SOIL ECOLOGY LETTERS

SEL

RESEARCH ARTICLE

Volume 6 / Issue 1 / 230181 / 2024

https://doi.org/10.1007/s42832-023-0181-7

Influence of different land-use types on selected soil properties related to soil fertility in A Luoi District, Thua Thien Hue, Vietnam

Khoa Phuc Nguyen[1,*], Tan Trong Tran[1], Huy Dinh Le[1], Phuong Thuy Nguyen[1], Hien Thao Thi Pham[1], Dien Thanh Nguyen[2], Ngu Huu Nguyen[1]

1 University of Agriculture and Forestry, Hue University, Hue City, Thua Thien Hue 52000, Vietnam

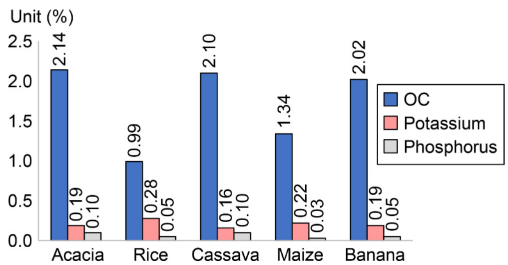
2 School of Biotechnology, Tan Tao University, Tan Duc E, City, Duc Hoa, Long An, 850000, Vietnam

* Corresponding author. E-mail: npkhoa@hueuni.edu.vn, nhuungu@hueuni.edu.vn (K.P. Nguyen)

Received January 18, 2023; Revised April 14, 2023; Accepted April 28, 2023

ABSTRACT

- Land use type affects the physicochemical properties of soil.
- The value of OM and TN is high in acacia soils.
- Strong acidity of soil is considered a serious constraint for agriculture.
- Suitable cash crops are acacia, cassava, banana, rice and maize.



Soil fertility is affected by land-use types and land management, which exacerbates soil erosion and various other forms of soil degradation in the mountainous regions of Vietnam. This study was conducted in A Luoi District, Thua Thien Hue, Vietnam to identify the effects of land-use types on specific soil physicochemical characteristics related to soil fertility. Soil physicochemical properties, such as organic matter (OM), total nitrogen (TN), total phosphorous (TP), and K^+ were significantly affected by land-use type. The results showed that the soils were sandy in rice but clay loam for acacia and cassava. The mean bulk density value of acacia soil was significantly greater than that of other soils. TN were higher in the acacia soils than those in the rice, maize, and banana soils. The OM content was significantly higher in the acacia, cassava, and banana soils than those in the rice and maize soils. The mean of exchangeable K^+ in the rice soil was higher compared to those in other soils and was affected by land-use type. The high exchangeable acidity content in the soils was probably due to intensive precipitation. However, both land use type and management did not affect the CEC value. Overall, the inappropriate land use caused the disturbance of soil physicochemical properties, indicating that the conditions of rice and maize soils are becoming worse than acacia soils. Therefore, lowering the intensity of cultivation, adopting incorporated soil fertility management, and applying organic fertilizer should preserve the existing conditions and enhance soil properties.

Keywords Land-use types, soil characteristics, soil fertility, suitable crop, Vietnam

1 Introduction

Soil fertility is a major concern owing to the increasing population and rapid economic growth worldwide. Human activities, such as modern agriculture, land-use changes, and pollution increasingly affect natural ecosystems, soil fertility, and nutrient balances (Dumanski and Pieri, 2000; Chapin, 2003). Unsustainable land use is a major factor affecting soil degradation (Liu et al., 2022). Topsoil loss is primarily caused by erosion, which also affects soil structure, biological activity, and nutrient availability (Gomiero, 2016). It is widely known that in conventional farming systems, farmers use animal manures, plant residues, household trash, bush fallow, and other inorganic nutrient sources to maintain soil fertility and soil organic contents (Kugbe, 2019). The spatial distribution of soil fertility varies from the field to larger regional scales and is influenced by both land-use types and soil management practices (Liu et al., 2022; Li et al., 2022). It is crucial for improving sustainable land-use strategies to reveal the spatial variability of soil fertility and its influencing factors. At the field scale, the main variables affecting soil fertility quality are variations in fertilization, cropping systems, and farming techniques.

Vietnam is located in South-east Asia and stretches on the Indochina Peninsula (Hai and Egashira, 2008; Tung et al., 2018). The total inland surface is approximately 33 115 000 ha, but only 28.4% is used for agriculture (Ha, 2010). Strong deforestation and conversion into agricultural land are mainly characterized by the inappropriate use of land in the

Cite this: Soil Ecol. Lett., 2024, 6(1): 230181

mountainous region of Vietnam (Cochard et al., 2017). Rice, maize, cassava, acacia, and banana are the main distributed pattern crops in the mountainous region of the Thua Thien Hue Province, Vietnam (Herzberg et al., 2019; Tung et al., 2022). The main factors affecting soil fertility are these farming techniques, cropping systems, and cultivation patterns (Wezel et al., 2002). In addition, inappropriate agricultural practices and continuous cropping without adequate nutrients are occurring in many regions in Vietnam (Ha, 2010; Anh et al., 2014). For example, acacia plantations can improve soil organic carbon (SOC) and total nitrogen (TN) compared to other type of land-use, like grassland, secondary forest, and abandoned land (Sang et al., 2013; Anh et al., 2014; Dong et al., 2014). Changes in soil pH and acidification are caused by deforestation and cultivation (Sisay Golla, 2019). The distribution of P and some exchangeable cations in the soil are affected by the differences in land-use types and management practices (Sang et al., 2013). Soil management requires particularly integrated practices that can increase soil fertility and nutrients. Agriculture in A Luoi District, Thua Thien Hue Province, has ongoing difficulties, like a lack of land for growing crops, soil erosion, intensive precipitation, inorganic fertilizer application, and declining soil fertility, which has resulted in low yield production. However, only a few studies have examined how land use affects soil characteristics. Therefore, this study aimed to determine how various land-use types affected a few specific soil physicochemical characteristics for better soil management decisions and the improvement of yield production.

