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Typical Soil Physical and Chemical Characteristics in the Highland Area of Dak Lak Province, Vietnam

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ABSTRACT

Background: In the highland area of Dak Lak province, Central Vietnam, nearly 300,000 ha are covered with ferralitic soils. One of the main obstacles to agricultural production in the region is the low fertility of ferralsols. The current study attempts to relate the features of soil samples by presenting data on 10 physical and chemical aspects.

Methods: 85 composite soil samples that were collected from five communes in Dak Lak province representing for the highland area, were taken from the 0-30 cm layer at the beginning of the crop season in December 2024. They were air dried and sieved at a 2 mm mesh, then were analyzed to physico-chemical characterization using standard laboratory techniques in 2025.

Result: According to our findings, all of these soils have sand >38% and clay <26%, an average of higher than 3% organic matter and are acidic (pH in KCl <5). As a result, the cation exchange capacity (CEC), which averages >10 cmolc kg^{-1}, is rather high. Simple correlation and principal component (PC) analyses were used to look at the structure and mutual interference of the 10 variables. The 85 soil samples were separated based on their potassium (PC3 axis), organic matter (PC2 axis) and texture (PC1 axis). Further research will devote to soil characteristics following cropping patterns in order to consider the suitable management practice for sustainable production in this highland area.

Key words: Correlation, Highland area, Location, PCA, Soil properties.

INTRODUCTION

Dak Lak's province has a natural area of 18,096 km^2, equal to 3.9% of the total area in the whole nation and a population of around 3.3 million people spread across 102 administrative districts and communes. This province is characterized by its rich natural landscape of mountains, forests, waterfalls, fertile basalt soils and a diverse, multi-ethnic culture with unique traditions. The highland soils of Dak Lak province are primarily red basaltic (Ferralsols) and Acrisols, known for their high fertility and suitability for valuable industrial crops including coffee, rubber and pepper. The red basaltic soils are especially beneficial due to their good structure properties, high porosity and water infiltration capacity (Anh *et al*., 2015; Thuy *et al*., 2019). 92.39% of the land is covered with basaltic soils with slopes less than 15°, of which 84.83% is made up of a layer that is more than 100 cm thick (Cuong *et al*., 2025). Currently, 247,190.70 ha of land are used for agriculture; the remaining portion is left undeveloped and not used for farming. However, through many different processes of use and natural impacts as well as human factors cause of degradation in agricultural and forestry lands, it has led to the state of desertification and degradation of basalt soil (Cuong *et al*., 2025). Therefore, studying the characteristics of the soil use in Dak Lak province is very necessary to help in indicating the directions for the rational use of this land resource and obtain high efficiency in developing agricultural production. Numerous studies have been performed in both the North and South regions in Vietnam to evaluate soil fertility (Vo *et al*., 2020; Chau *et al.,* 2024; Cuong *et al.,* 2024a, b; Nguyen *et al*., 2024), but there is still limited research on the soil fertility in Dak Lak province. Therefore, this study presents soil characteristic information of 85 soil samples collected from the old Ea Kar district, representing for the Central highland of Dak Lak province and seeks to connect their attributes to agricultural practices.

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MATERIALS AND METHODS

Study area

To significantly represent the agro-ecological conditions of the highland area, the old Ea Kar district (12.48.35°N and 108.26.55°E) in Dak Lak province was designated, specifically in five new communes, namely Ea Knop, Ea Kar, Cu Yang, Ea O, Ea Pal, which was characterized as in Table 1. Data in Table 1 indicated that five communes have just reestablished in 2025 including total of 224 villages with 42,295 households (175,878 people) (Statistical Yearbook of Dak Lak province, 2024). The total agricultural land area of the whole five communes is 94,359 ha, accounting for 90.99% of the total natural area (103,700 ha), in which, Ea Knop commune has the highest agricultural land area occupying nearly 50% of the total agricultural land area of the five communes, but mainly production forest land area. The climate of five communes is tropical, with distinct wet and dry seasons and year-round high temperatures. Significant seasonal changes in humidity and rainfall are characteristics of the climate. All year long, temperatures are scorching, usually ranging from 17°C to 34°C. Thus, rice, cassava, sugarcane, rubber, pepper, coffee and fruit trees like longan, litchee and durian are the primary crops of the five communes. The commune's severe yearly droughts and problems with water scarcity underscore the difficulties in controlling the periodic rainfall patterns.

