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Degradation of Soil Quality Related Physical and Chemical Properties Affected by Agricultural Practice in Le Thuy District, Quang Binh Province, Vietnam

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ABSTRACT

Background: Agricultural practice is considered as main factor affecting land degradation in several regions in Vietnam. However, there are limited studies relating to degraded soil properties and their soil fertility. This paper aimed to evaluate the degradation of agricultural soil under different land management practices.

Methods: A total of 80 samples at 0-10 cm of agricultural soil were collected to analyze selected physicochemical properties. The group of degradation soil properties was classified based on their soil fertility using principal component analysis.

Result: The results showed that physicochemical properties in agricultural soil along coastal regions were relatively lower than in hilly regions/secondary forests. High ratio of C:N in agricultural soil was because of degradation. The organic matter, nitrogen and phosphorous contents were low in the soil in lowland areas indicating a high level of degradation (1.43%, 0.09% and 0,04%, respectively). The samples classified into four groups (G_1, G_2, G_3, G_4) using principal component analysis indicated differences in soil properties due to degradation. Insufficient and excessive application of inorganic fertilizer could be a further reason affecting the status of soil properties. Overall, soil physicochemical properties indicated poor conditions for agriculture systems, thereby, careful soil management is the primary solution.

Key words: Degradation, Soil Organic Matter, Soil Physicochemical Properties, Vietnam.

INTRODUCTION

Agricultural management is considered a main factor affecting land degradation. The physical and chemical properties of topsoil are affected by the conversion of forest to agriculture and unappropriated land use types (Wezel *et al.,* 2002). The soil organic matter (SOM) and selected soil properties (*e.g*., soil pH and phosphorus, potassium and nitrogen contents) are not similar under different land use types and agricultural history. For example, organic carbon sequestration occurs on the surface soil after land use conversion (Zilverberg *et al.,* 2018). Soil pH value can also reduce because of inorganic fertilizer application and the large addition of organic matter with trash harvesting (Hartemink, 2004). The phosphorus and potassium contents could be lost in conditions of extensive precipitation and tillage practice (Yaşar Korkançe *et al.,* 2019). Thus, soil nutrition is going to be depletion and strongly influencing agricultural products (Zhu *et al.,* 2017). Soil is the most important component in sustainable land management (Kiflu *et al.,* 2013). The soil physicochemical indicators, including texture, pH, total nitrogen, total phosphorus, potassium and soil organic matter, have been used to assess soil quality and observe soil degradation but they are scared in tropical regions.

In Vietnam, agricultural product plays an important role in national economy and food security. The agricultural land accounts for approximately 84.5% of the total area and with a cultivated area of 9.6 million ha (ADB, 2021). Annual and perennial crops (e.g., rice, cassava, maize, acacia) are known for their long agricultural history (Dong *et al.,* 2014; Bich *et al.,* 2018). These crops are mostly done with intensive tillage, insufficient and excessive application of inorganic fertilizer. This is a main cause to increase soil degradation which indicates the reduction of organic matter, nitrogen, potassium and phosphorus content (Tung *et al.,* 2018). The reduction of soil properties can be led to depress production and crop yield. Thus, soil properties are a good criterion to select sustainable land use types. The land use types and land management are recognized by an effective climate change mitigation option. Appropriate agricultural practices are known to maintain soil fertility. However, the studies relating to degraded soil properties are limited Vietnam.

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This paper aimed to obtain the degradation of soil properties under different agricultural practices and land use types in Le Thuy district and recommended solutions to maintain soil fertility. Organic matter, nitrogen, soil pH, phosphorous and potassium contents in the soils were assessed to evaluate the level of degradation.

MATERIALS AND METHODS

Characteristic studying site

The study was conducted on agricultural soils in Le Thuy district, Quang Binh province, Vietnam. The site was located at Lat 16°55′N to 17°26′N and at Long 106°17′E to 106° 59′E. The soil depth and vegetation cover were homogeneous in the study areas. The history of agriculture indicated that they had been under cropping systems with added organic fertilizer for up to 20 years. Investigated soils were fine, loamy-clay, sandy-loam, siliceous and reddish-yellow oxidizing conditions predominate, with Fe- and Al-oxides being the most abundant elements. These soils were mostly classified as Acrisols and Arenosol (Bo *et al.,* 2002; IUSS Working Group, 2022). These soils were low fertility status which is a main factor restricting the agricultural plantation. The slope of region was gentle and approximately 10-15% (Fig 1). The site receives a total annual rainfall of 2,200 mm, ranging from 1,500 to 2,500 mm. The minimum and maximum average temperatures were approximately 16.9°C to 34.3°C, respectively. The plantation was originally a secondary forest that had been converted to agriculture. Major plant species were rice, maize, beans, cassava and acacia.

