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Identifying Key Parameters Influencing Soil Quality at Various Depths in Tram Chim National Park, Dong Thap Province, Vietnam

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ABSTRACT

This study used multivariate statistics including cluster analysis (CA) and principal component analysis (PCA) to evaluate the variability and key indicators causing changes in soil quality in Tram Chim National Park, Dong Thap province, Vietnam. Soil samples were collected in the dry season at the habitats of *Ischaemum rugosum* (CM), *Panicum repens* (CO), *Nelumbo nucifera* (LS), *Eleocharis dulcis* (NO), *Oryza rufipogon* (LM), Rice field (RL), *Melaleuca cajuputi* (T) in two layers: A (0–20 cm) and B (20–40 cm). The parameters of pH, total nitrogen (TN), total phosphorus (TP), total acidity (TA), organic matter (OM), total iron (Fe) and exchanged aluminum (Al^{3+}) were used to assess soil quality. The results showed that soil pH was low in both A and B layers. Fe and Al were both high, and the concentrations of these metals in layer A were higher than those in layer B. The OM content was medium while the TN and TP levels were very low. Most of the soil quality indicators tended to decrease with the depth (except for TA). The results of CA analysis showed that there was almost no major change in soil quality between the two soil layers; however, the soil quality in rice field habitat was different from other habitats. The cause may be due to human impact in adding fertilizers/pesticides during farming practices. The PCA results showed at least five influencing factors, explaining 99.7% and 99.9% of soil quality variation in A and B layers. The Al^{3+}, TA, OM, and TP parameters had the main influence on the soil quality of layer A. Meanwhile, the pH, Al^{3+}, TA, TN, Fe_t indicators had influence on the soil quality of layer B. These indicators need to be future surveyed to assess the evolution of soil quality in the study area.

Keywords: soil quality, national park, organic matter, alkaline soil, multivariate analysis.

INTRODUCTION

Tram Chim National Park (TCNP) is the largest remaining natural area of the Dong Thap Muoi region, the floodplain ecosystem of the Mekong River. This is one of the most vulnerable areas in the Mekong Delta to climate change and human impacts. Tram Chim National Park is a wetland ecosystem that is very diverse in terms of flora and fauna living on different natural elements of sediment, geomorphology and soil, especially red-crowned cranes (*Grus antigone*). Recognized as one of the 2000 Ramsar sites in the world and the fourth Ramsar site in Vietnam, Tram Chim National Park plays an extremely important role and function in preserving the wetland ecosystem. Characterized by a closed flood field and heavily contaminated with acid sulfate soil, in the habitats of Tram Chim National Park, over many years of exploitation and use, there have been changes in morphology and physical and chemical characteristics in the soil. Especially in the dry season, the process of soil oxidation causes reactions in the soil, releasing a large amount of pyrite materials, affecting biological activity in the soil, crop yield and water quality (Mathew et al., 2001; Gosavi et al., 2004; Kawahigashi et al., 2008). The development of household economy along with the increase in population has contributed to promoting intensive rice cultivation and aquaculture around the area. In parallel, the generation of waste and the increasing demand for pesticides, fertilizers and chemicals have the potential to affect the quality of soil, water and aquatic ecosystems in the TCNP (Sum et al., 2016; Hung et al., 2017). Several studies have focused on morphology and physical and chemical properties of acid sulfate soils in Dong Thap Muoi (Hung et al., 2017) as well as adaptive characteristics of *Eleocharis ochrostachys* and *Eleocharis dulcis* to the environment. In recent years, multivariate statistical methods have been widely used in environmental quality assessment (Singh et al., 2005; Salah et al., 2006). Methods such as cluster analysis (CA), principal component analysis (PCA) can provide good support in explaining the main drivers of environmental quality variability (Feher et al., 2016) and environmental quality subgroups (Chounlamany et al., 2017). This study used cluster analysis (CA) and principal component analysis (PCA) to explain the variation and identify the main parameters affecting the variation in soil quality at different layers. The results provide scientific information to support soil quality monitoring in the study area.

