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Soil Characteristics under Different Cropping Systems in Thua Thien Hue Province, Vietnam

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ABSTRACT

Background: Soil characterization is important in evaluating sustainable soil management practices. This study presents findings on ten physical and chemical properties of soil samples obtained from the mountainous region of Thua Thien Hue province and correlates these characteristics with various cropping patterns.

Methods: 245 composite soil samples were collected from the 0-30 cm layer of different cropping systems from November to December 2022. The samples were air-dried and passed through a 2 mm mesh sieve, after which they were analyzed physico-chemical characteristics using standard laboratory techniques in 2023.

Result: The findings of our study reveal a significant correlation between soil properties and various cropping patterns. All ten analyzed properties show significant differences between cropping systems, with CEC and OC content being the most critical factors influencing other soil characteristics.

Key words: Correlation, Cropping systems, Mountainous zone, Soil characteristics.

INTRODUCTION

Geographically, the mountainous area has an average altitude of about 1000 m and a slope of 35°. It has the potential for developing specialized farming areas and perennial crops. A Luoi is a mountainous district in the west of Thua Thien Hue province, 70 km away from Hue City and covers an area of 1,224.64 km^2. As a bordered district with an 84 km national border, A Luoi is an important-place adjacent to many different territories. In recent years, the covered vegetation at A Luoi district has shown signs of decline in both scale and quality. Meanwhile, the terrain is mainly mountainous with elevations from 680 m to 1,150 m, which is dividedby multiple stream systems, between highmountains and steep passes. In particular, A Luoi is well known as the heavy rain center of Thua Thien Hue province with rainfall amounts of over 2,700 mm/year (Nguyen *et al.,* 2023; Nguyen *et al.,* 2020a).

The analytical results showed that the yellow-red soil on metamorphic clay and yellow-red loam on metamorphic clay had a highrisk of landslides and accounted for 53 percentof the total area in A Luoi district (Nguyen *et al*., 2020a). The dominant land use in A Luoi district is agriculture. The main cropping pattern is food and perennial crops including rice, maize, cassava, fruit trees and acacia. They are traditional crops that provide the main food for local people. Forestry also predominates in the remaining areas (Nguyen *et al*., 2024). The low fertility of Feralitic soil in the topics is a major constraint to agricultural productivity. Most of these soils are strongly acidic and have low organic matter content. In addition, as the clay fraction is also high in these soils, the cation exchange capacity (CEC) mostly depends on organic matter which serves as the major component of the adsorbing complex (Anh *et al.,* 2014; Nguyen *et al.,* 2020b; Bufebo and Elias, 2020; Tamene *et al*., 2023; Nguyen *et al*., 2024).

Several investigations have already been conducted in the North and the South to assess soil fertility, but have focused mainly on alluvial soils and coastal soils (Nguyen *et al*., 2018; Son *et al*., 2019; Nguyen and Nguyen, 2021). Therefore, detailed characterization of soils in mountainous areas will be useful in assessing their actual and potential fertility and in determining adequate practices for sustained productivity. This paper reports data on 245 soil samples collected from the A Luoi district representing for mountainousarea of Thua Thien Hue province and attempts to relate their characteristics to cropping patterns.

MATERIALS AND METHODS

Selection of study sites

Six representative communes from A Luoi district (16°00′57″ to 16°27′30″N and 107° 0′3’ to 107°30′30″E) in Thua Thien Hue province were chosen for studying, *i.e.*

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A Ngo, Son Thuy, Hong Bac, Quang Nham, Hong Thai and A Luoi town. Some characteristics of 6 communes are presented in Table 1. The total agricultural land area of the whole district is 108,527 ha, accounting for 94.49% of the total natural area (114,850 ha), while the total agricultural production land area in 6 studied communes is 2,733 ha. Data in Table 1 indicated that the rice, cassava and acacia area from 6 studied communes was 697.1 ha, 674.0 ha and 491.0 ha (accounting for 25.5%, 24.6% and 17.9% of the total agricultural production land area in these communes, respectively) (Statistical Yearbook of Thua Thien Hue Province, 2023).