Soil sampling and characterization

The following criteria were used to gather 85 representative soil samples from the five communes in December 2024 including: (1) major agricultural systems; (2) the quantity of land devoted to these cropping systems; (3) topographic features; and (4) soil type and farm management. Each commune's soil sample count was displayed as follows: Ea Knop (21 samples), Ea Kar (31 samples), Cu Yang (12 samples), Ea O (11 samples) and Ea Pal (10 samples).

Composite soil samples were taken from the 0-20 cm layer of field plots (the average area of one plot in the study zone was approximately 1,500 m^2). As soon as possible after sampling, they are air dried and sieved at 2 mm. The 85 soil samples are subjected to physico-chemical characterization using standard laboratory techniques outlined in Page *et al*. (1996). The following attributes are quantified including particle size distribution (pipette method), bulk density (volumeter), pH of soil-1M KCl suspensions (1:5 ratio), organic carbon (C, Walkley and Black method; Organic matter-% OM = 1.724*% OC), total nitrogen ($N_{tot,}$ Kjeldahl method), total phosphorus (P_{tot}, extraction with aqua regia), total potassium (K_{tot}, flamephotometery method) and cation exchange capacity (CEC, extraction of exchangeable cations by 1M NH_4OAc, pH 7, desorption of NH_4^+ by 1M KCl). All analyses are conducted following standard methods with 3 replications at the University of Agriculture and Forestry, Hue University, Vietnam from January to June 2025.

Data analysis

Using STATISTIX 10.0 and XLSTAT 2025 software analysed the set of data from 85 soil samples including mean, min, max, median, standard deviation (SD) and principal component analysis (PCA) among soil samples following 10 soil physical and chemical characteristics.

RESULTS AND DISCUSSION

Overview of the properties of 85 soil samples in Dak Lak province

Descriptive statistics of soil characteristics are presented in Table 2. The relative difference between mean and

Table 1: General information on the 5 studied communes, Dak Lak province in 2025.

Commune	No. of villages	No. of households	Population (persons)	Total land area (ha)	Agricultural land (ha)	Main crops
Ea Knop	49	8,818	36,390	44,864	42,637.23	Sugarcane, litchee, longan, cassava
Ea Kar	98	20,730	86,945	19,868	17,077.32	Coffee, rubber, rice, durian
Cu Yang	26	3,725	16,601	14,943	12,957.89	Rubber, coffee, rice
Ea O	30	5,517	20,993	13,773	12,356.81	Rubber, coffee, rice
Ea Pal	21	3,505	14,949	10,252	9,330.26	Sugarcane, coffee, rubber
Total	224	42,295	175,878	103,700	94,359.51	

Table 2: Descriptive statistics of physical and chemical properties of the 85 soil samples.

Parameter	Mean	Median	Min	Max	SD
Sand (%)	38.42	39.65	2.68	83.40	21.87
Silt (%)	34.64	32.48	8.86	68.51	14.25
Clay (%)	26.94	26.35	7.75	76.50	11.07
BD (g cm^{-3})	1.42	1.46	1.01	1.82	0.21
pH_{KCl}	4.26	4.13	3.68	5.37	0.41
OM (%)	3.58	3.51	0.32	8.62	1.84
N (%)	0.13	0.11	0.04	0.24	0.05
P_{tot} (% P_2O_5)	0.02	0.02	0.00	0.08	0.01
K_{tot} (% K_2O)	0.30	0.24	0.00	1.45	0.29
CEC (cmolc kg^{-1})	10.50	9.58	4.37	26.04	3.99

BD: Bulk density; OM: Organic matter; CEC: Cation exchange capacity.