Agricultural land use type distribution

Agricultural distribution is illustrated in Table 1 and Fig 2. Wetland rice is a majority component of agriculture with 49.3%. The wetland rice season started from January to April and from May to August. The inorganic fertilizers, such as nitrogen, phosphorus and potassium were applied approximately 200 kg ha^{-1}, 400 kg ha^{-1} and 150 kg ha^{-1}, respectively, for each season as seen in Table 2. The annual crop occupied about 5,041 ha (22.7%) with cassava, maize and bean plantation. Perennial crops were about 6,223.2 ha (28.0%) and mostly acacia, rubber and fruits in the garden.

Soil sampling

Soil samples were randomly selected from land use types after harvesting crops at 0-15 cm depth. A total of 74 samples were collected from agricultural land of rice, cassava, acacia and maize plantations. There were 32 samples from hilly and 42 samples from lowland regions, respectively. In addition, 10 samples were also taken from the secondary forest/or nearby secondary forest. The number of samples was determined according to the technical regulations on soil degradation investigation of the Natural Resources and Environment Ministry, Vietnam (Circular No. 60/2015/TT-BTNMT). All samples were air dry and sieved through a 2mm screen before analysis.

Soil analysis

The soil pH was determined by mixing an aliquot of sample with 1 mol L^{-1} potassium chloride solution, at a soil/liquid ratio of 1:5 (w/v). A glass electrode was used to measure the value for each sample (HI5521, Hana Instrument Co., Ltd, Vietnam).

The particle-size distribution of soils was determined by a combination of sieving and pipette methods. In brief, a 10-g sample of air-dried soil was pretreated with hydrogen peroxide solution (30%). Coarse (0.2-2 mm) and fine sand (0.02-0.2 mm) content were determined using the sieving

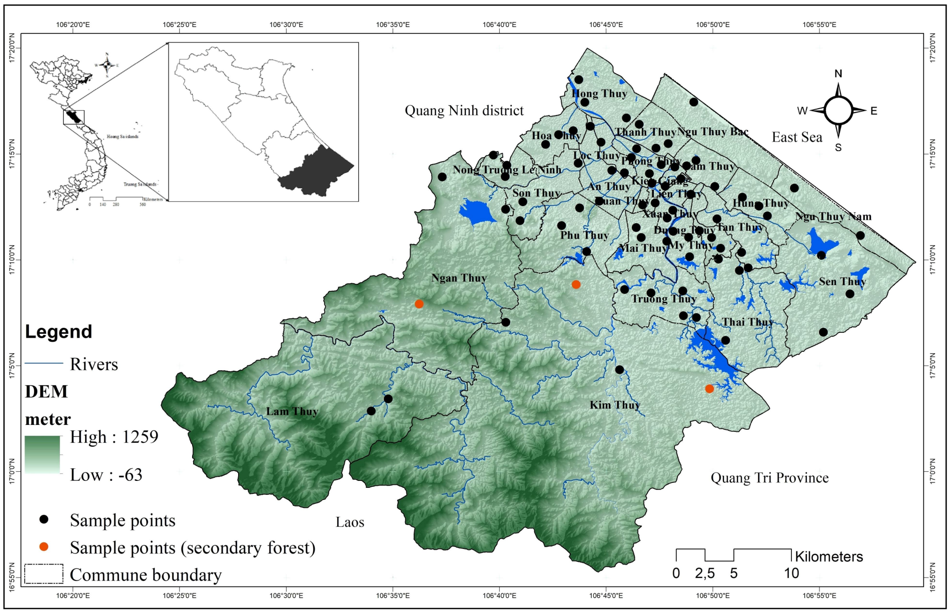

Fig 1: Soil sampling at study site.

method. The initial pH value of the soil solution was adjusted from 9 to 10 using NaOH solution. The silt (2-20 µm) and clay (< 2 µm) content of the sample were determined using the pipette method (Gee and Or, 2002).

Soil organic matter (OM) content was analyzed using the Walkley-Black procedure. A 1.0 g of air-dried soil was added with $K_2Cr_2O_7$ solution and then swirl the flask gently to dispense the soil. Concentrated sulfuric was directly added into the suspension and then using H_3PO_4 solution with a concentration of 85%. Finally, organic matter was titrated by the solution of $FeSO_4$ 0.5 mol L^{-1} (Roper *et al.,* 2019).

Absolutely 1.0 g of air-dried soil was added solution of acid sulfuric and hydrochloric acid at 105°C temperature until the solution becomes clear. The solution was used to determine nitrogen, phosphorus and potassium contents. Total nitrogen content was analyzed by the Kjeldal method (UDK 129, VELP Scientifica Srl, Italy). Total phosphorus was measured using the color comparison method using spectrophotometer (UV1700, Shanghai Instrument Co., China). The total potassium content in the sample was determined by using Flame Photometer (FP640, Shanghai Drawell Scientific Instrument Co., Ltd, China).

