International Journal of Technology and Education Research

https://e-journal.citakonsultindo.or.id/index.php/IJETER

E-ISSN: 2986-0733

Status Of Soil Chemical Properties In Cocoa (*Theobroma Cacao*) Plantation Land In Lanona Village, Bungku Tengah District, Morowali Regency, Central Sulawesi

Nadine Sandra Agustina[1]*, Epriani Rimbun[1], Iskandar[1], Hasnia[2]

[1] Department of Agrotechnology/Soil Science, Faculty of Agriculture, Tadulako University, Palu, Indonesia

[2] Student of Agrotechnology Study Program, Faculty of Agriculture, Tadulako University, Palu, Indonesia

**Correspondence: Nadine Sandra Agustina (ninakabi88@gmail.com)*

Abstract

Cocoa (Theobroma cacao) is a major plantation commodity in Lanona Village, Bungku Tengah District, Morowali Regency, yet its productivity remains low, partly because the chemical fertility status of the local soils has not been documented. This study aimed to determine the status of soil chemical properties (pH, organic carbon, total N, and total P) in cocoa plantation land in Lanona Village according to slope position and soil depth. A soil survey was carried out at three slope positions (footslope, midslope, and summit) and two depths (0–20 cm and 20–40 cm), with three replicates for each combination, yielding 18 soil samples. Soil pH ranged from acidic to neutral (5.22–7.15), with the highest values at the midslope and the lowest at the summit. Organic carbon content was moderate to high (2.26–4.60%), highest at the midslope and decreasing with depth. Total N was low to moderate (0.11–0.28%), whereas total P varied widely (2.78–25.02 ppm), with a very high status found only at the midslope. Slope position, together with base leaching and organic matter accumulation, was the main factor controlling the observed variation in soil chemical properties. The midslope showed the chemical fertility status most favourable for cocoa cultivation, whereas the footslope and summit required improvement, particularly through dolomitic liming, organic matter addition, and more targeted N and P fertilisation.

Keywords: cocoa; soil chemical properties; slope position; soil fertility; Morowali

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Technology and Education Research

https://e-journal.citakonsultindo.or.id/index.php/IJETER

E-ISSN: 2986-0733

INTRODUCTION

Soil is a growth medium that supplies nutrients, water, and air to plants and simultaneously provides habitat for soil biota involved in nutrient cycling (Hanafiah, 2014). Soil chemical properties — particularly soil reaction (pH), organic carbon, total N, and total P — directly influence the growth, development, and yield of cocoa (*Theobroma cacao*) (Andrian and Marpaung, 2014; Darlita et al., 2017).

Cocoa is a strategic plantation commodity in Indonesia, contributing substantially to export earnings and providing the main livelihood for many smallholder farmers. Sulawesi Island alone accounts for about 65% of national cocoa production, with Central Sulawesi Province as its largest contributor (BPS Sulawesi Tengah, 2015; Directorate General of Estate Crops, 2016). Nevertheless, cocoa productivity in Bungku Tengah District, Morowali Regency, remains low (582 kg ha^{-1}; Statistik ATAP, 2021), including in Lanona Village, where cocoa land is dominated by smallholder gardens managed without adequate information on the actual soil fertility status. Continuous fertilisation without reference to actual nutrient status risks causing nutrient imbalance and declining land productivity (Puja et al., 2013).

Previous studies on cocoa land in Sulawesi have reported considerable site-to-site variation in soil chemical fertility status. Syahrul et al. (2021) reported very acidic to acidic soil pH together with low total N and available P across several land-use types in Parigi Moutong Regency. Mamori et al. (2020) found high to very high cation exchange capacity in former cocoa plantation land in South Manokwari, while Nurhasni and Isrun (2021) and Toknok (2018) reported slightly acidic to neutral pH with moderate organic carbon in cocoa land and cocoa agroforestry systems in Central Sulawesi. This variability confirms that soil chemical fertility status is highly site-specific and strongly influenced by topographic/slope position, so that site-specific assessment — including in Lanona Village — is warranted for each cocoa production centre.