median values is smaller than 10% for silt, clay, pH_{KCl}, OM, N_{tot}, P_{tot}, K_{tot}, CEC, it is in the 10-15% range for sand content and bulk density; this relative difference is the highest for sand content and CEC. The average clay content of the 85-soil collection is less than 27% and the average organic matter content is higher than 3%. Consequently, the cation exchange capacity of these soils is rather high (average value > 10 cmolc kg^{-1}). Some characteristics of soils can be considered as intrinsic properties whereas others are direct or indirect consequences of these ones. So, texture, organic matter content (as inferred from oxidizable C) and pH govern or have deep influence on many other characteristics such as CEC, extractable acidity, organic N and P (which are usually close to total N and P) (Table 2). Based on this broad analysis of the data, it seems that some samples cannot be classified as clay soils even if they were taken in the province's mountainous region. In fact, we can see that the majority of samples are clustering in the classes of loamy sand, loamy clay and clay soils. Yegna *et al.* (2024) also found that cultivated lands in Ethiopia contained a considerable amount of clay and very little sand. Most of soil samples in this study are acidic (pH 4.26), high OM (3.58%), average N (0.13%) and CEC (10.50 cmolc kg^{-1}), poor total P (0.02%) and K (0.30%) (MONDRE, 2024). A significant amount of arable land is currently covered by acidic soils, which hinder crop growth by lowering the availability of vital nutrients like P and containing high levels of harmful elements like manganese (Mn) and aluminium (Al) (Getaneh and Kidanemariam, 2021). The result of this study agrees with the findings of Nguyen *et al*. (2025); Nguyen *et al.* (2024); Molla *et al.* (2022) who reported that soil characteristics were influenced by soil forming and practice management (bare land or deforestation).

Correlation among soil characteristics

The highest correlation was found for sand and silt contents (r = -0.90) (Table 3); it means that the variation of sand content is closely linked to an opposite variation of silt content; the increase of sand content is also accompanied by a decrease in clay content (r = -0,82), but with less systematic variation. The two sand and silt content are also well correlated with CEC (r = -0.59 and 0.57), the high sand content with low CEC values but the high silt content with high CEC values, which is not to surprise in a collection of soils with limited range of textural variation and similar pedo-climatic context. There were correlations between soil texture parameters and physicochemical properties. CEC had significant correlation with most of soil properties such as pH, BD, total N, P. Similar result was found by Mishra *et al*. (2022) noting that CEC in all land uses with highest correlation in desert land use (r = 0.94; p<0.05). Conversely, CEC was significantly and negatively correlated with sand in all land uses, with highest negative correlation obtained in desert land use (r = -0.84; p<0.05). OM exhibited no significant correlation with other characteristics, this is inverse with other studies from Ye *et al*. (2024); Pham and Vo (2023) who indicated that soil microbes play a vital role in the mineralization of C and N nutrients and all of them were aggregated with clay, which suggests that among the different textured soils, clay was the most relevant to soil C and N nutrient status. OM and other soil characteristics show low correlation coefficient (r <0.15); the mean C/N value of the 85 soils is around 31, which is high for not well humified organic matter; it means that the studied soils still fix nutrients by microorganisms, which can be related to low biological activity in acid sandy soils; Besides, soil acidity is caused by a variety of factors, including rainfall, leaching, the presence of acidic parent material, the breakdown of organic matter and intensive farming (Dogiso *et al*., 2025).

Structure of soil properties variation through principal component analysis (PCA)

The multivariate statistical method of PCA is a very useful tool for reducing the number of variables in a data set and for obtaining useful two-dimensional views of a multiple dimensional data set (Abdel-Fattah *et al*., 2021). Our set of data contains 10 measured variables which will be reduced to a smaller number of more synthetic variables called principal component (PC); the aim is to explain the

Table 3: Pearson correlation coefficient among soil characteristics in 85 studied samples.