MATERIALS AND METHODS

Soil sampling and analysis

The soil samples were collected in the dry season in 2019 according to TCVN 7538-2:2005 at various habitats, including *Ischaemum rugosum* (CM), *Panicum repens* (CO), *Nelumbo nucifera* (LS), *Eleocharis dulcis* (NO), *Oryza rufipogon* (LM), Rice field (RL), *Melaleuca cajuputi* (T) in two layers: A (0–20 cm) and B (20–40 cm). The locations of the soil samples collected are shown in Figure 1.

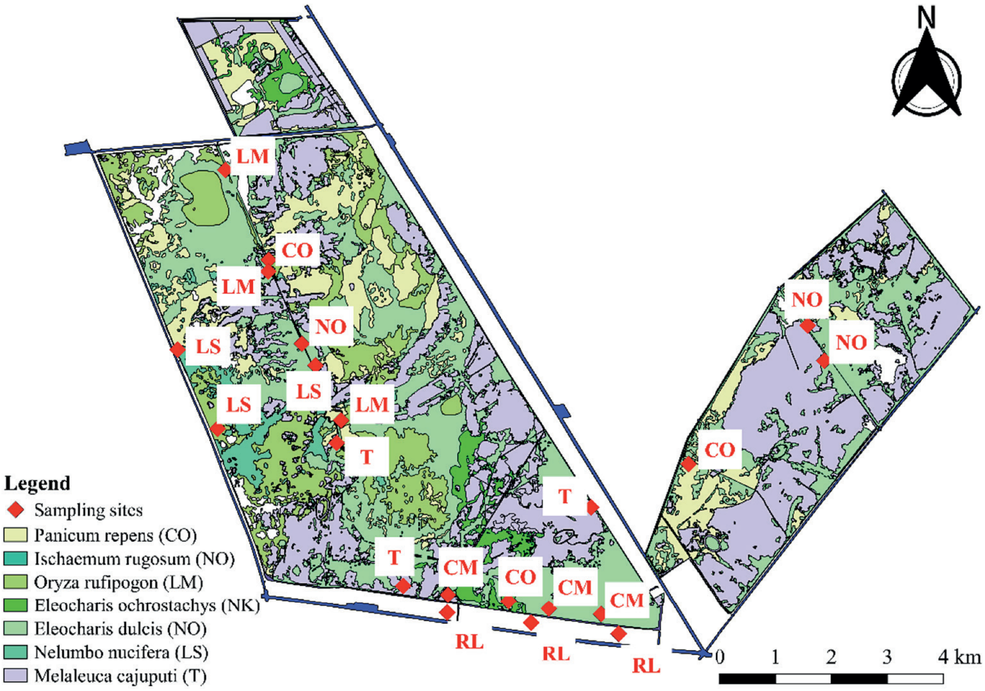

Figure 1. Map of soil sampling locations in TCNP

Table 1. Analysis method of soil environmental parameters

No	Parameters	Unit	Analytical methods
1	pH	-	Extracted with distilled water, ratio 1:5 (soil/water), pH determined by pH meter
2	Organic matter (OM)	%	Walkley Black
3	Total nitrogen (TN)	%	Kjeldahl
4	Total phosphorus (TP)	% P_2O_5	Colorimetric method
5	Total iron (Fe_t)	%	Colorimetric method
6	Total acidity (TA)	meqH^+/100g	Extracted with KCl and titrated with 0.01N NaOH solution
7	Exchanged aluminum (Al^{3+})	meqAl^{3+}/100g	Extracted with KCl, 4% NAF solution to complex with Al, titrated with 0.005N H_2SO_4.