Soil sampling and characterization

Based on agricultural production land area and cropping patterns in the six communes mentioned above, we have collected randomly 245 soil samples for analysis. Table 2 presents the number of soil samples for each commune and the corresponding cropping patterns. Composite soil samples were collected from November to December 2022 at the 0-30 cm layer of field plots. They were air-dried and sieved at 2 mm immediately after sampling. Physico-chemical characterization of the 245 soil samples was carried out in January to March 2023 according to classical laboratory procedures that were described in the extended soil analyses book of Page *et al.* (1996). The following characteristics are measured: particle size distribution (pipette method), pH of soil-1M KCl suspensions (1:5 ratio), organic carbon (C, Walkley and Black method), total nitrogen (N, Kjeldahl method), total phosphorus (Ptot, extraction with aqua regia), available phosphorus (Pav, Bray II method), total potassium (Ktot, flame photometry) and cation exchange capacity (CEC, extraction of exchangeable cations by 1M NH4Ac, pH 7, desorption of NH4+ by 1M KCl). All analyses were carried out at the University of Agriculture and Forestry, Hue University.

Statistical analysis

Data was analyzed by utilizing the STATISTIX 10.0 software. Descriptive statistics such as mean and standard deviation (SD) were computed. Additionally, Pearson correlation was assessed at a significance level of P0.05 along with one-way ANOVA analysis.

Results and Discussion

Soil properties following studied communes

Data from Table 3 indicated that soil samples from 6 communes had soil texture belonging to the group of clay loam to clay. Soil texture was more significantly clay in A Luoi town and Son Thuy commune than in the remaining communes. The pHKCl was acidic and ranged from 4.95 to 5.44 with no significant differences in studied communes. Organic carbon (OC) was from 1.48% to 1.90% with the highest value in correlation with the clay content (48.74%) in A Luoi town. Similarly, N content was found higher significant differences in the A Ngo commune than in Hong Thai and Quang Nham communes. Most of the available phosphorus content was poor level (<10 mg/100 g) (MONDRE, 2024). The highest values of total potassium were observed in A Luoi town and Hong Bac commune from 0.56-0.59%. The lowest mean value of CEC is observed in Hong Thai (4.25 cmolc kg^{-1}) and the highest in Son Thuy (7.47 cmolc kg^{-1}). Our evaluation revealed the correlation among clay, organic carbon and cation exchange capacity (CEC) levels.

Specifically, in A Luoi town and Son Thuy commune, higher clay content was associated with increased organic

Table 1: General information on the 6 studied communes in A Luoi district, Thua Thien Hue province in 2023.

Commune	No. of villages	No. of households	Population (people)	Total land area (ha)	Agricultural land area(ha)	Main crops
A Luoi town	7	2,139	8,013	1,426	330,6	Rice, cassava, maize, vegetable, acacia, fruit tree, banana
Hong Thai	4	327	1,309	6,906	424,2	Rice, cassava, maize, vegetable, acacia, fruit tree, banana
Quang Nham	8	1,171	4,927	4,337	724,5	Rice, cassava, maize, vegetable, acacia, fruit tree, banana, coffee
A Ngo	6	980	3,863	874	309,3	Rice,cassava, vegetable, acacia, fruit tree,banana
Son Thuy	6	756	3,059	1,676	258,8	Rice, cassava, maize, vegetable, acacia, fruit tree, banana
Hong Bac	4	555	2,350	3,123	68,0	Rice, cassava, maize, vegetable, acacia, fruit tree, banana

carbon and CEC levels. This trend can be partially attributed to the increased cation exchange sites facilitated by soil organic matter (Deng *et al.,* 2018; Nguyen *et al.,* 2024). The findings align with the studies conducted by Pham *et al.* (2018), Nguyen *et al.* (2024) and Nguyen *et al.* (2024), whichhig hlighted the soil characteristics in the A Luoi district of Thua Thien Hue province in Central Vietnam. also highlighted.

Discrimination of soil properties following cropping pattern

One main objective of this study is to evaluate possible relationships between soil use and soil properties in the mountainous zone of the province. Indeed, mountainous soils naturally lack fertility and therefore the choice of adapted crops is more crucial than in more favored contexts. Other constraints for local agriculture result from adverse weather conditions. Therefore there is a great diversity of crops and cropping systems in the mountainous zone to cope with these difficulties and to increase the land use index per year (Jamala *et al*., 2013; Tahat *et al*., 2020).