Data analysis

Before analysis, all data were checked for normality distribution using the Kruskal-Wallis test. The differences in soil chemical properties were assessed using analysis of variance (ANOVA) with Duncan multiple range test (DMRT) to compare means among land use types. The T-test was used to compare means between land use types. Principal component analysis (PCA) was performed on the soil properties of soil samples to assign a factor score for each sample. Statistical analysis was performed using SPSS Version 20 (IBM, New York, USA).

RESULTS AND DISCUSSION

General soil properties

The general soil properties including soil particles, soil organic matter (OM), nitrogen (N), phosphorous and potassium, are presented in Table 2. The coefficient of variation ranged from 7.6% to 46.8% indicating that the condition of soil formation was relatively uniform. The soil was mostly similar in terms of parent material, topography and native vegetation; but varied in terms of management practice and intensity. Thus, differences in soil properties associated with management practice must be distinguishable from those associated with natural.

Varian of soil properties under different land use types

Soil particle distribution

The particle size distribution under different plantations in each commune is presented in Fig 3. The soils were mainly sandy and the dominant textural classes were sandy and sandy clay loam. The sand, silt and clay contents of the soil samples varied from 23.8% to 99.6%, 0.06% to 42.1% and 0.65% to 33.6%, respectively. Samples from Sen Thuy, Hung

Table 1: Agricultural patterns and major land use types in Le Thuy district.

Items	Area (ha)	Land use types	Fertilizer application (kg ha^{-1})
Rice	10,957	Wet rice	200N-400P-150K
Annual crops	5,041	Cassava	None
		Maize	100N-200P-100K
		Bean	150N-100P
		Others	160N
Long term crops	6,223	Rubber	None
		Acacia	None

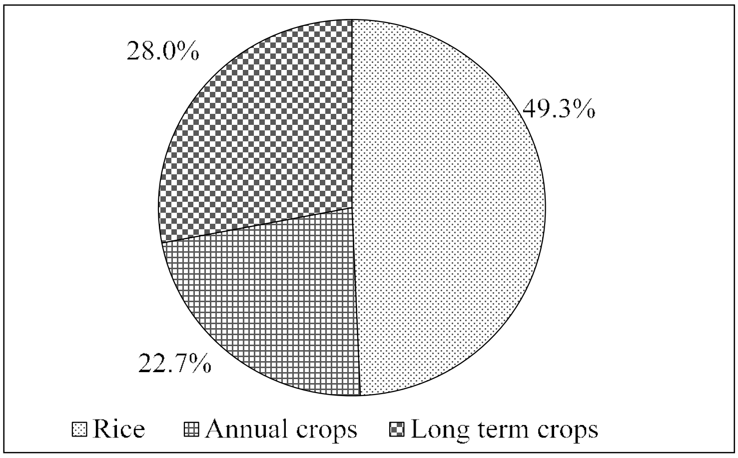

Fig 2: The distribution pattern of agriculture in Le Thuy district.

Thuy, Cam Thuy, Ngu Thuy Nam and Ngu Thuy Bac communes had high percentage of sand content, with ranged from 50 to 98%. This was because these communes are nearby river**s** and coastal zones. Meanwhile, silt and clay contents in these samples ranged from 5 to 35% and 2 to 30%, respectively. The higher clay and silt contents in the soils were distributed in mountainous and hilly regions. The high contents of clay and silt were probably due to soil erosion that caused the movement of surface layers. Both N and C were found negative relationship with sand content while positively correlated with silt and clay contents (Fig 3, 4). The previous reported that clay content had positive correlation with concentrations of C, N, or P in the soil (McGrath *et al.,* 2001). The lower clay content and lack of aggregation (*i.e*. absence of soil organic matter protection and stabilization) in coarse-textured soil were major factors limiting soil C storage capacity, despite higher C input from litterfall (Xiangmin *et al.,* 2014).

Soil pH value

The average values of soil pH_{KCl} in each commune are in Fig 5. As expected, no significant differences in soil pH_{KCl} distribution were found among communes, including the secondary forest site. The mean of pH_{KCl} values below 4.13 ranged as extremely acidic, between 4.5 and 5.0 as very strongly acidic. These soils were classified at levels of pH2 and pH3 that indicated poor conditions for agriculture. The soils having low pH values were in Van Thuy, Thai Thuy, Kim Thuy communes. This was probably due to continuous cultivation for a long period and vegetative coverage, which caused extensive secretion of organic acids associated with accelerated organic matter decomposition. Decreases in soil pH have often been found to be the result of plantation establishment (Liao *et al.,* 2012). The low acidic soil organic matter and the displacement of base cations resulted from the production of H^+ during nitrification. Subsequently, the leaching cations from the soil profile due to high rainfall may be other reason for the acidity rise.