2 Materials and methodology

2.1 Study site

The study region was in A Luoi District of Thua Thien Hue Province in central Vietnam (Tables 1 and 2). It is located in a mountainous area approximately 80 km from Hue city, and ranges between 16°00′57″ N to 16°27′30″ N and 107°0′3″ E to 107°30′30″ E, near Laose's boundary. The district lies in a mountainous region with an average elevation of approximately 600–800 m above sea level. The topography slope of the study site ranged from 20° to 25°, which is not convenient for cropping or intensive livestock production. The climate in this region is characterized by a tropical monsoons with a rainy season in cold winters and relatively dry summers. The mean annual precipitation is higher than 3500 mm, concentrated between September and December (Fig. 1), and associating with high-frequency tropical typhoons (Hung et al., 2017; Tung et al., 2018). The mean annual temperature is 24.9°C, with the lowest and highest mean monthly temperatures in January (17.4°C) and June (25.3°C), respectively (Fig. 1). The natural vegetation of tropical semi-deciduous monsoon forests and secondary forests is still found in areas where human impact on vegetation is low,

Table 1 Site studying and sampling points in A Luoi District, Thua Thien Hue Province.

Sampling sites	Longitude	Latitude
1	107°22′48.7″	16°04′36.7″
2	107°12′26″	16°13′18.5″
3	107°11′12.3″	16°19′39.7″
4	107°13′24.3″	16°15′37.8″
5	107°22′31″	16°05′23,9″
6	107°13′23″	16°13′12.3″
7	107°23′11.1″	16°19′36.2″
8	107°12′23.2″	16°15′30.9″
9	107°14′29.1″	16°17′45.7″
10	107°12′25.8″	16°15′5.5″
11	107°23′26.1″	16°18′41.3″
12	107°23′6.8″	16°18′52.7″
13	107°21′47.1″	16°06′44.1″
14	107°20′28.4″	16°07′43.7″
15	107°19′19.8″	16°18′54.7″
16	107°23′5.1″	16°05′17.6″
17	107°23′43.5″	16°06′4.5″
18	107°20′44.5″	16°07′39.6″
19	107°19′25.2″	16°07′27.1″
20	107°19′0.2″	16°12′30.8″
21	107°20′55.7″	16°11′47.8″
22	107°12′30.3″	16°19′35.7″
23	107°10′19.6″	16°14′33.3″
24	107°11′40.3″	16°18′34.7″
25	107°20′50.6″	16°08′58.5″
26	107°13′6.9″	16°17′28.4″
27	107°12′12.5″	16°18′58.5″
28	107°16′24.7″	16°12′18.8″
29	107°18′39.3″	16°12′15.6″
30	107°17′44.4″	16°14′58.9″
31	107°14′10.6″	16°14′39.3″
32	107°14′51.4″	16°14′18.6″
33	107°12′6.7″	16°16′10.9″
34	107°11′20.4″	16°13′43.7″
35	107°04′12.3″	16°23′10.8″
36	107°24′42.7″	16°18′21.6″
37	107°19′56.4″	16°12′48.6″
38	107°21′10.1″	16°18′33″
39	107°12′57.2″	16°19′34.2″
40	107°11′12.7″	16°13′14.4″

(*Continued*)

Sampling sites	Longitude	Latitude
41	107°13′39.5″	16°12′19.8″
42	107°19′21.6″	16°03′30.1″
43	107°13′2.7″	16°15′17.5″
44	107°11′5.1″	16°21′36.5″
45	107°13′59.5″	16°18′13.2″
46	107°12′27″	16°15′13.1″
47	107°11′56.4″	16°17′4.5″
48	107°15′33″	16°14′10.8″
49	107°13′7.5″	16°15′1.5″
50	107°12′15.6″	16°14′9.4″
51	107°10′39.3″	16°14′44.5″
52	107°04′52.3″	16°24′7.1″
53	107°13′3.5″	16°16′46.7″
54	107°14′40.9″	16°16′3.8″
55	107°16′37.9″	16°14′45″
56	107°13′29″	16°17′8.2″
57	107°07′9.2″	16°22′31.5″
58	107°03′28″	16°23′30.9″
59	107°03′38.8″	16°22′5.2″
60	107°06′22.4″	16°22′11″
61	107°05′59.6″	16°24′37.1″
62	107°19′6.3″	16°18′36.2″
63	107°14′23.5″	16°15′50.2″
64	107°14′42.7″	16°15′2.2″
65	107°11′6.2″	16°19′36.5″
66	107°13′10.7″	16°17′31.6″
67	107°16′1.3″	16°15′41.5″
68	107°11′54.7″	16°20′41.7″
69	107°12′12.8″	16°17′2.1″
70	107°10′17.5″	16°21′36.6″
71	107°16′32.5″	16°15′6.8″
72	107°10′47.7″	16°20′3.4″
73	107°11′29″	16°13′22″
74	107°14′29″	16°15′16.6″
75	107°14′2.8″	16°16′43.2″

and replaced by agricultural land elsewhere. Soils in the study region are mostly siliceous and sandy and are classified into groups (e.g., Acrisols, Cambisols, Alisols, and Leptosols) of red or yellow soils (Sang et al., 2013; Dong et al., 2014). The soil has a high proportion of the coarse content (> 2 mm) derived from siliceous parent materials, such as sandstone, mudstone, granite, and metamorphic rocks (VMI, 2000).

2.2 General characteristics of the farmers in A Luoi District

The general characteristics of the farmers in A Luoi District are listed in Table 3. Paco and Cotu are the main ethnicities with averages of 48% and 30%, respectively. The average age of the household head ranged from < 30 to > 60 years and was divided into four groups. The group under 30 years old accounted for 15%, 30–45 years old accounted for 52%, 45–60 years old accounted for 23%, and > 60 years old accounted for 10.31%. Education levels of the farmers were primary school, secondary school, high school, and bachelor's degree with an average of rate 36%, 30%, 28%, and 6%, respectively. The main economic activity in A Luoi District is farming.

