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Assessment of Soil Quality Parameters under Rice and Maize Cropping Systems in Hilly Region of Central Vietnam

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ABSTRACT

Background: Assessments of the soil quality can be used to evaluate sustainable soil management techniques. There is currently a considerable risk of desertification and soil deterioration in the Central region of Vietnam, which includes the province of Nghe An. The present research aims to report data on 10 physical and chemical properties of soil samples collected from the hilly zone of Nghe An province and relate their characteristics to cropping patterns.

Methods: 142 composite soil samples were taken from the 0-20 cm layer of rice and maize crop plots after the harvest in the summer autumn season of 2022. They were air dried and sieved at a 2 mm mesh, then were analyzed to physico-chemical characterization using standard laboratory techniques in 2023.

Result: Our results indicate that soil properties were linked significantly to different cropping patterns including paddy soils and maize soils. Analysis of soil characteristics demonstrated that rice soils are finer textured (clay content ≈30.1%), whereas maize soils have clay content lower than 25%. All 10 properties are significantly different for the rice field and another of which CEC and organic matter content are the most important to govern other characteristics. The content of organic matter was higher in fields with two rice crops (3.49%) than in fields with maize crops (2.20%).

Key words: Correlation, Hilly zone, Maize, Rice, Soil properties.

INTRODUCTION

Soil quality assessments can be used to evaluate the sustainability of soil management practices. Bünemann *et al*. (2018) defined soil quality as, "the capacity of a soil to work within ecosystem and land-use boundaries to sustain biological productivity, preserve environmental quality and advance plant and animal health". It is determined by combining and evaluating several physical, chemical and biological markers associated with the functioning and processes of soil.

Generally, soil quality refers to the soil's capacity to sustain human requirements, preserve and enhance the water and air in the soil and supply nutrients to plants (Tahat *et al*., 2020). Unfortunately, in many parts of the world, soil quality is quickly declining due to a variety of factors, such as the conversion of forest areas to arable land (Das *et al*., 2017) and intensive land use for crop production (Jamala and Oke, 2013). Changes in soil indicators and other characteristics can be used to quantify improvements in soil quality brought about by crop rotation or other land use practices (Basu *et al*., 2018). To assess the soil quality indicators under various land use types, numerous research has been carried out (Pham *et al.,* 2018; An *et al*., 2022; Meitasari *et al*., 2024).

There is currently a considerable risk of erosion and leaching induced soil degradation in the central region of Vietnam, which includes the province of Nghe An. The region is concentrated in mountainous and semi-mountainous areas (Pham *et al*., 2018, Nguyen *et al*., 2023; Ngu Huu Nguyen *et al*., 2023) and is affected by tropical weathering due to its high average annual temperature (24-25°C) and very wide range of daily and annual temperature variation.

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The average annual rainfall is significant (over 2700 mm) and concentrated in the seasons; the rainy season accounts for 75% of the annual rainfall, so the process of soil erosion is widespread in steep hilly areas, as well as landslides, floods and burials of arable land in the foothills and valleys (Nguyen *et al*., 2023). The Nghe An province has quite a lot of poor areas, restored forests, forests without reserves, with low canopy cover (only about 30-50%) and no role in surface water regulation; only nearly 8.71% of the area has a high canopy cover of 70-80% and 7.5% of the forest area has a canopy of 80-90%. This dramatically affects soil fertility and soil degradation. Besides excessive exploitation and use of land for wrong purposes, excessive use of chemical fertilizers and pesticides are also the causes of soil degradation. The objectives of this study were to: (a) assess the soil quality under different cropping systems in Do Luong district, Nghe An province; (b) relate soil characteristics to cropping patterns.

MATERIALS AND METHODS

Study area

Do Luong district (105°15′ - 105°45′ E and 18°55′ - 19°10′ N) was selected as the study area which is located in the west of Nghe An province, Central Vietnam with semi-mountain terrain and a total natural area is 35.372.18 ha including 32 communes and a town. The investigation area only consists of 7 communes in the Northwest semi-mountainous region *viz.* Ngoc Son, Lam Son, Boi Son, Giang Son Dong, Giang Son Tay, Hong Son and Bai Son communes. This is a sub-region with the potential for comprehensive agricultural development, especially a hilly garden economy combined with agroforestry systems. Covering a total natural area of 10.013 ha, these studied communes' characteristics are alternating two terrain types (hills and valleys). Hilly terrain runs in the Northeast direction from Giang Son Tay commune to Ngoc Son commune and valley terrain comprise basin valley with streams flowing through Giang Son Dong, Hong Son, Bai Son communes and valley type inclined slope including Boi Son and Lam Son communes).