Potassium content

The total potassium of agricultural soil is shown in Fig 6. The content of total potassium varied from 0.3 to 1.6% in the soil. This result indicated that soil in these regions decreased soil nutrient levels, as has been noted by previous studies (Wang *et al.,* 2014). However, potassium content in Kim Thuy and Hoa Thuy communes was high in the soil (1.6%, 1.3% and 1.2%, respectively). This was because these samples were mostly collected from rice plantations

Table 2: General agricultural soil properties in Le Thuy district.

Items	Unit	Min	Max	Average	Std.	CV
pH		3.63	4.76	4.13	0.31	7.61
Sand	%	23.8	99.6	62.1	16.7	26.9
Silt	%	0.06	42.1	19.9	9.33	46.8
Clay	%	0.65	33.6	17.8	7.12	40.1
OM	%	0.46	3.36	2.31	0.52	22.7
N	%	0.04	0.20	0.13	0.03	24.7
P	%	0.02	0.09	0.05	0.02	39.8
K	%	0.26	1.86	0.73	0.28	38.4
C:N		10.5	20.8	17.7	2.20	12.4

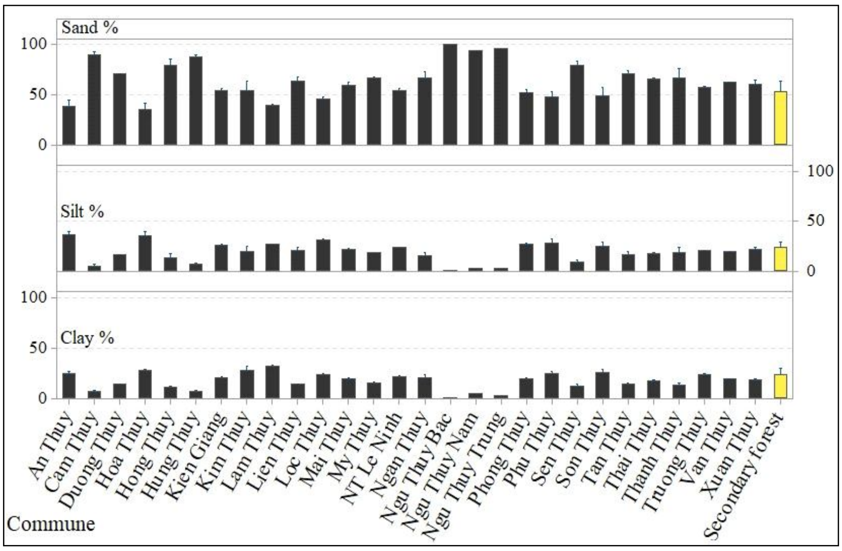

Fig 3: The particle size distribution in agricultural soil.

that had high application of inorganic potassium fertilizer. Previous studies noted that a high amount of potassium application represented a high level of potation in the soils (Ahogle *et al.,* 2022).

Phosphorus content

Phosphorus content in agricultural soil is exhibited in Fig 7. The value of phosphorus was relatively low in the soil, ranging from 0.03% to 0.09%. A small P content was probably because of erosion and runoff in the hilly/ mountainous region (Zhong *et al.,* 2018). Phosphorus content An Thuy and Phu Thuy communes (0.09% and 0.08%, respectively), was higher than Cam Thuy, Ngu Thuy Trung and secondary forest sites (Fig 6). This was probably a result of the higher fertilizer application added to the higher concentration of P found in the agricultural soil. P content was tiny in lowland region probably as the result of high sand content. A relatively higher P in agricultural soil than those in forest and sandy land was found in the present study.

Total nitrogen content

The total nitrogen was relatively low values in agricultural soil as seen in Fig 8. The total nitrogen content varied between 0.05% and 0.19% in the soil. This was probably the lower nitrogen content because of continuous tillage conditions, indicating high soil degradation. Nitrogen content was the smallest in Ngu Thuy Bac commune (0.05%) while the biggest in Lam Thuy commune (0.19%). The lower nitrogen content was because of very high sand content in the soil. Lower N content in the soil may be due to some factors including rapid nutrient uptake by agricultural production, lower rate of decomposition despite increase in litter production (Ahogle *et al.,* 2022) and leaching of available nutrients due to high rainfall. A higher nitrogen content was due to high clay content the soil, particular in