2.3 Soil characterization

Soil parameters were surveyed in the agricultural fields of the district (e.g., acacia, rice, cassava, maize, and banana fields). Soils were sampled from different dominant land-use types. For each land-use type, soil samples were collected at a depth of 0–10 cm. Before the laboratory analysis, the samples were sieved through a 2 mm screen after being air-dried.

Soil bulk density (BD) was determined from cores that had been dried at 105°C to constant weight (Jabro et al., 2020). The soil pH was measured by mixing an aliquot of samples with water or 1 mol L^{-1} potassium chloride solution, at a soil/liqid ratio of 1:5 (weight soil: liquid volum mixture). A glass electrode was used to determine the value for each sample (HI5521, Hana Instrument Co., Ltd, Vietnam). The particle-size distribution of soils was determined using a combination of sieving and pipette methods (Gee and Or, 2002). Total nitrgen content was analyzed by means of a Kjeldahl method (UDK-129 Distillation Unit, VELP Scientifica Srl,

Table 2 Characteristics of each land use type in A Luoi, Thua Thien Hue Province.

Land use	Samples No.	Land use defined	Historical land use management	Time (years)	Elevation (m)	Scale
Acacia	21	5-year-growing cycle cropland	Minimum tillage	10	589−644	9
Rice	10	1-year-growing cycle cropland	Intensive tillage fertilizer, irrigation	20	591−752	7
Cassava	17	1-year-growing cropland	Intensive tillage	5	588−610	1
Maize	14	1-year-growing cropland	Intensive tillage	2	598−672	3
Banana	17	3-year-growing cropland	Intensive tillage, garden	3	578−664	5

The AHP is carried out in accordance with earlier studies (Herzberg et al., 2019; Canco et al., 2021)

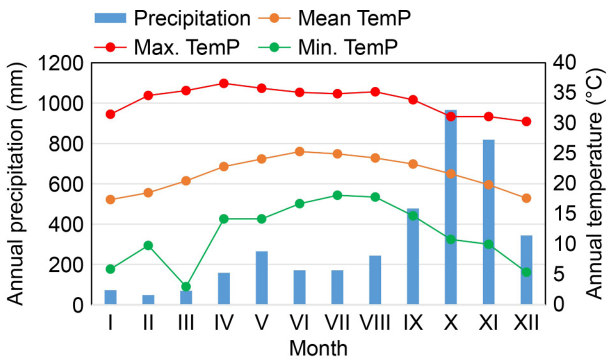


Fig. 1 Average temperature and precipitation in A Luoi District, Thua Thien Hue Province.

Table 3 Characteristics of agricultural farmers in A Luoi District, Thua Thien Hue Province.

	Characteristics	Number (household)	Rate (%)	Scale
Ethenic	Kinh	17	9	9
	Ta Oi	25	13	3
	Co Tu	59	30	5
	Pa Co	93	48	7
Gender	Male	89	46	5
	Female	105	54	4
Age of head household	Under 30 years	29	15	5
	From 30 to 45 years	100	52	7
	From 45 to 60 years	45	23	9
	Over 60 years	20	10	3
Education level	Primary school	69	36	3
	Secondary school	58	30	5
	High school	54	28	7
	Bachelor	13	7	9

Italy). Total phosphorus content was analyzed using the color comparison method using spectrophotometer (Yoke Sepectrophotometer UV1700, Sanghai Yoke Instrument Co., Ltd, China). The total potassium content in the sample was determined by using Flame Photometer (FP640, Shanghai Drawell Scientific Instrument Co., Ltd, China). Exchangeable Al^{3+} and H^+ using the titration method (Abreu et al., 2003). In order determine CEC value, the residual soil after ammonium acetate extraction was first washed with 96% ethanol, and the remaining NH_4^+ was finally extracted with NaCl 0.1 mol L^{-1} solution (Burt, 2004). The NH_4^+ solution was then determined using Kjeldahl method (UDK-129 Distillation Unit, VELP Scientifica Srl, Italy). The rganic carbon content was analyzed using the Walkley–Black wet oxidation procedure and the soil organic matter content was determined from organic carbon (Nelson and Sommers, 1996; Batjes, 2014).

Carbon or nitrogen content at each soil depth (0–10 cm) were calculated using the formula described by Batjes (2014):

Carbon or nitrogen content (Mg ha^{-1}) = C-content $_{layer}$ (g kg^{-1}) × BD_{layer} (g cm^{-3}) × soil depth (m) × 10^{-3} Mg kg^{-1} × 10^4 m^2 ha^{-1}.

2.4 Household survey procedure

We focued on crop yield, land-use types, and land size, which are the main criteria for choosing a suitable crop to develop farmers' incomes in A Luoi District. To obtain data, we randomly selected the household heads of farms in the district for a survey. A total of 194 were willing to participate in the research and were interviewed at their homesteads using questionnaires, if any of the household heads were absent, another member was interviewed. We assumed that their cropping patterns included paddy terraces, dynamic agriculture, the ability of market access, and government services. Land-use types are probably influenced by the presence of labor, indirect costs (fertilizer and seeds), soil properties, and land management practices, among others. Acacia, cassava, banana, and rice maize were chosen as suitable crops to maintain the economy of this region

2.5 Data analysis

Data analysis was performed for each land-use type (acacia, rice, cassava, maize, and banana). The Kruskal–Wallis test was performed to check the normality of the data before statistical analysis. A general linear model was subjected to a one-way ANOVA test of the statistical analysis system to compare significant differences among the soil parameters, crop yields, and land-use systems. Significant differences among the groups were tested using Tukey's test, if the original data followed a normal distribution, or Bonferroni's method if the original data had a non-normal distribution. The normality test, one-way ANOVA, and multiple comparison analyses were conducted using IBM SPSS 20 software (IBM Corp., Armonk, NY, USA). The selection of suitable crops was evaluated by the Analytic Hierarchy Process (AHP) based on criteria of weather conditions, characteristics of land use types, cropping yield, agricultural farmer characteristics, and soil properties. The higher weighting of each criterion by AHP is indicated the different level in the physical attributes of crop selections.