The collected soil samples were air-dried, ground and sieved. The prepared soil samples were used for the analysis of pH, total nitrogen (TN), total phosphorus (TP), total acidity (TA), organic matter (OM), total iron (Fe_t) and aluminum exchange (Al^{3+}). The soil parameters were analyzed at the laboratory of Environmental Science Department, College of Environment and Natural Resources, Can Tho University, Vietnam according to the standard methods (Table 1).

Data analysis

The different soil quality data between the two layers of A and B were determined by one-way analysis of variance (ANOVA) at 5% significance level using IBM SPSS statistics for Windows software, Version 20.0. IBM Corp., Armonk, NY, USA). Cluster analysis (CA) was applied to spatially group soil quality (Feher et al., 2016). The soil sampling sites with similar characteristics are grouped into the same cluster, while different characteristics are grouped into another cluster. The cluster analysis was carried out according to Ward's method (Salah et al., 2012) and presented as a tree structure or dendrogram (Feher et al., 2016). Principal factor analysis (PCA) is widely used in multivariate analysis used to extract important information from primary data sets (Feher et al., 2016). PCA reduces the original data variables that did not make a significant contribution to the data variability while creating a new group of variables called the principal or principal (PC) variables. The important value to consider the main components is the eigenvalue coefficient, the larger this coefficient, the greater the contribution that major component contributes to explaining the variability of the original data set. The correlation between the principal component and the initial data variables is indicated by the loading correlation coefficients (Feher et al., 2016). The absolute value of the weighted correlation coefficient greater than 0.75 means that there is a strong correlation between the principal components (PCs) and the soil quality parameter, from 0.75 to 0.5 is the average correlation, and 0.5–0.3 is a weak correlation (Liu et al., 2003). CA and PCA analyses were performed using Primer 5.2 software for Windows (PRIMER-E Ltd, Plymouth, UK).

RESULTS AND DISCUSSION

Soil quality in Tram Chim National Park

The analysis results showed that the pH between the two soil layers in the habitats ranged from 3.55 ± 0.08 – 4.57 ± 0.12 (A layer) and 3.18 ± 0.03 – 4.4 ± 0.07 (B layer), the highest in the rice field habitat and the lowest in the habitats of CO (layer A) and CM (layer B) (Figure 2). The results of ANOVA analysis showed that there was a statistically significant difference between the habitats of RL and LS, T and CO, CM, LM, and NO ($p<0.05$). The pH value tended to decrease between the two soil layers, which is caused by the acidity-producing substances at the bottom following the capillary action upward and stopping at the B layer (20 – 40 cm) (Sylla, 1994). On the other hand, at the time of sample collection at the end of the rainy season (high flooding water) and the beginning of the dry season, the flood water level recedes slowly, acid sulfate soil washing occurs in the surface soil, H^+ ions are diluted, causing the H^+ ion value decrease leads to higher pH values in the A layer (Anh et al., 2013). The above-mentioned values showed that the pH at representative sampling sites in the two soil layers of the habitats in the NP ranged from acidic to very acidic (USDA, 1983). Especially, the pH in soil layer B (20 – 40 cm) was significantly lower than that of layer A. The results of soil pH analysis in the studied habitats in Tram Chim National Park are relatively consistent with the study of Ni et al. (2011) at the Phu My species and habitat conservation area in Kien Giang; the average pH value of CM habitats was 3.48; CO was 3.52. This proves that the flora and fauna in these habitats could adapt well under heavy acid soil conditions. Particularly for Melaleuca trees, the pH limit of tolerance is very low ($pH < 2.9$), so the soil does not affect the development of Melaleuca (Ba, 2003). In rice fields, when the pH value is <4.2, the concentration of Fe^{2+} and Al^{3+} in the solution form complexes with cations that limit the ability of roots to absorb nutrients (Ca, Mg, P,...) (Anh et al., 2013). Besides, the suitable pH range for rice ranges from 5.5 to 6.5, so it can be seen that the pH in the study area may have partly affected rice yield. In general, the pH values in the studied habitats are in the range of pH commonly found in acidic soils according to TCVN 7377:2004 (pH = 3.4 – 6.1).