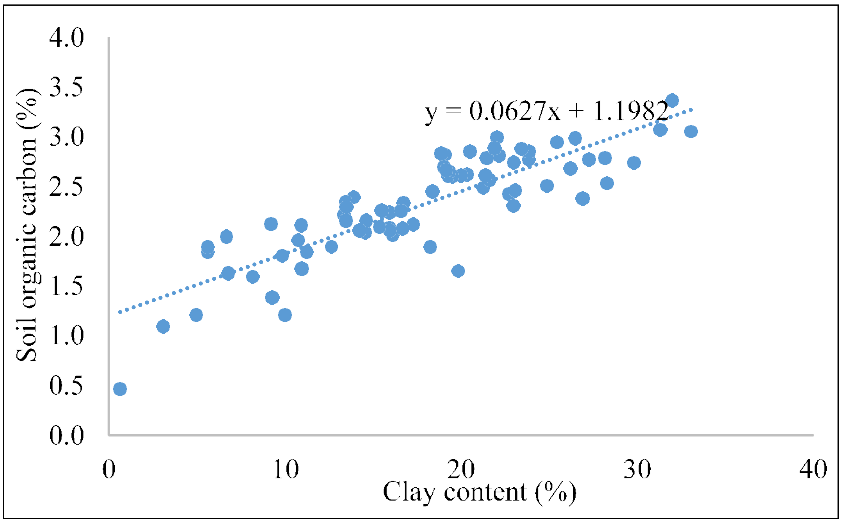

Fig 4: The correlation between clay content and soil organic carbon.

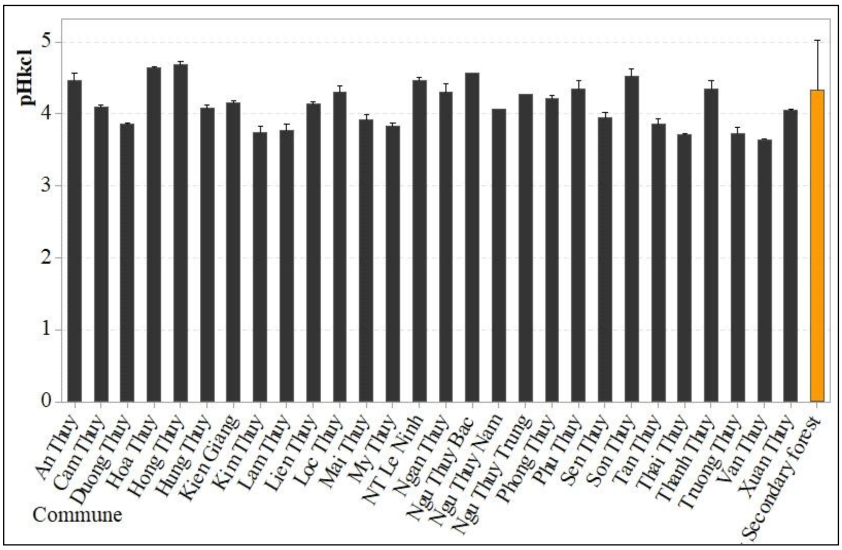

Fig 5: pH_{KCl} value of agricultural soil in Le Thuy district.

Lam Thuy commune. Another reason was the sample collected from the acacia site could be an important reason for the higher nitrogen content. Acacia had substantial nitrogen-fixation ability, particularly decomposition of acacia products (*e.g.*, litterfall and root) could be the main reason for the high nitrogen content (Yang *et al.,* 2010). These outcomes have been linked to the large amounts of litter deposited by acacia plantations, which can lead to increased capacity of the soil to store nitrogen content.

Total organic matter

Total organic carbon contents in agricultural soil in Le Thuy district are illustrated in Fig 9. The mean values of organic carbon ranged from 0.5% to 2.8% in the soil. The secondary forest and acacia plantation had higher organic carbon content than annual cropland. The contents of organic carbon in Loc Thuy (2.8%), Son Thuy (2.85%), Lam Thuy (2.75%) and Kim Thuy (2.72%) were significantly higher than those in Ngu Thuy Bac (0.4%), Ngu Thuy Trung (1.1%) and Ngu Thuy Nam (1.2%). Higher SOC in the secondary forest site as compared to the agricultural soils (Fig 9) was due to the availability of plant residues after site clearing and preparation. Agricultural management practices, such as tilling and removing all residual of agricultural biomass, were probably the main reasons. An increase of 25% litterfall in secondary forests indicated higher soil organic carbon (Zilverberg *et al.,* 2018). The decrease in the amount of SOC is attributed to a decrease in the amount of plant residues returning to the soil and to an increase in the amount of CO_2 released from the soil organic matter to the atmosphere due to decomposition (Zhu *et al.,* 2017). In addition, there was a positive correlation between soil organic carbon and total nitrogen content among land uses (Fig 10). This linear regression showed that higher the soil carbon content, the