3 Results and discussion

3.1 Selected soil characteristics

The soil parameters in different agricultural fields in this study, and corresponding statistical analyses, are summarized in Table 4. The values obtained for most of the listed

Table 4 Selected soil parameters of agricultural soils in A Luoi District, Thua Thien Hue Province.

Items	Bulk density	$pH_{(H_2O)}$	pH_{KCl}	Clay	Silt	Sand	P_2O_5	K_2O	OC	N	H^+	Al^{3+}	CEC
Acacia	1.29	4.9	4.0	40	33	27	0.05	0.19	21.4	1.9	1.0	5.7	19
Max	1.55	5.7	4.4	55	46	66	0.49	0.71	44.9	2.6	1.5	12.0	25
Min	1.03	4.2	3.6	16	18	10	0.00	0.04	6.7	0.5	0.4	1.7	13
SD	0.12	0.5	0.2	13	8	20	0.11	0.18	12.6	0.7	0.3	2.9	11
CV (%)	9	10	5	32	24	75	110	95	59	53	30	50	55
Rice	1.39	4.4	3.9	24	21	56	0.10	0.28	14.9	1.0	1.2	3.2	21
Max	1.57	5.3	4.9	44	44	75	0.13	0.60	16.5	1.8	2.2	4.2	34
Min	1.20	3.8	3.4	17	4	33	0.01	0.10	3.4	0.5	0.4	1.7	13
SD	0.12	0.6	0.5	8	13	15	0.03	0.14	4.3	0.4	0.7	0.8	7
CV (%)	9	13	12	34	61	26	60	50	43	36	57	25	33
Cassava	1.43	5.2	4.0	44	37	19	0.05	0.16	21.0	1.5	1.8	8.0	18
Max	1.57	5.6	4.4	51	53	29	0.28	0.49	45.4	2.3	2.8	12.1	33
Min	1.20	4.4	3.6	18	23	13	0.01	0.05	4.2	0.4	0.8	2.3	11
SD	0.14	0.3	0.2	9	7	5	0.08	0.12	11.3	0.4	0.6	3.2	5
CV (%)	10	6	5	19	19	26	80	63	54	24	33	40	10
Maize	1.40	4.7	4.2	23	26	52	0.03	0.22	13.4	1.0	1.1	3.1	18
Max	1.57	5.7	5.3	40	50	79	0.08	0.33	16.8	2.2	2.6	5.0	31
Min	1.20	3.8	3.4	18	2	24	0.00	0.10	9.6	0.8	0.1	2.5	3
SD	0.10	0.5	0.6	6	13	14	0.03	0.08	2.4	2.4	0.7	1.1	10
CV (%)	7	13	14	24	49	27	100	36	18	195	62	35	57
Banana	1.410	4.9	4.0	36	33	31	0.05	0.19	20.2	1.4	1.0	3.4	16
Max	1.70	5.3	4.8	5	50	70	0.33	0.33	37.0	2.5	2.1	6.0	28
Min	1.20	4.6	3.6	12	18	12	0.00	0.06	11.1	0.5	0.4	1.2	11
SD	0.15	0.2	0.4	15	9	20	0.07	0.09	7.5	0.5	0.4	1.3	6
CV (%)	11	5	9	40	26	63	140	47	37	39	36	38	36
Average	1.38	4.9	4.0	35	31	34	0.05	0.20	18.2	1.4	1.2	4.9	18
Max	1.70	5.7	5.3	55	53	79	0.49	0.71	45.4	2.6	2.8	12.1	31
Min	1.03	3.8	3.4	12	2	10	0.00	0.04	3.4	0.4	0.1	1.2	9
SD	0.14	0.5	0.4	14	11	21	0.08	0.13	10.0	0.6	0.6	2.9	10
CV (%)	10	10	9	39	35	61	160	65	55	43	50	59	54

Unit: BD: g cm^{-3}; soil texture, P_2O_5 and K_2O: %; OC and N: g kg^{-1}: CEC, Al^{3+} and H^+: cmol kg^{-1}.

properties were significant under different land use types. The surface soils from acacia, rice, maize, cassava, and banana fields were, in general, acidic with the averages pH of H_2O and KCl being 4.9 and 4.0 respectively. The lower soil pH agricultural plantations might be associated with the uptake of basic cation by the tree roots that enhances the accumulation of Al^{3+} and H^+ (Molla et al., 2022). In addtion, the lower in value of soi pH in the agricultural soils was due to poor managed cultivation. The pH (H_2O) value of the rice soil was significantly lower than that of other plantations. The inappropriate use of inorganic fertilizers in rice fields and ongoing cultivation techniques may be to blame for the pH variations. This result agrees with previous studies that reported pH values in the soils were different under different land use types (Muche et al., 2015; Fekad et al., 2020). The exchangeable Al^{3+} content was relatively high (4.9 cmol kg^{-1}), the coefficient variation exceeding 59% on average; hence soil acidity was considered a serious constraint for agricultural production. The findings demonstrated that these regions had higher exchangeable acidity contents due to intensive farming, excessive precipitation, and the use of inorganic fertilizers. The average soil texture was clay loam to clay, and the particle size distribution differed the various soils. The clay content was higher in the acacia and cassava plantations (40% and 44%, respectively) than that in the rice, maize, and banana plantations (24%, 23%, and 36%, respectively). The highest sand content (56%) was recorded in the rice plantation. These results were probably due to the deposition of alluvial areas along rice fields near streams and rivers. Previous studies have mentioned that non-stop cropping and intensive land use have some effects on the particle size distributions and these changes are related to cultivation period (Nanganoa et al., 2019; Bufebo and Elias, 2020).