Do Luong district has a complex climate regime, characterized by a hot and humid tropical climate, with lots of rain but unevenly distributed among the months of the year. The climate is divided into two seasons, (1) hot season from April to October with an average temperature of 30°C-35°C and (2) the cold season from November to March with an average temperature of 20°C-23.6°C. The average annual temperature ranges from 23°C-24°C, the highest temperature of the year is 40°C - 41°C (July) and the lowest temperature of the year is 12°C (January).

Based on the international classification systems (FAO, 2015), there were two main soil groups in this region *i.e* Fluvisols (16.42%) and Ferralic Acrisols (83.58%). The total agricultural land area of the whole district is 24,996 ha, accounting for 70.67 % of the total natural area (35,372 ha). Data in Table 1 indicated that the rice and maize area from 7 studied communes was 2.150 ha (accounting for 21.55% of the total natural area in these communes) and 558 ha (accounting for 5.60% of the total natural area in these communes), respectively (Statistical Yearbook of Nghe An province, 2023).

Soil sampling and characterization

Representative soil samples (n=142) were collected from each commune based on the following criteria: (1) major agricultural systems, (2) area planted to these cropping systems, (3) topographic features, (4) type of soil and farm management and (5) household income. Number of soil samples and associated crops are shown in Table 1.

Composite soil samples were collected at the harvest in the summer-autumn season of 2022 from the 0-20 cm layer of field plots (the mean area of one single plot in the study zone was around 1,000 m^2). They were air-dried and sieved at 2 mm immediately after sampling. Physico-chemical characterization of soil samples was carried out in 2023 according to classical laboratory procedures described in Page *et al.* (1996). The following characteristics were 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 (P_{tot}, extraction with aqua regia), available phosphorus (P_{av}, Bray II method), cation exchange capacity (CEC, extraction of exchangeable cations by 1M NH_4Ac, pH 7, desorption of NH_4^+ by 1M KCl).

Statistical analysis

Statistical analysis of data was performed using the STATISTIX 10.0 program. Descriptive statistics including mean, min, max and standard deviation (SD) were carried out and Pearson correlation at $P_{0.05}$ value, ANOVA (one factor) analysis and T_{test} were calculated.

RESULTS AND DISCUSSION

Soil properties following studied communes

Statistical analysis presented in Table 2 allows quantifying possible significant differences between the mean properties of soils from the 7 communes. The properties of the 142 soil samples indicated that the mean of sand, silt and clay contents was 39.44, 30.19 and 27.21%, respectively. It means that the soil texture of these soils in 7 communes was belonging to group from sandy loam to loamy clay. As far as texture was concerned following communes, the most important observation was that the soils from Bai Son had lower sand content and higher silt content than

Table 1: Land area and soil samples of studied communes in 2023.

Communes	Total natural area (ha)	Rice area (ha)	Maize area (ha)	No. of representative soil samples		
				Total soil samples	Rice crop	Maize rice crop
Bai Son	1.300.58	238	61	24	14	10
Boi Son	910.21	320	87	18	12	6
Giang Son Dong	2.210.11	248	78	16	10	6
Giang Son Tay	1.783.10	276	112	18	11	7
Hong Son	1.491.88	279	80	18	12	6
Lam Son	1.904.15	685	53	24	16	8
Ngoc Son	413.26	104	87	24	14	10
Total	10.013.29	2.150	558	142	89	53

Table 2: Soil characteristics following administrative communes.