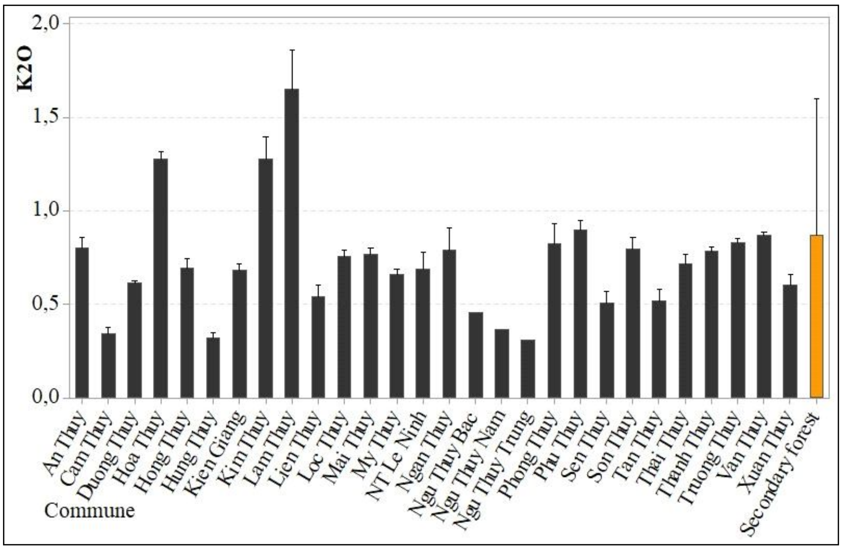

Fig 6: The total potassium K_2O (%) pattern in agricultural soil.

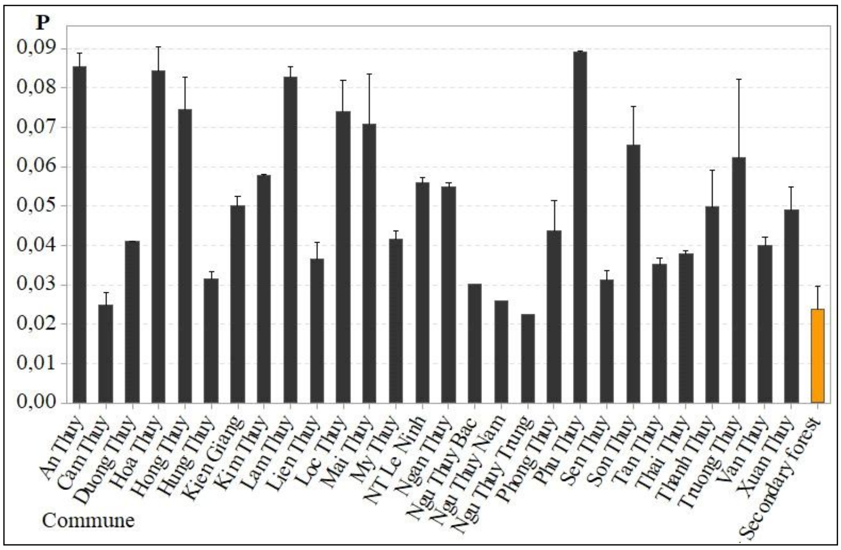

Fig 7: Total phosphorus distribution P (%) in agricultural soil.

ability of soil to retain nitrogen will be also higher (Wibowo and Kasno, 2021). This result also indicated that the land use plays a major role in the distribution of soil carbon and total nitrogen (Xue and An, 2018).

The high ratio of C:N in the soil reflected a high decomposition rate of nitrogen due to cultivation (Table 3). This was explained by a nitrogen loss and no carbon gain during agricultural land management. The C:N ratio is crucial indices indicating residue quality and rate of residue decomposition. Previous studies reported that C:N ratio is low indicating high decomposition rates of residues and mineralization of litter found in agricultural soil (Oladele and Adeyemo, 2016). The observation of lower soil C:N ratio was due to the nitrogen dynamic, favoring faster organic matter decomposition and nitrogen mineralization by microorganisms in the soil (Fang *et al.,* 2015).

Degradation of agricultural soil

The grouping samples based on total nitrogen, soil organic matter, potassium and phosphorous content of agricultural soil are shown in Fig 11. Cluster analysis using the factor scores determined by principal component analysis allowed the 74 soil samples to be separated into four groups. The mean values of soil properties for the different groups are shown in Table 3. The soil carbon content in groups 1 and 2 was higher 2.71±0.22% (mean ± standard deviation) and 2.75±0.23% than that of other groups. Moreover, the nitrogen contents were also relatively higher than those in groups 3 and 4. This was because these samples were collected from acacia sites and long-term crops (Fig 2). Previous studies reported that acacia could enhance soil organic matter and nitrogen in the soil (Brockwell *et al.,* 2005). Other studies reported that higher productivity and leguminous properties