The land-use types had a significantly greater impact on bulk density value ($P \leqslant 0.05$), as shown in Table 4. Acacia plantation had low mean value of bulk density (1.29 g cm^{-3}), and high mean value was observed in the rice, maize, cassava, and banana plantations (1.4 g cm^{-3}). This was probably due to the intensive tillage cultivation that would have possibly caused better bulk density values in the rice, maize, cassava, and banana plantations than in the acacia plantation. The lower BD was probably related to high inputs of OM and plant residues from acacia litter biomass and low impacts of rain droplets on the surface soil layer. Whereas, higher BD in the soils could be related to tramping effect of animals during plowing and after harvest. Furthermore, the increasing exposure of the soil to direct temperature and raindrop effects can be attributed to the increasing BD. Previous studies have provided evidence that the soil nutrients and related soil processes, such as leaching, oxidation, erosive oxidation, and mineralization, are impacted by land use and soil management practices (Lal, 2018; Ghosh, 2019). In addition, the vegetative biomass is a factor that impacts the soil organic carbon content in acacia-cultivated land as reported by Hung et al. (2017). After cultivating untilled soils, soil quality typically deteriorates due to significant alteration caused by land use change (Wang et al., 2001). The cause of the relatively high bulk density of soil in the rice, maize, and banana plantations could be due to the low clay content (Table 4). This was comparable to earlier studies relating influences land luse types and land management on soil properties, organic carbon, and bulk density (Haghighi et al., 2010). Other previous studies also found that the highest and lowest BD were in the cultivated and forest lands, respectively (Bewket and Stroosnijder, 2003).

Soil organic matter (OM) content was significantly affected by the land-use types (Table 4). OM variability was significantly higher in acacia and cassava (21 g kg^{-1}), which was due to the high clay content in the acacia- and cassava-cultivated soils (Fig. 2). In addition, the high productivity and leguminous properties of acacia plantations may be linked to the recovery of soil nutrients and the speeding up of nutrient cycling in soils (Dong et al., 2014; Hung et al., 2017). Another reason was that the higher OM could be due to the addition of plant litter to the soil and reducing the rate of risk of erosion. However, the lower OM from rice and maize soils could be the removal of crop residues for energy and animal feed and soil disturbances during plowing and harvesting that expose the soils. The results were similar to previous studies that have reported a lesser amount of organic

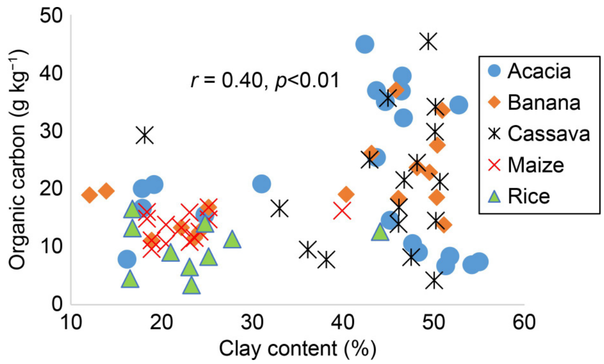


Fig. 2 Pearson correlation between clay and organic carbon content under different land use.

carbon in cultivated soils than in grass soil (Clemens et al., 2010; Anh et al., 2014). TN was also significantly affected by land-use type and land managment. The mean TN ranged from low (1.0 g kg^{-1}) in rice soils to high (1.9 g kg^{-1}) in acacia soils (Table 4). The high TN in acacia soil may be associated with the capacity of the species to restoration atmospheric N through symbiosis with root-nodulating bacteria (Giller, 1993; Hung et al., 2017). The result of this study was in agreement with previous studies reported that TN was affected by different land-use systems (Trakooyingcharoen et al., 2012; Sang et al., 2013).

Our results showed soil characteristics similar to those of previous studies. The soils were thought to have low in OM and TN contents as well as low soil pH. The findings demonstrated that acacia soils had relatively higher levels of organic carbon and nitrogen than soils from other types of land use. The total nitrogen content found in this study was comparable to that found in earlier studies conducted in Vietnam (Table 4). Our results showed that the acacia soils had a higher level of TN than that of other soils. Acacia plants have been shown to be able to fix atmospheric nitrogen through symbiosis with root-nodulating bacteria, which has been linked to the high concentration of TN in acacia soils (Giller, 1993; Brockwell et al., 2005). In addition, TN can also be better in acacia soils because of the excessive nitrogen content in the litter and root biomass (Brockwell et al., 2005; Selassie et al., 2015). The results also showed that the organic carbon content in acacia soil was relatively higher than that in rice and maize soils but did not significantly differ from those in cassava and banana soils (Table 4). The greater carbon content in acacia plantations has been connected to the retention of all residues at harvest (Hardiyanto and Nambiar, 2014; Bich et al., 2018), and the extra C leached as dissolved organic C to mineral soils through litter decomposition (Novara et al., 2015). However, the value of C in acacia soil was not significantly different from that of cassava and banana soils, mainly because of similar clay content (Table 4).

TP was noticeably higher in the rice soil compared to the other soils (Table 4). The excessive TP in the soil of rice fields (0.10%) was because of the non-stop application of mineral P fertilizer for some years as indicated with the aid of using exclusive farmers in the area. However, acacia and maize soils had no application of P fertilizer, as indicated by the low total P content. Previous studies have reported that the phosphorus content of soils was affected by land-use type (Liu et al., 2006; Deng et al., 2018; Liu et al., 2018). Exchangeable K^+ content was significantly higher in the rice soil than in the other soils. The high exchangeable K^+ content in rice soil was possibly because of non-stop cultivation and inorganic farming practices. The cultivation using inorganic fertilizer with forming K^+ could be strongly affected the distribution of K in the soil system. The CEC values of the soil samples did not differ under different land use types. CEC values were in the range of 16 cmol kg^{-1} in banana soil to 21 cmol kg^{-1} in rice soil. Previous works have reported the depletion of exchangeable bases due to non-stop intensive cultivation and the application of acid-forming inorganic fertilizers, which decreased the CEC in cultivated land (Muche et al., 2015; Molla et al., 2022).