Communes	Soil texture			Bulk density	pH_{KCl}	OM (%)	N (%)	P_2O_5 (%)	K_2O (%)	CEC
	% Sand	% Clay	% Silt	(g cm^{-3})						(cmolc kg^{-1})
Giang son dong	40.02^{b}±5.23	29.90^{ab}±6.69	30.07^{bc}±6.88	1.79^{a}±0.18	5.53^{a}±0.52	2.75^{b}±1.11	0.10^{a}±0.03	0.08^{a}±0.01	1.05^{ab}±0.25	10.41^{ab}±2.67
Giang sõn Tay	42.70^{ab}±4.42	31.78^{a}±5.88	25.52^{c}±5.70	1.54^{b}±0.19	4.85^{bc}±0.45	2.64^{b}±1.62	0.09^{a}±0.03	0.08^{a}±0.02	0.97^{b}±0.20	10.25^{ab}±4.06
Boi son	40.63^{b}±3.92	28.96^{ab}±3.79	30.41^{bc}±6.03	1.14^{c}±0.21	5.07^{ab}±0.42	3.63±0.83	0.11^{a}±0.02	0.09^{a}±0.01	0.93^{b}±0.15	11.85^{a}±2.49
Hong son	40.92^{b}±3.55	26.97^{bc}±6.96	32.11^{ab}±6.00	1.51^{b}±0.17	4.68^{c}±0.38	3.12±1.18	0.10^{a}±0.02	0.08^{a}±0.02	0.98^{b}±0.19	11.40^{a}±3.63
Bai son	37.46^{c}±2.51	28.51^{ab}±4.28	34.03^{a}±5.61	1.55^{b}±0.13	5.47^{a}±0.24	1.95^{c}±0.91	0.08^{a}±0.02	0.07^{a}±0.01	0.98^{b}±0.15	7.59^{b}±2.84
Lam son	43.54^{a}±4.80	24.08^{c}±6.87	32.44^{ab}±6.61	1.21^{c}±0.23	5.24^{ab}±0.73	3.62±1.12	0.11^{a}±0.03	0.07^{a}±0.01	1.16^{a}±0.18	11.95^{a}±2.64
Ngoc son	39.54^{ab}±4.53	25.98^{bc}±3.78	33.64^{a}±3.75	1.55^{b}±0.06	5.43±0.48	3.65±1.20	0.11^{a}±0.02	0.09^{a}±0.01	1.05^{ab}±0.17	12.51^{a}±2.70
Mean	39.44	30.19	27.21	1.41	4.99	2.97	0.10	0.08	0.99	10.61

a, b, c indicated significant differences at P<0.05 level on the same column.

the soils from the other communes. Mean values of the clay fraction were significantly higher in Giang Son Dong and Giang Son Tay communes. Organic matter was especially low in Bai Son commune (1.95%), with the highest mean values being found in Boi Son, Lam Son and Ngoc Son communes. This was to be related to differences in CEC; indeed, the lowest mean value of CEC was observed in Bai Son commune (7.59 cmolc kg^{-1}) and the highest in Ngoc Son commune (12.51 cmolc kg^{-1}). pH_{KCl} was an acid with a mean value of 4.99. Significant differences are also found for pH_{KCl} with values in Giang Son Dong, Bai Son and Ngoc Son higher than in the other communes, the range of variation exceeded 0.5 units around pH from 4.68 to 5.53. The average clay content of the 142 soil collection was 27% and the average organic matter content was lower than 4%. Consequently, the cation exchange capacity (CEC) of these soils was medium (average value from 10-20 cmolc/kg). Our assessment showed the relationship between sand, organic matter and CEC contents, *i.e.* in Bai Son commune where the higher sand content would lead to lower organic matter and CEC contents. CEC explains a greater amount of variation of SOC content in subsoils with a pH>5.5. However, this pattern could be partially explained by the increase in cation exchange sites provided by soil organic matter (Kong *et al.,* 2021; Vu Thanh Pham and Quang Minh Vo, 2023). Overall, our results of a complex role for soil pH in shaping the relationship between CEC and subsoil organic C strongly supports previous experimental and conceptual studies indicating that soil pH can serve as an important indicator of the mechanisms controlling SOC stabilization (Solly *et al*., 2020). The finding that clay content explains less variation in SOC content than CEC strongly supports the emerging conceptual understanding that other edaphic properties, such as soil mineralogy and metal cations interacting with soil organic matter, could predict the potential persistence of SOC better than the amount of clay (Rasmussen *et al*., 2018). Similarly, total N, P and CEC were in the level of medium, except for K in the poor range (<1%) (MONDRE, 2015). These results are consistent with Pham *et al*. (2018); Ngu Huu Nguyen *et al.* (2023) and Nguyen *et al*. (2024) who indicated soil characteristics in A Luoi district, Thua Thien Hue province, Central Vietnam.