Table 4 substantiates this visual observation and provides detailed information regarding the differences in mean properties between rice soil and other types of crop soils. Notably, all ten properties exhibit significant differences between the different soil types. These variations arise not only from inherent soil characteristics, particularly texture and organic matter content, which are crucial in influencing other properties but also from agricultural practices. The waterlogged conditions prevalent in paddy fields lead to soil reduction and initiate a series of physico-chemical and biological processes. Following submersion, the pH of acid soils tends to rise; however, the soluble ferrous iron released from Fe (III)-oxyhydroxides competes with exchangeable bases for adsorption sites (Fahmi *et al*., 2018). When paddy soils undergo re-aeration, Fe(II) transforms back into Fe (III), leading to the re-protonation of liberated sites or the incorporation of aluminum. This phenomenon accounts for the notably lower pH levels observed in dried paddy soils compared to other soil types (Gu *et al.,* 2019). Additionally, rice soils exhibit a higher cation exchange capacity (CEC), enabling them to retain a greater quantity of exchangeable bases. However, it is important to note that the overall content of exchangeable bases remains quite low, with the retention of essential nutrients like potassium being particularly vital (Fahmi *et al*., 2023; Yang *et al*., 2024).

The breakdown of soil or added organic material occurs relatively quickly in aerobic environments where oxygen serves as the electron acceptor. In contrast, submerged conditions present a limited or nonexistent supply of free oxygen, leading to the decomposition of organic matter being reliant on the presence of alternative electron acceptors such as ferric iron or sulfate. Furthermore, these alternative electron acceptors, including ferric oxyhydroxides or sulfate, are less effective in degrading organic matter compared to oxygen. As a result, the decomposition process is notably slower and less complete in flooded or anaerobic soil environments (Bi *et al.,* 2023).

Table 2: Number of soil samples collected in the 6 communes and corresponding cropping patterns in A Luoi district, Thua Thien Hue province.

Commune	Paddy rice	Cassava	Maize	Vegetable	Banana	Fruit tree	Acacia	Total
Total area (ha)	697.1	674.0	214.0	219.2	181.6	256.5	491.0	2,733
A Luoi town	10	5	2	4	2	4	4	31
Hong Thai	4	15	2	2	2	4	7	36
Quang Nham	11	15	10	3	5	6	18	68
A Ngo	12	2	-	3	2	3	5	27
Son Thuy	11	2	2	2	3	2	10	32
Hong Bac	10	13	4	5	4	5	10	51
Total	58	52	20	19	18	24	54	245

Table 3: The properties of the 245 soil samples following 6 communes.

Parameters	A Luoi town	Hong Thai	Quang Nham	A Ngo	Son Thuy	Hong Bac
Sand (%)	33.05^{b}±3.23	32.29^{b}±2.57	31.84^{b}±3.32	33.84^{b}±3.62	27.06^{c}±3.21	42.27^{a}±4.49
Silt (%)	18.21^{c}±2.43	33.28^{b}±3.65	37.79^{ab}±2.87	40.16^{a}±4.78	34.18^{b}±4.29	30.15^{bc}±3.81
Clay (%)	48.74^{a}±5.54	34.34^{c}±4.21	30.37^{d}±1.98	26.00^{e}±2.65	38.76^{b}±3.35	27.58^{e}±2.93
pHKCl	5.44^{a}±0.27	5.29^{a}±0.15	5.15^{b}±0.30	5.27^{a}±0.24	4.95^{b}±0.42	5.38^{a}±0.23
OC (%)	1.90^{a}±0.51	1.53^{b}±0.41	1.88^{a}±0.35	1.81^{a}±0.59	1.73^{ab}±0.37	1.58^{b}±0.42
N (%)	0.11^{a}±0.04	0.09^{b}±0.03	0.09^{b}±0.02	0.13^{a}±0.03	0.12^{a}±0.05	0.10^{a}±0.03
Ptot (% P_2O_5)	0.07^{b}±0.02	0.06^{b}±0.02	0.08^{a}±0.02	0.08^{a}±0.02	0.07^{b}±0.03	0.09^{a}±0.03
Pav (mg P_2O_5 100 g^{-1})	10.99^{a}±1.61	8.15^{c}±1.52	9.19^{b}±1.69	9.70^{b}±1.74	9.44^{b}±1.83	6.98^{d}±1.86
Ktot (% K_2O)	0.56^{a}±0.16	0.33^{c}±0.26	0.40^{b}±0.20	0.44^{b}±0.15	0.32^{c}±0.17	0.59^{a}±0.23
CEC (cmolc kg^{-1})	4.95^{bc}±2.80	4.25^{c}±1.64	5.43^{b}±2.11	7.04^{a}±1.85	7.47^{a}±1.92	4.54^{c}±1.66

Different letters on the same row indicated significant differences at 0.05 level; Mean±SD.

This phenomenon may contribute to the elevated levels of organic carbon found in paddy soils, alongside other factors such as the increased clay content that helps stabilize humic substances.