Parameter	pH_{KCl}	BD	OM	N	P	K	CEC	Sand	Silt	Clay
pH_{KCl}	1.00									
BD	-0.21*	1.00								
OM	-0.36**	0.09^{ns}	1.00							
N	0.03^{ns}	-0.48**	0.04^{ns}	1.00						
P	0.34**	-0.53**	0.00^{ns}	0.50**	1.00					
K	-0.23*	0.36**	0.15^{ns}	0.11^{ns}	-0.10^{ns}	1.00				
CEC	0.24*	-0.25*	0.04^{ns}	0.26*	0.54**	0.02^{ns}	1.00			
Sand	-0.40**	0.54**	0.08^{ns}	-0.29**	-0.48**	0.05^{ns}	-0.59**	1.00		
Silt	0.36**	-0.53**	-0.03^{ns}	0.32**	0.52**	-0.03^{ns}	0.57**	-0.90**	1.00	
Clay	0.33**	-0.40**	-0.12^{ns}	0.15^{ns}	0.27*	-0.07^{ns}	0.43**	-0.82**	0.48**	1.00

**Indicated significant differences at p<0.01; *Significant differences at p<0.05; ^{ns}non significant differences at p≥0.05. BD: Bulk density; OM: Organic matter; CEC: Cation exchange capacity.

maximum amount of variance with the fewest number of independent components. Accordingly, the first principal component (PC1) in our data set explains 41% of the variation, while the subsequent components (PC with eigen values > 1) (Table 4) explained 15% and 12% of the variance, respectively. This indicates that PC1 and PC2 account for 55% of the variance, while PC1-PC2-PC3 accounts for 67%. The circles of correlation between the initial variables and the computed principal components PC1, PC2 and PC3 are displayed in Fig 1. The two parameters that have the highest correlation coefficients with PC1 are sand content (0.91) and silt content (-0.85); it should come as no surprise that other characteristics including pH_{KCl}, N, P, K, CEC correlate with PC1 ($0.21<|r|<0.72$) (Table 4).

Notably, the bulk density and sand vectors are nearly perpendicular to the PC1 axis, indicating that bulk density and sand are almost entirely independent of the first principal component and related to the original variables.

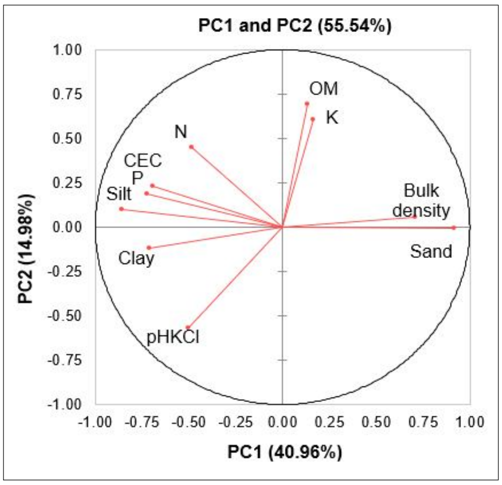

Fig 1: Circles of correlation among 10 soil characteristics and principal component axis.

The highest correlations for the second axis, PC2, are obtained for OM (r = 0.66) and N (r = 0.55). Simple variables and PC3 do not show any particularly strong link; the best values are r = 0.56 for K and r = 0.49 for bulk density. Reducing our data to three independent and synthetic variables allows us to summarise its structure as follows: PC2 is the axis of OM, PC3 is the axis of K (very roughly) and PC1 distinguishes the soils based on texture and P concentration (and related variables). Because of its synthetic physico-chemical meaning and the fact that, as was previously said, the association between CEC and clay was less than anticipated, it was also taken into consideration. Similar results were found by Abdel-Fattah *et al.* (2021) who pointed out that the first PC has stronger positive relationships with EC, OM, CEC, available NPK, ESP and clay, while the second PC has a substantial association with silt and Li *et al.* (2020) reported that soil silt was significantly negatively correlated with total K content but significantly positively correlated with available K. Furthermore, the CEC of tillage layer soil showed a positive correlation with the amount of silt and clay in the soil. This was because higher clay content increased the specific surface area of soil colloids and soil charge, which enhanced the soil's ability to adsorb ions, which was consistent with findings from earlier research (Pelster *et al.*, 2018; Chen *et al.*, 2021).