Soil properties following cropping patterns

One of the primary objectives of this research was to assess potential correlations between soil use and soil attributes in the nghe an province's hilly region (Table 3). We investigated possible differences between paddy soils and maize soils. In reality, all ten quality parameters differed significantly between the two types of soil use. This is due not just to changes in intrinsic soil features, with texture and organic matter content being the most essential in governing other traits, but also to cropping practices followed in different crops. Indeed, waterlogged conditions in paddy fields promote soil loss and initiate several physical-chemical and biological processes. This may explain why the pH of

paddy soils, as measured after drying, is much lower than in other soils (Lu *et al*., 2022). Rice soils, however, have a greater CEC and can hold more exchangeable bases. Soil or additional organic matter decomposes relatively quickly in aerobic circumstances when oxygen serves as an electron acceptor. However, under submerged conditions, free oxygen is limited or absent and organic matter breakdown is dependent on the availability of electron acceptors such as ferric iron or sulphate (Wang *et al*., 2022). Furthermore, other electron acceptors (ferric oxyhydroxides or sulphate) are less effective at destroying organic matter than oxygen. As a result, organic matter breakdown is rather sluggish and incomplete in flooded or anaerobic soils (Gao *et al.,* 2023; Minh Quang Vo *et al*., 2020). This could be one of the explanations for the increased organic carbon concentration reported in paddy soils, together with the higher clay content, which stabilizes humic compounds. Double rice cropping is mainly practiced in fields with lower topography which allows irrigation during the dry summer season. As shown in Table 5, there were significant differences between most of the properties of soils in the two cropping patterns. In this study, sand content varied slightly in two different cropping systems. Soils with double rice crops were, on average, less sandy and more silty and clay than those with maize crops, particularly in terms of clay concentration. Organic matter content was significantly greater in fields with double rice crops (3.49%) than in fields with maize crops (2.20%). This could be attributed to the increased yearly return of crop residues (rice straw, rice roots) in soils cultivated throughout two cropping seasons compared to soils left fallow throughout the dry season, which stabilizes humid compounds (Somchai, 2024). Indeed, Liu *et al*. (2024) reported that the addition of organic matter to the soil in the form of straw can increase soil organic matter content in rice systems. We also found that the mean N content did not differ between the two cropping patterns, resulting in a greater mean C/N value for double rice crops (C/N=32) than for maize crops (C/N=22). This showed that the humification process is more complete in soils with a single rice crop, which is supported by fallow periods (soil aeration) and a reduced annual return of rice straw with a high C/N ratio. In terms of CEC, the only notable difference was that rice soils have a greater mean value than other soils, which was consistent with rice soils′ higher clay and C contents (Bu *et al*., 2020).

Some characteristics of soils can be considered as intrinsic properties whereas others are direct or indirect consequences of these. So, texture, organic matter content

Table 3: Soil characteristics following cropping patterns.

Parameters	Rice crop (n=89)				Maize crop (n=53)			
	Mean	Min	Max	SD	Mean	Min	Max	SD
Sand (%)	41.09[a]	21.56	51.40	4.77	40.36[a]	32.00	52.40	4.47
Silt (%)	28.93[a]	14.30	42.64	5.63	34.70[b]	17.70	47.10	6.43
Clay (%)	30.06[a]	15.60	43.60	5.37	24.74[b]	16.70	40.10	6.44
Bulk density (g cm^{-3})	1.44[a]	0.74	2.01	0.32	1.50[a]	0.83	1.97	0.15
pH_{KCl}	5.29[a]	4.14	6.60	0.55	4.90[b]	4.12	6.10	0.56
OM (%)	3.49[a]	0.88	5.23	1.20	2.20[b]	0.88	4.75	1.03
N (%)	0.11[a]	0.06	0.15	0.03	0.10[a]	0.06	0.12	0.02
P_{tot} (% P_2O_5)	0.08[a]	0.04	0.10	0.02	0.10[a]	0.05	0.10	0.01
K_{tot} (% K_2O)	1.03[a]	0.60	1.50	0.20	1.00[a]	0.70	1.35	0.20
CEC (cmolc kg^{-1})	11.47[a]	4.50	17.50	3.42	9.80[b]	5.00	17.50	3.00

a, b indicated significant differences at P<0.05 level on the same column.