This study aimed to assess the status of soil chemical properties (pH, organic carbon, total N, and total P) in cocoa land in Lanona Village, Bungku Tengah District, Morowali Regency, according to slope position and soil depth, to provide a basis for more targeted nutrient management recommendations for local farmers.

Materials and methods

Study site and period

The study was conducted on a ±1 ha smallholder cocoa plantation in Lanona Village, Bungku Tengah District, Morowali Regency, Central Sulawesi (2°24’18.6” S; 121°52’38.7” E), from

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.

December 2025 to February 2026. Soil chemical analyses were carried out at the Soil Science Laboratory, Tadulako University, Palu. The site has undulating topography with slopes ranging from 0–8% to 65%, a moderate climate with annual rainfall of about 2000 mm, and mean temperatures of 30–32 °C. The cocoa trees studied were approximately 20 years old, planted at a density of 930 trees ha^{-1} (3 × 4 m spacing).

Tools and materials

Tools used included a GPS device, a soil auger, a crowbar, sample bags, labels, and a measuring tape. The material used was disturbed soil samples.

Sampling design and locations

Sampling points were determined using a land-unit map of Lanona Village, covering three slope positions: footslope, midslope, and summit. At each slope position, three replicate points were sampled, and at each point, soil was sampled at two depths, 0–20 cm and 20–40 cm, giving a total of 18 soil samples. Samples from the 0–20 cm layer were collected using a soil auger after clearing surface vegetation residue, while samples from the 20–40 cm layer were collected after initial excavation with a crowbar. Samples were placed in transparent plastic bags and labelled according to sampling point and depth.

Laboratory analysis

Soil samples were air-dried for approximately 4 × 24 h, sieved through 0.5 mm and 2.00 mm sieves, and then analysed following standard methods: soil pH (in H_2O and 1 N KCl) was measured using a pH meter; organic carbon was determined by the Walkley and Black method; total N was determined by the Kjeldahl method; and total P was determined by 25% HCl extraction. Results were evaluated against the criteria of the Center for Soil Research (Pusat Penelitian Tanah, 1983) for organic carbon, total N, and total P, and Sulaiman et al. (2005) for soil pH.

Data analysis

Data were analysed using a descriptive quantitative approach to characterise the status of soil chemical properties at each slope position and depth, which were then compared against the applicable soil fertility criteria and the optimal growth requirements of cocoa.

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Technology and Education Research

https://e-journal.citakonsultindo.or.id/index.php/IJETER

E-ISSN: 2986-0733

RESULTS

Soil pH

Soil pH in KCl was consistently lower than pH in H_2O across all observation points, indicating that the soils at the study site still carried a net negative charge (Table 1). At the footslope, soil pH was slightly acidic at both depths (mean 5.84 at 0–20 cm and 6.08 at 20–40 cm). At the midslope, pH was neutral (6.88 at 0–20 cm and 7.15 at 20–40 cm). At the summit, pH was acidic at 0–20 cm (5.22) and slightly acidic at 20–40 cm (5.82). The highest pH value was found at the midslope, 20–40 cm depth, while the lowest was found at the summit, 0–20 cm depth.

Table 1. Soil pH at three slope positions

Slope position	Depth	Mean pH (H_2O)	Criterion
Footslope	0–20 cm	5.84	Slightly acidic
Footslope	20–40 cm	6.08	Slightly acidic
Midslope	0–20 cm	6.88	Neutral
Midslope	20–40 cm	7.15	Neutral
Summit	0–20 cm	5.22	Acidic
Summit	20–40 cm	5.82	Slightly acidic

Source: Laboratory analysis (2026).

Organic carbon

Organic carbon content at the footslope and midslope was high at both depths (3.31–4.60%), whereas at the summit it was moderate (2.26–2.98%) (Table 2). At all slope positions, organic carbon in the 0–20 cm layer was higher than in the 20–40 cm layer.