Table 5 shows the carbon content of the first 10 cm under for various land-use types. In the agricultural plantation, intensive cultivation techniques and absence of an organic layer led to a generally low C and N concentration. In terms of C storage under different land-use types, C content was higher in the acacia, banana, and cassava plantations than in the rice and maize plantations. These results were similar to the most previous ideas on how soil C content was affected by soil cultivation (Jacinthe and Lal, 2005; Wu et al., 2022). It could be examined that the rice field, which more intensively affected the flooding of the A-Sap river, may have caused a richer sand content texture (Table 4). Due to the adsorption of organic compounds at clay surfaces, these conditions were harmful for the rich inorganic matter protection (Kalita et al., 2016; Nath et al., 2018). The majority of the carbon was recovered in the heavy mineral fraction, indicating a significant interaction with the mineral phase and a possibly higher stabilization of the carbon. The lower C content in the rice and maize fields, whose texture was sandier than that of the other fields (Table 4), provides additional support for this. Another cause was erosion that occurred at maize fields in this region under heavy rain conditions (Wezel et al., 2002). The C:N ratio in acacia soil was significantly lower than that of other soils. This was possibly due to the loss of nitrogen from the agricultural systems. Our result was similar to previous studies that reported a decreased level of soil N in the rice, maize, and cassava fields after shifting cultivation from fallow land (Vien, 2003; De et al., 2008).

Table 5 Carbon stocks under different land use types in A Luoi District, Thua Thien Hue Province.

No	Land use type	C:N	Stocks of carbon (Mg ha^{-1})
1	Acacia (21)	11.76	31 ± 17^{A}
2	Rice (10)	14.30	14 ± 7^{B}
3	Cassava (17)	14.46	28 ± 17^{A}
4	Maize (14)	14.71	19 ± 3^{AB}
5	Banana (17)	14.44	29 ± 12^{A}

3.2 Cropping systems, yield, and suitable crops in A Luoi District

Agricultural land in mountainous regions may be used for cash crops such as acacia, cassava, banana, rice, and maize. The different land-use types, yield, and its contributed cash values in A Luoi District are listed in Tables 6 and 7. The coefficient of variation was mostly below 50%, which indicates small variability among the samples for each land-use type in A Luoi District.

The choice of suitable crops and cropping systems are often very delicate, as shown in Tables 6 and 7. These selections were based on expectation of farmers, local government and expertise supporting. Acacia was the most interesting crop, with a size area and number of households of 94% and 33%, respectively. Acacia yield was calculated to be approximately 93 Mg ha^{-1} after five years of cultivation. Acacia was frequently cited as a plant species that can grow easily in this area as a cash crop. Cassava crop accounted for approximately 27% of farmers who participated in this survey, and its yield value varied from 6 to 16 Mg ha^{-1}. However, rice, maize, and banana still dominated this area. Yield of rice crop was from 2 to 5 Mg ha^{-1}, with an average

Table 6 The yield of crops in A Luoi District, Thua Thien Hue Province.

Items	Acacia (*n*=151)	Rice (*n* = 87)	Maize (*n* = 62)	Cassava (*n* = 124)	Banana (*n* = 40)
Maximum (Mg ha^{-1})	143	5	5	16	58
Minimum (Mg ha^{-1})	42	2	3	6	15
Average (Mg ha^{-1})	92	4	5	12	39
Standard deviation (Mg ha^{-1})	43	0.6	0.7	2.4	12
CV (%)	47	16	14	21	29

Table 7 Cropping system distribution in A Luoi District, Thua Thien Hue Province

No	Crops	*n*	Percentage (%)		AHP weighting	Rank
			Hectare*	Household interview		
1	Acacia	151	94^{a}	33^{a}	0.32	1
2	Cassava	124	1.9^{b}	27^{a}	0.07	4
3	Rice	87	1.6^{b}	19^{ab}	0.31	2
4	Maize	62	0.7^{b}	13^{b}	0.05	5
5	Banana	40	1.9^{b}	8^{b}	0.19	3

* Value from household interviewed.

of 4 Mg ha^{-1}. Average yield of maize was approximately 5 Mg ha^{-1} (minimum of 3 Mg ha^{-1} and maximum of 5 Mg ha^{-1}). A total size area of banana was smaller compared to other land use types because farmers have cultivated over the last three years and, it was accounted for approximately 9%. A minimum of banana yield was 15 Mg ha^{-1} while maximum yield was 58 Mg ha^{-1}. In comparison, the crop yield in A Luoi was relatively low compared to other regions because of the natural and social conditions (Dong et al., 2014; Hedlund et al., 2004; Müller, 2003; Hai and Hung, 2018; Bich et al., 2018). There were many things to take into account, including the number of years of farming experience, education level, number of visits by extension agents, farm size, dependence ratio, region, production knowledge, and household characteristics (age, religion, size, and gender of household head), and level of specialization (whether a farmer farmins full- or part-time).

4 Conclusion

Our findings imply that the rice and maize had sandy soils, whereas the acacia and cassava had clay to loam soils. In comparison to the other soils, the acacia soil's mean bulk density value was significantly higher. TN were higher in the acacia soils than those in the rice, maize, and banana soils. Carbon content was significantly higher in the acacia, cassava, and banana soils than that in the rice and maize soils. The mean of exchangeable K^+ of the soil was significantly higher in rice soils and was affected by land-use type. The exchangeable acidity content was high in the soil probably because of intensive precipitation. However, the CEC value was not affected by land-use types or land management. The selected properties of this study are similar to those of previous studies. The most suitable crops in A Luoi District could be acacia, cassava, banana, and rice plantations, along with their various cropping system and relative yield. Overall, the development of agriculture with careful management of soil properties is necessary in the mountainous regions of Vietnam.

Acknowledgments

This work was funded by Hue University (No. DHH-2021-2-155). We gratefully thank the farmers in A Luoi District and students for their cooperation in interviews field data collection and experimental analysis. We especially thank the reviewers who went through the manuscript with valuable remarks and improved the paper substantially.

References

Abreu, C.H. Jr, Muraoka, T., Lavorante, A.F., 2003. Exchangeable aluminum evaluation in acid soils. Scientia Agrícola 60, 543–548.