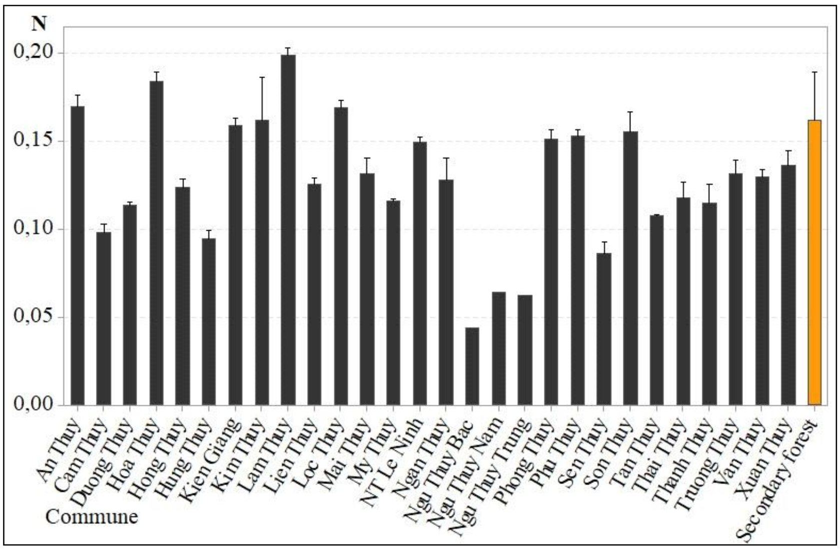

Fig 8: Total nitrogen N (%) distribution in agricultural soil.

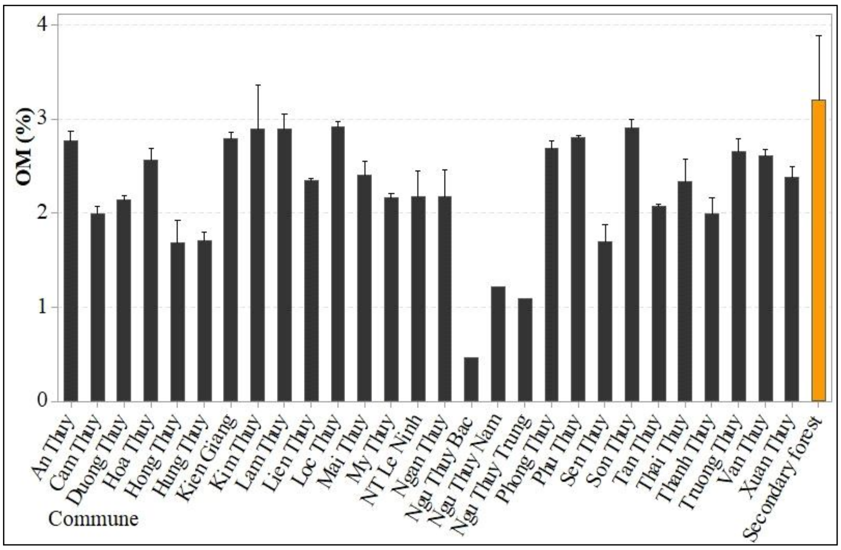

Fig 9: Total soil organic matter (%) distribution in agricultural soil.

of acacia are assumed to be associated with the recovery of soil nutrients and acceleration of nutrient cycling in their degraded soils (Sang *et al.,* 2013). Previous studies noted that the total carbon and nitrogen contents, phosphorus and some exchangeable cations in soils under acacia plantation could significantly increase by acacias and higher than under other species (Dong *et al.,* 2014). In addition, the lower ratio of C:N in these groups indicated that soil was a small level degradation. The C:N ratio was low could be attributed to the decomposition rates of residues and mineralization of litter which increased the accumulation of humus thereby increasing soil fertility. In addition, these groups had a higher content of phosphorus because of the inorganic addition during crop cultivation. Previous studies reported that a higher amount of inorganic fertilizer added during cultivating would show higher status in the soil (Liu *et al.,* 2018). The soil having well management could have great content of phosphorus compared to degraded soils. The phosphorus content could be increased for several years after conversion (McGrath *et al.,* 2001).