Table 2. Soil organic carbon at three slope positions

Slope position	Depth	Organic C (%)	Criterion
Footslope	0–20 cm	3.36	High
Footslope	20–40 cm	3.31	High
Midslope	0–20 cm	4.60	High

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Technology and Education Research

https://e-journal.citakonsultindo.or.id/index.php/IJETER

E-ISSN: 2986-0733

Slope position	Depth	Organic C (%)	Criterion
Midslope	20–40 cm	3.55	High
Summit	0–20 cm	2.98	Moderate
Summit	20–40 cm	2.26	Moderate

Source: Laboratory analysis (2026).

Total nitrogen

Total N was low at the footslope and summit (0.11–0.19%), whereas at the midslope it was moderate (0.21–0.28%) (Table 3). At all slope positions, total N in the 0–20 cm layer was higher than in the 20–40 cm layer.

Table 3. Soil total N at three slope positions

Slope position	Depth	Total N (%)	Criterion
Footslope	0–20 cm	0.19	Low
Footslope	20–40 cm	0.13	Low
Midslope	0–20 cm	0.28	Moderate
Midslope	20–40 cm	0.21	Moderate
Summit	0–20 cm	0.14	Low
Summit	20–40 cm	0.11	Low

Source: Laboratory analysis (2026).

Total phosphorus

Total P showed the widest variation among the four parameters examined (Table 4). At the footslope, total P was low at both depths (4.74–4.81 ppm). At the midslope, total P was very high (18.33–25.02 ppm). At the summit, total P was low at 0–20 cm (6.68 ppm) and very low at 20–40 cm (2.78 ppm).

Table 4. Soil total P at three slope positions

Slope position	Depth	Total P (ppm)	Criterion
Footslope	0–20 cm	4.74	Low

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.

International Journal of Technology and Education Research

https://e-journal.citakonsultindo.or.id/index.php/IJETER

E-ISSN: 2986-0733

Slope position	Depth	Total P (ppm)	Criterion
Footslope	20–40 cm	4.81	Low
Midslope	0–20 cm	18.33	Very high
Midslope	20–40 cm	25.02	Very high
Summit	0–20 cm	6.68	Low
Summit	20–40 cm	2.78	Very low

Source: Laboratory analysis (2026).

DISCUSSION

Soil pH

Differences in pH among slope positions are closely related to base leaching and the accumulation of eroded material. At the lower positions (footslope and midslope), base cations leached from the upper slope accumulate together with surface runoff, thereby raising soil pH (Hardjowigeno, 2003). The higher pH at the midslope is also linked to the decomposition and mineralisation of organic matter, which releases base cations (Hardjowigeno, 2007). Beyond topography, intensive and prolonged use of inorganic fertiliser (particularly urea) by local farmers likely contributes to soil acidification, consistent with Karamina et al. (2017), who reported that long-term inorganic fertilisation can lower soil pH unless offset by organic matter, which acts as a pH buffer.

The soil pH range at the study site (5.22–7.15) generally falls within the range suitable for cocoa cultivation, i.e. pH 5.5–7 and not lower than 4 (Djaenudin et al., 2011). Nevertheless, the footslope and summit positions, which fall into the acidic to slightly acidic criteria, are recommended for dolomitic lime application to neutralise pH, as dolomitic lime containing 30% Ca and 22% Mg can raise soil pH (Hanafiah, 2013).

Organic carbon

The higher organic carbon content in the surface layer (0–20 cm) compared with the subsurface layer (20–40 cm) is consistent with the general pattern of organic matter accumulation from surface litter (Surya et al., 2017). Organic carbon serves as an important energy source for soil biota and contributes to humification, nutrient mineralisation, and the maintenance of soil structure (Hanafiah, 2007).

The higher organic carbon values at the footslope and midslope compared with the

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.

summit are likely influenced by elevation-related temperature differences and surface runoff patterns. At the summit, relatively lower temperatures slow organic matter decomposition (Karim and Hifnalisa, 2008), while on steeper slopes, organic-matter-rich soil particles are more readily transported by surface runoff to lower slope positions (Arsyad, 2010). Overall, organic carbon status at all observation points (>2%) is adequate to support soil fertility, given that organic matter content is ideally maintained at no less than 2% (Harahap et al., 2020).