Anh, P.T.Q., Gomi, T., MacDonald, L.H., Mizugaki, S., Van Khoa, P., Furuichi, T., 2014. Linkages among land use, macronutrient levels, and soil erosion in northern Vietnam: A plot-scale study. Geoderma 232–234, 352–262.

Batjes, N.H., 2014. Total carbon and nitrogen in the soils of the world. European Journal of Soil Science 65, 10–21.

Bewket, W., Stroosnijder, L., 2003. Effects of agroecological land use succession on soil properties in Chemoga watershed, Blue Nile basin, Ethiopia. Geoderma 111, 85–98.

Brockwell, J., Searle, S., Jeavons, A., Waayers, M., 2005. Nitrogen fixation in Acacias: an untapped resource for sustainable plantations, farm forestry and land reclamation. Aciar Monograph 115, 1–132.

Bich, V. N., Eyles, A., Mendham, D., Dong, L. T., Ratkowsky, D., Evans, K. J., Hai, D. V., Thanh, V. H., Thinh, V N, Mohammed, C., 2018. Contribution of harvest residues to nutrient cycling in a tropical Acacia mangium willd plantation. Forests 9, 1–16.

Bufebo, B., Elias, E., 2020. Effects of land use/land cover changes on selected soil physical and chemical properties in Shenkolla watershed, south central Ethiopia. Advances in Agriculture 2020, 1–8.

Burt, R., 2004. Soil Survey Laboratory Methods Manual 2004. United States Department of Agriculture.

Canco, I., Kruja, D., Iancu, T., 2021. AHP, a reliable method for quality decision making: A case study in business. Sustainability (Basel) 13, 13932.

Chapin, F.S., 2003. Effects of plant traits on ecosystem and regional processes: A conceptual framework for predicting the consequences of global change. Annals of Botany 91, 455–463.

Clemens, G., Fiedler, S., Cong, N.D., Van Dung, N., Schuler, U., Stahr, K., 2010. Soil fertility affected by land use history, relief position, and parent material under a tropical climate in NW-Vietnam. Catena 81, 87–96.

Cochard, R., Ngo, D.T., Waeber, P.O., Kull, C.A., 2017. Extent and causes of forest cover changes in Vietnam's provinces 1993–2013: A review and analysis of official data. Environmental Reviews 25, 199–217.

Deng, L., Wang, K., Zhu, G., Liu, Y., Chen, L., Shangguan, Z., 2018. Changes of soil carbon in five land use stages following 10 years of vegetation succession on the Loess Plateau, China. Catena 171, 185–192.

De, V. N., Douglas, I., Mcmorrow, J., Lindley, S., Binh, T. N., Van, T. T., Thanh, H. L., Tho, N., 2008. Erosion and nutrient loss on sloping land under intense cultivation in Southern Vietnam. Geographical Research 46, 4–16.

Dong, T.L., Doyle, R., Beadle, C.L., Corkrey, R., Quat, N.X., 2014. Impact of short-rotation Acacia hybrid plantations on soil properties of degraded lands in Central Vietnam. Soil Research (Collingwood, Vic.) 52, 271–280.

Dumanski, J; Pieri, C., 2000. Land Quality Indicators (LQI): Monitoring and Evaluation. Land Use, Land Cover and Soil Sciences, II. Encyclopedia of Life Support Systems (EOLSS).

Fekad, S., Jembere, K., Fekadu, E., Wasie, D., 2020. Land use and land cover dynamics and properties of soils under different land uses in the Tejibara watershed northwest Ethiopia. The Scientific World Journal 20, 1479460.

Gee, G.W., Or, D., 2002. Particle-size Analysis. In: Dane, J.H., Topp, G.C., editors, Methods of Soil Analysis. Part 4. Physical Methods. SSSA Book Ser. 5. SSSA, Madison, WI: 255–293.

Ghosh, A.K., 2019. Characterization and classification of alluvium derived soils under different land uses in Varanasi district of Uttar Pradesh. Journal of the Indian Society of Soil Science, 67, 360–364.

Giller, K., 1993. Nitrogen fixation in tropical cropping systems. Field Crops Research 34, 230–232.

Gomiero, T., 2016. Soil degradation, land scarcity and food security: Reviewing a complex challenge. Sustainability (Basel) 8, 1–41.

Ha, P.Q., 2010. Carbon in Vietnamese Soils and Experiences to Improve Carbon Stock in Soil. Workshop on Evaluation and Sustainable Management of Soil Carbon Sequestration in Asian Countries, 28–29.

Haghighi, F., Gorji, M., Shorafa, M., 2010. A study of the effects of land use changes on soil physical properties and organic matter. Land Degradation & Development 21, 496–502.

Hai, Q. N., Egashira, K., 2008. Clay mineralogy of various Marginal soils in Vietnam. Journal of the Faculty of Agriculture, Kyushu University 53, 179–186.

Hai, X. N., Hung, A. P., 2018. Assessing soil erosion by agricultural and forestry production and proposing solutions to mitigate: A case study in Son la Province, Vietnam. Applied and Environmental Soil Science 2018, 1–10.

Hardiyanto, E.B., Nambiar, E.K.S., 2014. Productivity of successive rotations of Acacia mangium plantations in Sumatra, Indonesia: impacts of harvest and inter-rotation site management. New Forests 45, 557–575.

Hedlund, A., Witter, E., Hoang Fagerström, M.H., An, B.X., 2004. Nutrient management and farmers' concept of soil fertility and fertilisers: A case study in Southern Vietnam. International Journal of Agricultural Sustainability 2, 180–189.

Herzberg, R., Pham, T.G., Kappas, M., Wyss, D., Tran, C.T.M., 2019. Multi-criteria decision analysis for the land evaluation of potential agricultural land use types in a hilly area of Central Vietnam. Land (Basel) 8, 90.

Hung, T.T., Doyle, R., Eyles, A., Mohammed, C., 2017. Comparison of soil properties under tropical Acacia hybrid plantation and shifting cultivation land use in northern Vietnam. Southern Forests 79, 9–18.