The distribution of the observations (85 soils) in the new space created by the synthetic variables can also be seen using PCA. The 85 soil samples are shown in Fig 2 based on their coordinates with PC1 and PC2. With a tailing tendency of a dozen points, we observe extremely good scattering of the majority of points, indicating those soils with a higher OM content and/or less sandy texture. However, we are unable to detect actual subpopulations, which is a requirement for a useful PCA. This presentation style will be used to illustrate potential connections between soil attributes and sample location, soil preparation and cropping pattern. Points will be assigned various symbols

Table 4: Principal component analysis (PCA) for soil characteristic indicators in 85 studied samples.

Parameters	PC1	PC2	PC3	PC4	PC5
Eigen value	4.10	1.46	1.19	0.94	0.77
Variability (%)	40.96	14.58	11.89	9.42	7.73
Cumulative %	40.96	55.54	67.43	76.85	84.58
Loadings					
pH_{KCl}	-0.53	-0.53	0.05	-0.29	0.36
BD	0.71	-0.01	0.49	-0.17	0.30
OM	0.16	0.66	0.08	0.59	0.24
N	-0.46	0.55	-0.41	-0.36	-0.23
P	-0.72	0.25	-0.32	-0.17	0.34
K	0.21	0.53	0.56	-0.51	-0.16
CEC	-0.69	0.23	0.25	0.00	0.39
Sand	0.91	0.04	-0.31	-0.14	0.17
Silt	-0.85	0.08	0.17	0.05	0.02
Clay	-0.69	-0.18	0.39	0.19	-0.35

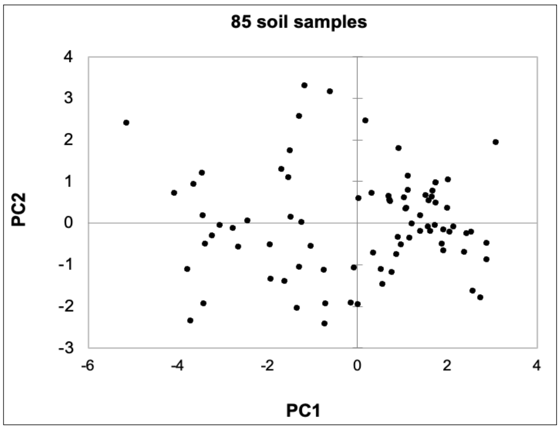

Fig 2: Scattering of 85 soil samples on the two first principal components.

based on these criteria. Rajput *et al*. (2023) indicated that the PCA method was shown to be somewhat superior for assessing soil quality in the North hill region in India. The PCA of soil physicochemical properties, soil microbial status and soil texture factors of various texture paddy soils, taking into account the overall pattern of soil physicochemical properties, also demonstrated that variations in nutrient content and physicochemical properties among soils can be reflected in soil texture (Ye *et al.,* 2024). Principal component analysis (PCA) was employed to establish a minimum data set (MDS) and to evaluate key physical and chemical properties affecting soil quality, along with the associated weight factor for each indicator (Ibrahim *et al.,* 2025).

Implications for sustainable agriculture in Dak Lak province

The results of this study provided a general picture on the physical and chemical characteristics of soil in Dak Lak province that influence the degree of soil quality in the areas under investigation. This implies that large areas of the study are degrading and have low soil quality. Assessing soil quality using key indicators through PCA analysis is essential for resilient agricultural systems, improving food security and encouraging sustainable resource management. This supports both ecological sustainability and economic growth. Soil characteristics improvement for sustainable agriculture in Dak Lak province including to increase application of more organic matter, control soil erosion by cover crops, use suitable cropping patterns, reduce tillage, enhance water and nutrient retention.

CONCLUSION

The physical-chemical properties of the soils from Dak Lak province are presented quantitatively in this study. A statistical examination of 10 features of 85 soils indicated some interesting information. These soils are predominantly loamy clay in texture, contain more than 3% organic matter and are acidic in nature. Simple correlation and principal component analysis were used to look at the 10 variables' structure and mutual interference. The 85 soil samples are divided into three separate principal components (PC) based on their sand content (PC1), OM (PC2) and K content (PC3). We looked for any potential significant variations in the mean attributes of these subpopulations and practices for sustainable agriculture in Dak Lak province.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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