Total nitrogen

The low total N status at the footslope and summit, and moderate status at the midslope, follows a pattern similar to organic carbon, since soil total N is strongly dependent on organic matter mineralisation. Higher total N in the surface layer compared with the subsurface layer indicates that N is more available within the active rooting zone (Hardjowigeno, 2003). The generally low total N at the study site is likely related to nitrate leaching by rainwater and uptake by plants and soil microorganisms, in addition to the prolonged use of high-dose inorganic fertiliser, which can accelerate soil structural degradation and deplete natural nutrient reserves (Triyono et al., 2013).

Total phosphorus

Total P showed the most pronounced variation among slope positions, with a very high status found only at the midslope. This pattern is closely related to soil pH, as optimal P availability occurs within a pH range of 5.5–7; at lower pH, P is fixed by Al and Fe, whereas at higher pH, P is fixed by Ca (Musyadik, 2019). This is consistent with the present findings, in which the highest (very high) total P was found at the midslope, which also had neutral pH, whereas the lowest (very low) total P was found at the summit at 20–40 cm depth, which was acidic. The high organic carbon content at the midslope likely also contributes to P availability through nutrient release from organic matter mineralisation (Munawar, 2011).

CONCLUSIONS

The status of soil chemical properties in cocoa land in Lanona Village varied significantly with slope position and soil depth. The midslope showed the most favourable chemical fertility status, with neutral pH, high organic carbon, moderate total N, and very high total P. The footslope showed slightly acidic pH with high organic carbon but low total N and total P. The summit showed the least favourable conditions, with acidic to slightly acidic pH, moderate organic carbon, and low to very low total N and total P. Slope position, base leaching, organic

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.

matter accumulation, and long-term inorganic fertiliser management were the main factors controlling this variation. Improved land management at the footslope and summit — through dolomitic liming, organic matter addition, and more precisely dosed and timed N and P fertilisation — is recommended to support optimal cocoa productivity in Lanona Village.

REFERENCES

Andrian, S. and Marpaung, P.: Effect of elevation and slope gradient on rubber (*Hevea brasiliensis* Muell. Arg.) yield at Hapesong Estate, PTPN III, South Tapanuli, Jurnal Agroteknologi, 2, 981–989, 2014.

Arsyad, S.: Konservasi Tanah dan Air (Soil and Water Conservation), 2nd edn., IPB Press, Bogor, 2010.

BPS Sulawesi Tengah: Sulawesi Tengah dalam Angka (Central Sulawesi in Figures), Statistics of Central Sulawesi Province, Palu, 2015.

Damanik, M. M. B., Hasibuan, B. E., Fauzi, Sarifudin, and Hanum, H.: Kesuburan Tanah dan Pemupukan (Soil Fertility and Fertilisation), USU Press, Medan, 2011.

Darlita, R. R., Benny, J., and Rija, S.: Analysis of several soil chemical properties on increasing oil palm yield in sandy soil at Selangku oil palm plantation, Jurnal Agrikultur, 28, 15–20, 2017.

Directorate General of Estate Crops: Indonesian Estate Crop Statistics: Cocoa, Ministry of Agriculture, Jakarta, available at: http://ditjenbun.pertanian.go.id (last access: 24 January 2024), 2016.

Djaenudin, D., Marwan, H., Subagio, H., and Hidayat, A.: Petunjuk Teknis Evaluasi Lahan untuk Komoditas Pertanian (Technical Guidelines for Land Evaluation for Agricultural Commodities), Center for Agricultural Land Resources Research and Development, Bogor, 2011.

Hanafiah, K. A.: Dasar-Dasar Ilmu Tanah (Fundamentals of Soil Science), 7th edn., Rajagrafindo Persada, Jakarta, 2014.

Hanafiah, K. A.: Ilmu Tanah (Soil Science), Rajagrafindo Persada, Jakarta, 2007.