Jabro, J.D., Stevens, W.B., Iversen, W.M., 2020. Comparing two methods for measuring soil bulk density and moisture content. Open Journal of Soil Science 10, 233–243.

Jacinthe, P.A., Lal, R., 2005. Labile carbon and methane uptake as affected by tillage intensity in a Mollisol. Soil & Tillage Research 80, 35–45.

Kalita, R.M., Rahman, M., Borogayary, B., Das, A.K., Nath, A.J., 2016. Carbon storage potential of Acacia plantation : A viable option for climate change mitigation. International Conference on Climate Change Mitigation and Technologies for Adaptation, (June). Synod College, Shillong, 793002, Meghalaya.

Kugbe, J.X., 2019. Increase in the use of organic fertilizers as complements to inorganic fertilizers in maintenance of soil fertility and environmental sustainability. World Journal of Agriculture and Soil Science 4, 1–4.

Lal, R., 2018. Land use and soil management effects on soil organic matter dynamics on Alfisols in Western Nigeria. In: Soil Processes and the Carbon Cycle. CRC Press, Boca Raton. pp. 109–126.

Li, Y., Liu, W., Feng, Q., Zhu, M., Yang, L., Zhang, J., 2022. Effects of land use and land cover change on soil organic carbon storage in the Hexi regions, Northwest China. Journal of Environmental Management 312, 114911.

Liu, J., Cade-Menun, B.J., Yang, J., Hu, Y., Liu, C.W., Tremblay, J., Bainard, L.D., 2018. Long-term land use affects phosphorus speciation and the composition of phosphorus cycling genes in agricultural soils. Frontiers in Microbiology 9, 1–14.

Liu, X., Herbert, S.J., Hashemi, A.M., Zhang, X., Ding, G., 2006. Effects of agricultural management on soil organic matter and carbon transformation - A review. Plant, Soil and Environment 52, 531–543.

Liu, Y., Wu, K., Cao, H., 2022. Land-use change and its driving factors in Henan province from 1995 to 2015. Arabian Journal of Geosciences 15, 247.

Molla, E., Getnet, K., Mekonnen, M., 2022. Land use change and its effect on selected soil properties in the northwest highlands of Ethiopia. Heliyon 8, e10157.

Muche, M., Kokeb, A., Molla, E., 2015. Assessing the physicochemical properties of soil under different land use types. Journal of Environmental & Analytical Toxicology 5, 1–5.

Müller, D., 2003. Land-use change in the Central Highlands of Vietnam. A Spatial Econometric Model Combining Satellite imagery and village survey data. Dissertation, Georg-August-University of Göttingen.

Nanganoa, L.T., Okolle, J.N., Missi, V., Tueche, J.R., Levai, L.D., Njukeng, J.N., 2019. Impact of different land-use systems on soil physicochemical properties and macrofauna abundance in the humid tropics of Cameroon. Applied and Environmental Soil Science 2019, 1–9.

Nath, A.J., Brahma, B., Sileshi, G.W., Das, A.K., 2018. Impact of land use changes on the storage of soil organic carbon in active and recalcitrant pools in a humid tropical region of India. Science of the Total Environment 624, 908–917.

Nelson, D.W., Sommers, L.E., 1996. Total carbon and soil organic matter. In: Sparks, D.L. Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E. eds. Methods of Soil Analysis. Part.3- Chemical Methods. ASA-SSSA, Madison, Wisconsin, USA. pp. 961–1010.

Novara, A., Rühl, J., La Mantia, T., Gristina, L., La Bella, S., Tuttolomondo, T., 2015. Litter contribution to soil organic carbon in the processes of agriculture abandon. Solid Earth 6, 425–432.

Sang, P.M., Lamb, D., Bonner, M., Schmidt, S., 2013. Carbon sequestration and soil fertility of tropical tree plantations and secondary forest established on degraded land. Plant and Soil 362, 187–200.

Selassie, Y.G., Anemut, F., Addisu, S., 2015. The effects of land use types, management practices and slope classes on selected soil physico-chemical properties in Zikre watershed, North-Western Ethiopia. Environmental Systems Research 4, 3.

Sisay Golla, A., 2019. Soil Acidity and its Management Options in

Ethiopia: A Review. International Journal of Scientific Research and Management 7, 27–35.

Trakooyingcharoen, P., Gilkes, R.J., Sangkhasila, K., 2012. Effects of land use on some physical, chemical, and mineralogical characteristics of Thai Oxisols. ScienceAsia 38, 82–89.

Tung, G. P, Hung, T. N., Kappas, M., 2018. Assessment of soil quality indicators under different agricultural land uses and topographic aspects in Central Vietnam. International Soil and Water Conservation Research 6, 280–288.

Tung, G. P., Chau, M T T., Hai, T. N., Ha, N. T., Ngoc, B. N., Ha, K. N. N., Tan, T. T., Huy, D. L., Quy, N. P. L., 2022. Land Evaluation for Acacia (*Acacia mangium* × *Acacia auriculiformis*) Plantations in the mountainous Region of Central Vietnam. Land (Basel) 11, 2184.

Vien, D. T., 2003. Culture, environment, and farming systems in Vietnam's Northern Mountain Region. South Asian Studies 41, 180–205.

Vietnamese Ministry of Industry (VMI), 2000. Geological Map of Vietnam.

Wang, J., Fu, B., Qiu, Y., Chen, L., 2001. Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on the loess plateau in China. Journal of Arid Environments 48, 537–550.

Wezel, A., Steinmüller, N., Friederichsen, J.R., 2002. Slope position effects on soil fertility and crop productivity and implications for soil conservation in upland northwest Vietnam. Agriculture, Ecosystems & Environment 91, 113–126.

Wu, F., Yang, W., Sun, B., Yang, T., Chen, X., Xu, Z., Song, H., 2022. Soil C, N and P stocks and stoichiometry under different vegetation on the surface of the Leshan Giant Buddha. Soil Ecology Letters 4, 69–77.