The primary agricultural products in the examined area consist of rice, maize, cassava, bananas, various vegetables (from home gardens), fruit trees and acacia. The traditional agricultural systems are diverse, having developed in response to the specific soil and climatic conditions, as well as social and ethnological preferences (Nguyen *et al.,* 2024; Nguyen *et al.,* 2024). It is common for traditional farmers to cultivate multiple crop species within a limited area. Intercropping, which involves the simultaneous cultivation of two or more crops in the same field, is prevalent across tropical regions and is frequently observed in the study area. Additionally, multi-layered homestead gardens, which integrate more than three annual crops and vegetable species alongside tree crops, are typical in humid regions (Gardarin *et al.,* 2022). In this analysis, we examine seven categories of land use: rice (58 samples), cassava (52 samples), maize (20 samples), fruit tree (24 samples), acacia (54 samples) and other crops (37 samples) (Table 2).

Table 4 indicates that soils utilized for maize and banana cultivation exhibit lower significant clay content (23.39 - 26.55%) and highers and content (34.12 - 42.21%) compared to other annual crop soil types, while fruit tree and rice soils have higher clay content (36.56 – 41.70%) than other crops. The average organic carbon content is marginally higher in rice soils (OC = 1.84%) and fruit tree soils (OC = 1.94%) than in cassava soils (OC = 1.64%) and acacia soil types (OC = 1.63%). The higher OC could be due to the addition of plant litter to the soil, the increased return of organic residues from nearby family residences, continuous cropping throughout the year and reducing the rate of risk of erosion. However, the lower OC from cassava and acacia soils could be the removal of crop residues, soil erosion and soil disturbances during plowing and harvesting that expose the soils (Molla *et al.,* 2022). The average pH values are slightly higher in rice and fruit tree soils compared to other soils, which can be attributed to earlier observations regarding the impact of waterlogging and organic matter on soil acidity (Fahmi *et al.,* 2018; 2023; Vu Thanh Pham and Quang Minh Vo, 2023). Regarding cation exchange capacity (CEC), the only notable characteristic is the higher average value found in rice soils compared to other soil types, which aligns with the increased clay and carbon content observed in rice soils (Solly *et al*., 2020; Yuan *et al.,* 2023).

Certain soil characteristics can be classified as intrinsic properties, while others arise as direct or indirect

Table 4: Mean values of soil properties following cropping patterns.

Parameter	Rice	Cassava	Maize	Vegetable	Banana	Fruit tree	Acacia
Sand (%)	32.99^{cd}±3.43	36.79$^{b\backslash}$±3.56	34.12^{cd}±2.78	35.93^{b}±3.67	42.21^{a}±4.35	36.32^{b}±4.12	25.86^{d}±2.87
Silt (%)	30.45^{de}±2,32	32.13^{cd}±3.45	42.49^{a}±4.76	39.84^{ab}±3.87	31.24^{de}±3.54	21.94^{e}±3.28	34.74^{bc}±3.56
Clay (%)	36.56^{b}±4.51	31.08^{cd}±2.98	23.39^{d}±2.12	34.23^{bc}±3.62	26.55^{d}±2.86	41.74^{a}±4.21	35.10^{bc}±3.09
pH_{KCl}	5.37^{a}±0.15	5.19^{a}±0.17	5.08^{a}±0.12	5.09^{a}±0.29	5.24^{a}±0.33	5.30^{a}±0.17	4.86^{a}±0.31
OC (%)	1.84^{b}±0.31	1.68^{d}±0.21	1.78^{c}±0.19	1.83^{b}±0.34	1.74^{c}±0.35	1.94^{a}±0.38	1.63^{d}±0.70
N (%)	0.08^{a}±0.01	0.06^{a}±0.01	0.06^{a}±0.02	0.09^{a}±0.03	0.06^{a}±0.02	0.07^{a}±0.03	0.06^{a}±0.03
P_{tot} (% P_2O_5)	0.06^{a}±0.02	0.05^{b}±0.01	0.06^{b}±0.01	0.05^{b}±0.02	0.05^{b}±0.01	0.05^{b}±0.02	0.04^{c}±0.01
P_{av} (mg P_2O_5 100 g^{-1})	8.77^{b}±1.87	7.77^{bc}±2.03	7.89^{bc}±2.12	8.23^{bc}±1.81	9.59^{a}±1.41	8.70^{b}±2.39	6.35^{c}±1.68
K_{tot} (% K_2O)	0.54^{a}±0.11	0.32^{c}±0.15	0.35^{c}±0.18	0.18^{d}±0.06	0.47^{b}±0.15	0.40^{bc}±0.16	0.39^{c}±0.18
CEC (cmolc kg^{-1})	5.47^{a}±1.53	4.42^{c}±0.90	4.86^{c}±0.87	5.33^{a}±0.68	4.77^{b}±1.04	4.77^{b}±0.94	4.68^{c}±1.89

Different letters indicated significant differences at 0.05 level on the same row; Mean±SD.