Harahap, F. S., Harahap, D. E., and Harahap, P.: Land characteristics and land evaluation for development on other use area rice fertiliser plants in District Salak, Regency Pakpak Bharat, Ziraa'ah Majalah Ilmiah Pertanian, 45, 195–204, 2020.

Hardjowigeno, S.: Klasifikasi Tanah dan Pedogenesis (Soil Classification and Pedogenesis), Akademika Pressindo, Jakarta, 2003.

Hardjowigeno, S.: Ilmu Tanah (Soil Science), Akademika Pressindo, Jakarta, 2007.

Karamina, H., Fikrinda, W., and Murti, A. T.: The complexity of temperature and soil moisture

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.

effects on soil pH in crystal guava plantations, Kota Batu, Jurnal Kultivasi, 16, 430–434, 2017.

Karim and Hifnalisa: A preliminary study of Arabica coffee varieties based on elevation in the Gayo Highlands, Agrista, 1, 2008.

Mamori, M. Y., Taberima, S., Tukayo, R. K., and Sudjatno, D.: Soil chemical characteristics of cocoa (Theobroma cacao L.) plantation land at former PT. Cokran Ransiki, South Manokwari Regency, Jurnal Agrotek, 8, https://doi.org/10.46549/agrotek.v8i1.275, 2020.

Munawar, A.: Kesuburan Tanah dan Nutrisi Tanaman (Soil Fertility and Plant Nutrition), IPB Press, Bogor, 2011.

Musyadik: Identification of soil nutrient status in dryland as a basis for soybean fertilisation in Andoolo Subdistrict, South Konawe Regency, Jurnal Ecosolum, 8, 2019.

Nurhasni and Isrun: Analysis of soil chemical properties across several land uses, Agrotekbis, 9, 778–785, 2021.

Pusat Penelitian Tanah (Center for Soil Research): Kriteria Penilaian Data Sifat Analisis Kimia Tanah (Criteria for Assessing Soil Chemical Analysis Data), Agency for Agricultural Research and Development, Ministry of Agriculture, Bogor, 1983.

Puja, I. N., Supadma, A. A. N., and Mega, I. M.: Assessment of paddy soil nutrients to determine fertility level, Journal on Agriculture Science, 3, 51–56, 2013.

Statistik Angka Tetap (ATAP): Estate Crop Production Data 2021, Plantation and Livestock Office of Central Sulawesi Province, Palu, 2021.

Sulaiman, Suparto, and Eviati: Analisis Kimia Tanah, Tanaman, Air dan Pupuk (Chemical Analysis of Soil, Plants, Water and Fertiliser), Center for Soil Research, Agency for Agricultural Research and Development, Ministry of Agriculture, Bogor, 2005.

Surya, J. A., Nuraini, Y., and Widianto: Study of soil porosity under different organic matter applications in Robusta coffee plantations, Jurnal Tanah dan Sumberdaya Lahan, 4, 2017.

Syahrul, S., Thaha, A. R., and Toana, M. R. C.: Analysis of several soil chemical properties across land-use types in West Tolai Village, Torue Subdistrict, Parigi Moutong Regency, Agrotekbis: e-Jurnal Ilmu Pertanian, 9, 1287–1295, available at: http://103.245.72.23/index.php/agrotekbis/article/view/1112 (last access: 1 January 2024), 2021.

Toknok, B.: Soil chemical conditions in agroforestry and mixed-garden land at Ngata Katuvua Dongi-Dongi, Palolo Subdistrict, Sigi Regency, Central Sulawesi, Jurnal Warta Rimba, 6, 2018.

Triyono, A., Purwanto, and Budiyono: Efficiency of N fertiliser use to reduce nitrate loss in

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.

agricultural land, in: Proceedings of the National Seminar on Natural Resource and Environmental Management 2013, Diponegoro University, Semarang, 526–531, 2013.

Copyright to the author of some rights reserved This work is licensed under aCreative Commons Attribution-ShareAlike 4.0 International License.