Table 4: Pearson correlation coefficient among soil characteristics in 142 samples.

	Sand	Clay	Silt	BD	pH_{KCl}	OM	N	P_2O_5	K_2O	CEC
Sand	1.00									
Clay	-0.14[ns]	1.00								
Silt	-0.54**	-0.75**	1.00							
BD	-0.42*	0.42**	-0.10ns	1.00						
pHKCl	-0.52**	-0.21ns	0.51**	0.30*	1.00					
OM	0.49**	-0.57**	0.12ns	-0.58**	-0.16ns	1.00				
N	0.44**	-0.56**	0.15ns	-0.48*	-0.02ns	0.98**	1.00			
P_2O_5	-0.08ns	0.19ns	-0.17ns	-0.06ns	-0.13ns	0.54**	0.53**	1.00		
K_2O	0.42*	-0.71**	0.33*	-0.03ns	0.41*	0.33*	0.40*	-0.43*	1.00	
CEC	0.54**	-0.46**	-0.02ns	-0.41*	-0.25ns	0.97**	0.95**	0.59**	0.31*	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).

(as inferred from oxidizable C) and pH governor have a deep influence on many other characteristics such as CEC, organic N and P (which are usually close to total N and P). Therefore, we have calculated correlation coefficients (r) between all soil characteristics (Table 4).

The highest significant correlations were found for N and organic matter (r=0.98), followed by CEC and organic matter (r=0.97); CEC and N (r= 0.95) (Table 4). It means that all soil samples had a high correlation between N, CEC and organic matter. Besides this, OM had a significant correlation with other characteristics such as pH_{KCl}, P, K. Some studies mentioned this correlation such as Voltr *et al*. (2024); Naikwade *et al*. (2019). The mean C/N value of the 142 soils was around 17, which was high for well-humified organic matter; it means that the studied soils still contained rough or partially decomposed organic debris, which can be related to low biological activity in acid sandy soils; moreover, many soils were collected in rice fields where humification in the waterlogged condition is slower than in aerated soils. The cation exchange capacity was to due organic matter; we observed significant correlation coefficients between CEC and organic matter (r = 0.97), similar to the results from Bi *et al*. (2023) and Somchai (2024). Previous studies showed that pH usually has a positive correlation with soil CEC for acid soils (Kong *et al*., 2021; Zhang *et al*., 2023), however, no significant negative correlation was found in our study between pH_{KCl} and soil CEC (r= -0.25), which could be attributed to narrow range of pH of the soil samples used in our study (acid, 4.24 - 6.60 with a mean of 4.99 in pH). Clay content usually also has a significant positive correlation with soil CEC (Bi *et al*., 2023), but our results neither found such a phenomenon of negative significant (r=-0.46), which possibly could be attributed to the high content of clay contents in our soil samples (meanly 272 g kg^{-1}). A significant positive correlation was found between soil CEC with sand content in our study (r= 0.54), which is consistent with the previous studies (Rahal and Alhumairi, 2019; Kong *et al*., 2021; Bi *et al*., 2023) and could be attributed to sand fraction mainly composed of quartz and iron concretions with low charge density (Silva *et al.,* 2020). Moreover, no significant negative correlation was also found between soil CEC with silt content in our study as in other studies (Khodaverdiloo *et al*., 2018; Rahal and Alhumairi, 2019).

CONCLUSION

This study provides a sound quantitative description of the physical-chemical properties of soils in the hilly region of Nghe An province. The main finding is that varied cropping patterns are typically associated with significant changes in soil attributes. The practice of planting two rice crops in a year is tied to topography and irrigation availability; nonetheless, soils under double rice crops are less sandy and more silty, clay and have a higher organic C content than soils under maize crops. These findings provide a solid foundation for future research into soil management, including organic and inorganic fertilization for long-term productivity. In this context, optimizing the organic matter cycle within farming systems should aim to maximize organic return to soils to ensure progressive nutrient release through mineralization as well as increased nutrient storage capacity.

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Conflict of interest

All authors declare that they have no conflict of interest.

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