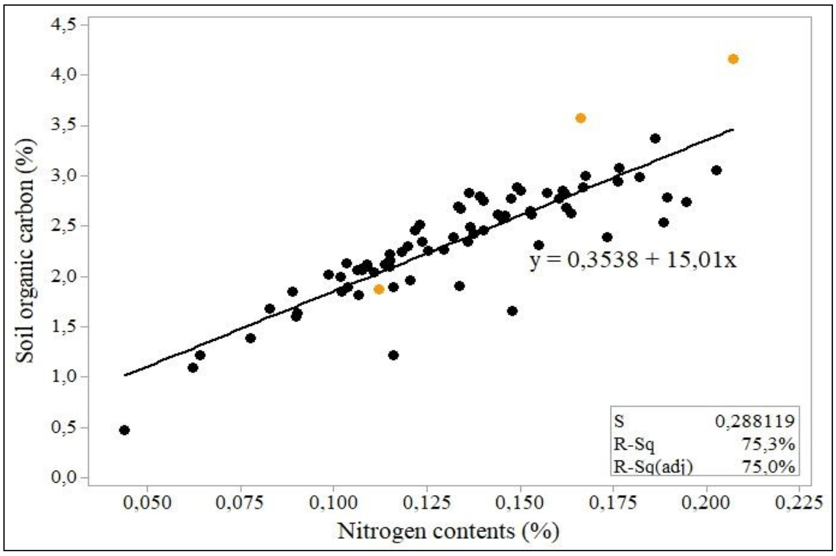

Fig 10: Correlation between organic carbon and nitrogen contents.

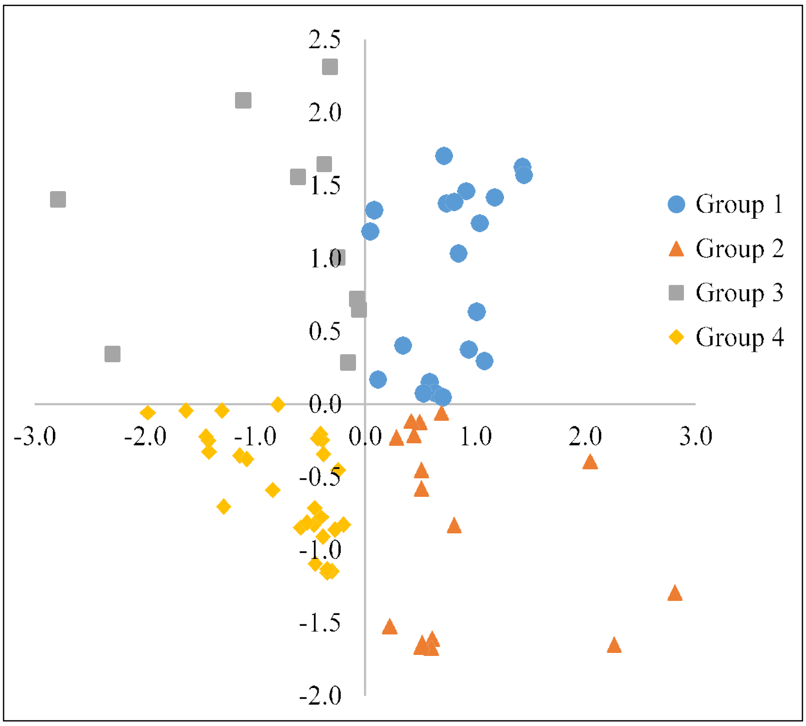

Fig 11: Degraded selected properties of agricultural soil groups.

Table 3: Status of selected agricultural soil properties.

Item	n	Sand	Silt	Clay	N	P	K_2O	OM	pH_{KCl}	C:N
					%					
Group 1	20	45.6	29.4	23.9	0.16	0.08	0.87	2.71	4.39	17
Std.		10.02	6.70	3.58	0.02	0.01	0.19	0.22	0.22	1.8
Group 2	16	54.1	22.9	22.6	0.15	0.05	0.96	2.75	3.87	18
Std.		8.26	44.5	4.84	0.02	0.02	0.34	0.23	0.23	1.9
Group 3	10	75.3	13.2	13.0	0.08	0.06	0.65	1.70	4.48	18
Std.		16.15	8.80	7.64	0.03	0.02	0.18	0.63	0.18	3.0
Group 4	28	73.8	13.9	12.4	0.11	0.04	0.53	2.00	3.96	19
Std.		10.62	6.35	3.87	0.02	0.01	0.15	0.28	0.16	0.9

CONCLUSION

Intensive land use has resulted in the degradation of soil fertility due to continuous cropping and removal of crop covers in Le Thuy district, Quang Binh province, Vietnam. Characterizing spatial variability of soil properties, such as organic matter, nitrogen, phosphorous and potassium content was crucial to understanding degradation under different land use types. The samples collected from perennial crops in mountainous communes had high clay content than that of coastal communes. Soil C, N and P contents were low in annual crops in the lowland region, suggesting that degradation was relatively higher than mountain region because of differences in land use types. In addition, high C:N ratio indicated that agriculture influenced soil degradation. Insufficient and excessive application of inorganic fertilizer could be a further reason affecting to the status of soil properties but it has been not analyzed. Overall, the continuous decline in soil quality was not sustainable for agricultural development. Therefore, farmers should apply reduced tillage practices and integrated crops to maintain fertility during cultivation.

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Conflict of interest

All authors declare that there are no any potential conflicts of interest related to the publication of their work. This includes any financial or personal relationships that could have potentially have appeared to influence the content of the publication.

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