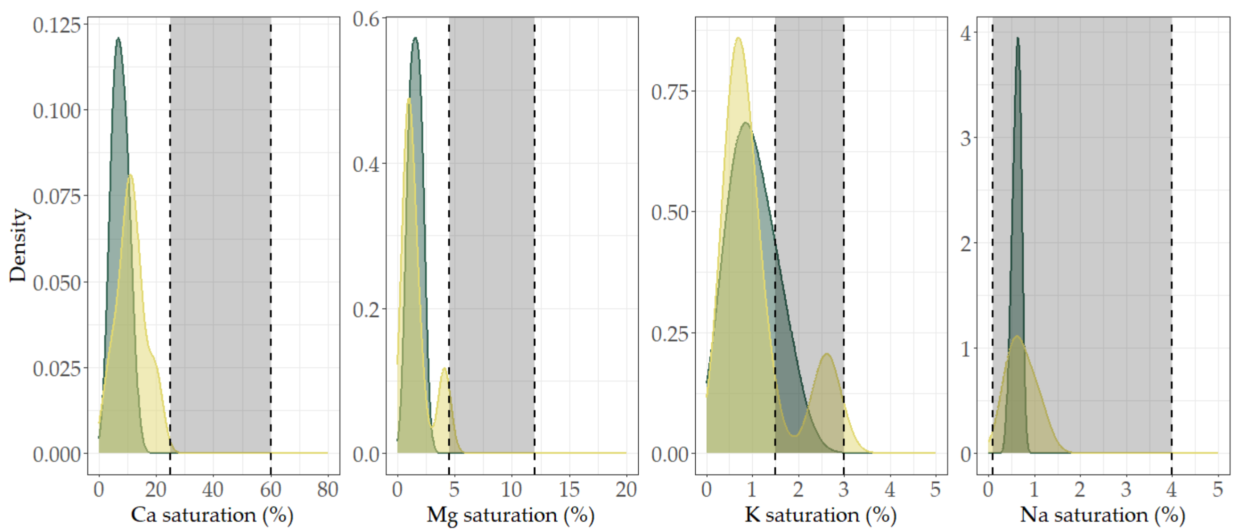

Figure 5. Distributions of Ca, Mg, K, and Na saturations with BCSR ideal ranges are denoted by black shaded vertical lines with soil type grouping. Green area depicts typic Dystrudept while yellow area represents typic endoaquept. Black shaded areas and vertical dashed lines were similar to those in Figure 4.

The results of CNP stoichiometries shown in Figures 2 and 3 demonstrated that both udic and aquic regimes of inceptisols (typic dystrudept and typic endoaquept, respectively; TP1, TK1-TK5) possess relatively similar C:N, C:P, and C:K, except for histic humaquept (TK6). Soils at TK6 exhibited a considerable C:N, C:P, and C:K which accounted for over 80, 1000, and 1500, respectively, indicating low-decomposed organic materials. Histic humaquept soil at TK6 experiencing soil organic matter accumulation with constrained decomposition due to its location at the depression areas experiencing long-term inundation (Figure 1). According to Figure 2, C:N, C:P, C:K, and P:K were relatively higher at 0-30 cm than those sampled at the lower depths. It can be attributed to high litter decomposition at the soil surface and similar to the trend reported by previous studies on tropical regions (Hu et al. 2023; Lu et al. 2023; Stone and Plante 2014), except for C:N. However, N:P and N:K showed opposite patterns, eventhough at extremely high organic C content at TK6 (Figure 3). At lower depth, N:P and N:K tended to be higher at TK2 compared to other soils, while no dramatic patterns were observed at upper depth, except for TK6.

While C:N mostly being used as a general signature of the decomposition of soil organic materials, the C:P was commonly employed to indicate organic phosphorus mineralization capacity in soils (Butler et al. 2021; Manzoni et al. 2010; Sterner and Elser 2003). Peñuelas et al (2012) stated that the soil N:P ratio can be used as a proxy for N saturation and evaluate the thresholds of nutrient limitation. Except for TK6, this study found that C:N at upper depth (0-30 cm) were 14.39 and 19.72 for typic endoaquept and typic dystrudept, respectively. The first soils were close to those C:N values reported globally on forest soils (Cleveland and Liptzin 2007; Xu et al. 2013), whereas both soils' C:N values indicated high decomposability of organic materials (Ostrowska and Porębska 2015; Paul 2007). Moreover, both soils had around four to five times those reported on global C:P on forest soils (Cleveland and Liptzin 2007; Xu et al. 2013; Figures 2 and 3), which indicated remarkably high C and P imbalance as well as partially suggested the lower P availability from organic material decomposition in soils at the studied site (Lu et al. 2023; Tian et al. 2010). Lu et al (2023) and Ostrowska and Porębska (2015) reported that C:N decreased along with the deepening of sampling depth, which are similar to those observed in this study (Figures 2 and 3). Furthermore, N:P reported in this study were relatively higher than those observed by previous studies in tropical regions (Hui et al. 2021; Lu et al. 2023; Xu et al. 2013).

CNP stoichiometries have been widely used as important indicators for understanding the biological process in soil and plant systems and also representing terrestrial and ocean biogeochemical cycling, nutrient limitation, and response to environmental change (Elser et al. 2008; Hu et al. 2023; Li et al. 2012; Penuelas et al. 2012; Sardans et al. 2021; Wang and Zheng 2021). The implementation of CNP stoichiometries would alleviate the ineffective and economically unsustainable single use of BCSR by introducing organic matter proxy, while not too far away from its proposed role as the biological indicator of soil health. Differently to other soil health biological indicators (Allen et al. 2011; Lehmann et al. 2020), more sophisticated and widely applied FMCSP method (Five Major Soil Chemical Properties; PPT 1983; Pulunggono et al. 2024), or long-term required for buildup and maintenance approach (Chaganti and Culman 2017; Olson et al. 1987) which may cost relatively higher to small-scale or subsistence farmers, the integration of BCSR with CNP stoichiometries can be an alternative to a simpler, low-cost, and quick soil fertility and health assessments, especially for the tropical region.

CONCLUSIONS

This study demonstrated the importance of using soil nutrient ratios to represent nutrient imbalances in the studied hydrosequence transect located in lowland areas. By employing nationally and internationally recognized basic cation saturation ratio/BCSR and a widespread global review of CNP stoichiometries criteria, this study found that all studied soils underwent cation deficiency, especially for their upper depth (0-30 cm) while also experiencing low availability of P and K as well as their imbalances with C and N at lower depth (0-60 cm). All cation ratios seemingly decreased along with the proximity to the Merang river, but increased with the deepening of the sampling depth. Furthermore, wetter, gleyed soils exhibited more cation imbalances but showed relatively conducive CNP stoichiometries. This study proposes the combination of BCSR and CNP stoichiometries as an integrated, muti-proxies approach for a simple, low-cost assessment of soil fertility and health.

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