Table 5: Pearson correlation coefficient among soil characteristics in 245 samples.

	Sand	Silt	Clay	pHKCl	OC	N	P_2O_5	Avail.P_2O_5	K_2O	CEC
Sand	1.00									
Silt	-0.64**	1.00								
Clay	-0.30**	-0.51**	1.00							
pH_{KCl}	0.51**	-0.19ns	-0.33**	1.00						
OC	-0.07ns	0.19ns	0.73**	-0.14ns	1.00					
N	0.00ns	0.05ns	0.34**	-0.21*	0.62**	1.00				
P_2O_5	0.25*	0.01ns	-0.32**	0.01ns	0.17ns	0.67**	1.00			
Avail. P_2O_5	-0.21ns	0.24*	-0.02ns	0.32**	0.73**	0.17ns	0.22*	1.00		
K_2O	0.57**	-0.38**	-0.22*	0.38**	-0.14ns	-0.04ns	0.33**	-0.22*	1.00	
CEC	-0.44**	0.50**	0.71**	-0.39**	0.71**	0.36**	0.17ns	0.41**	-0.29**	1.00

** indicatedsignificant differences at P<0.01; *significant differences at P<0.05; nsnon significant differences at P<0.05.

effects of these intrinsic features. For instance, factors such as texture, organic matter content (as indicated by oxidizable carbon) and pH significantly influence various other properties, including cation exchange capacity (CEC), organic nitrogen and phosphorus, which are typically closely associated with total nitrogen and phosphorus levels. Consequently, we computed correlation coefficients (r) among all soil characteristics, as presented in Table 5. The most substantial significant correlations were observed between CEC and clay (r=0.71), OC and clay, available P (r=0.73), OC and nitrogen (r=0.62) as detailed in Table 5. This indicates a strong correlation among nitrogen, CEC and organic carbon across all soil samples. Additionally, organic carbon exhibited significant correlations with other characteristics, including pHKCl, phosphorus and potassium. Previous research has noted similar correlations, as reported by Sang*et al.* (2013) and Naikwade *et al.* (2019). The average carbon-to-nitrogen (C/N) ratio of the 245 soil samples was approximately 16.1, which is indicative of well-humified organic matter. This suggests that the soils under investigation still contained coarse or partially decomposed organic material, potentially linked to low biological activity in acidic sandy soils. Furthermore, many samples were collected from rice fields, where the humification process occurs more slowly in waterlogged conditions compared to aerated soils (Fahmi *et al.,* 2018). The cation exchange capacity was influenced by organic matter, as evidenced by the significant correlation coefficients between CEC and OC (r=0.71), consistent with findings from Pham *et al.* (2018) and Somchai (2024). Previous studies have indicated that pH typically shows a positive correlation with soil CEC in acidic soils (Yunna *et al.,* 2018; Zhang *et al.,* 2023). However, our study did not reveal a significant negative correlation between pHKCl and soil CEC (r=-0.39), which may be due to the limited pH range of the soil samples analyzed (acidic, ranging from 4.95 to 5.44, with a mean of 5.34). While clay content is generally associated with a significant positive correlation to soil CEC, our findings are similarto previous studies (Bi *et al.,* 2023; Nguyen *et al*., 2024).

Conclusion

This research offers a comprehensive quantitative analysis of the physical and chemical characteristics of soils in the mountainous zone of Thua Thien Hue province. A key observation is that different cropping systems are generally linked to notable alterations in soil properties. Specifically, the cultivation of two rice crops annually is influenced by the landscape and the availability of irrigation; however, soils cultivated with rice crops and fruit trees exhibit lower sand content and higher levels of silt and clay, along with an increased organic carbon content compared to soils used for other crops. These results establish a robust basis for subsequent investigations into soil management practices, encompassing both organic and inorganic fertilization strategies aimed at sustaining long-term agricultural productivity. In this regard, enhancing the organic matter cycle within agricultural systems should focus on maximizing the return of organic materials to the soil, thereby facilitating gradual nutrient release through mineralization and improving the soil's nutrient retention capacity.

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Disclaimers

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Informed consent

None.

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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