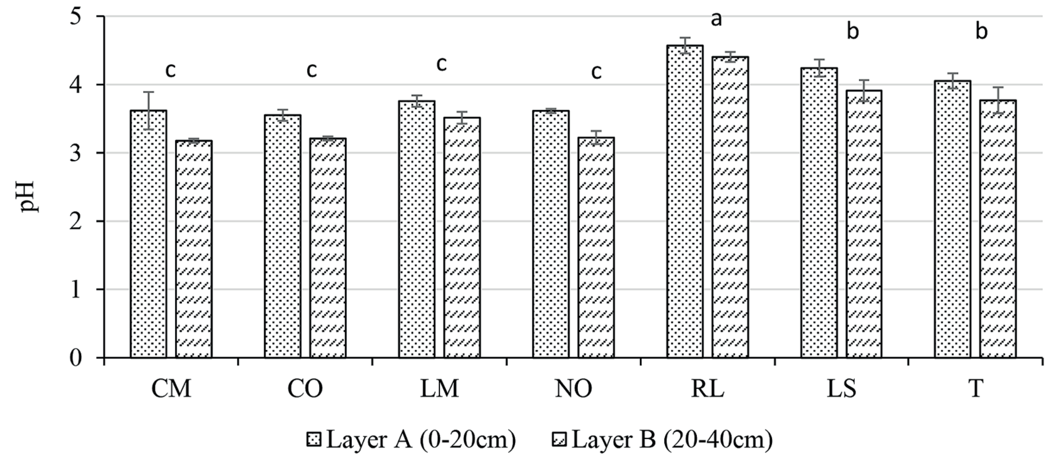

Figure 2. Changes in soil pH values in different habitats

The analysis results showed that the total acidity in the two soil layers is at a relatively high level with values ranging from 12.69 ± 1.49 – 16.58 ± 0.24 meq H$^+$/100g (layer A) and 12.83 ± 1.17 – 19.37 ± 0.56 meq H$^+$/100 g (layer B), the highest was in the weedy habitat, the lowest was in the RL habitat (Figure 3). The analysis results showed that there was a statistically significant difference between the productive habitats compared with RL and LS ($p<0.05$). This has shown the impact of agricultural farming in RL habitats and water storage in other habitats leading to the release of Al^{3+} in the flooded environment, affecting the nutrient composition in the soil. In general, the TA in most habitats (except grass and melaleuca) in the B layer was higher than that in the A layer. This variation was relatively consistent with the results of soil pH analysis (Figure 2). The differences between habitats were also recorded in NO, RL and LS habitats ($p<0.05$), while the remaining habitats were different from NO, but no difference was recorded between RL and LS.

Similar to the total acidity, there was a correlation between pH and Al^{3+} in the soil. High Al^{3+} in soil could lead to low soil pH, which results in high soil acidity. In the Mekong Delta, the total soil acidity includes Al^{3+} and H$^+$ in which Al^{3+} exchange is usually very high, and H$^+$ ions in acidic soil were low on acid sulfate soils (Hung et al., 2017). The analysis results showed that the exchangeable Al^{3+} in the soil in the habitats in two layers A and B was relatively different with the range of 7.24 ± 0.16 – 15.06 ± 1.39 meqAl^{3+}/100 g and 5.23 ± 0.51 – 13.41 ± 2.11 meqAl^{3+}/100 g, respectively (Figure 4). The exchangeable Al^{3+} in the A layer tended to be higher than that in the B layer, which is due to the influence of the oxidation process that often produces H$^+$ ions or the accumulation of organic matters which also acidify the soil along with the flooding regime in the study area. Flooding may lead to the release of Al^{3+} in the environment that can affect the growth of plants, as well as aquatic plants and animals in the study area. In addition, the study only

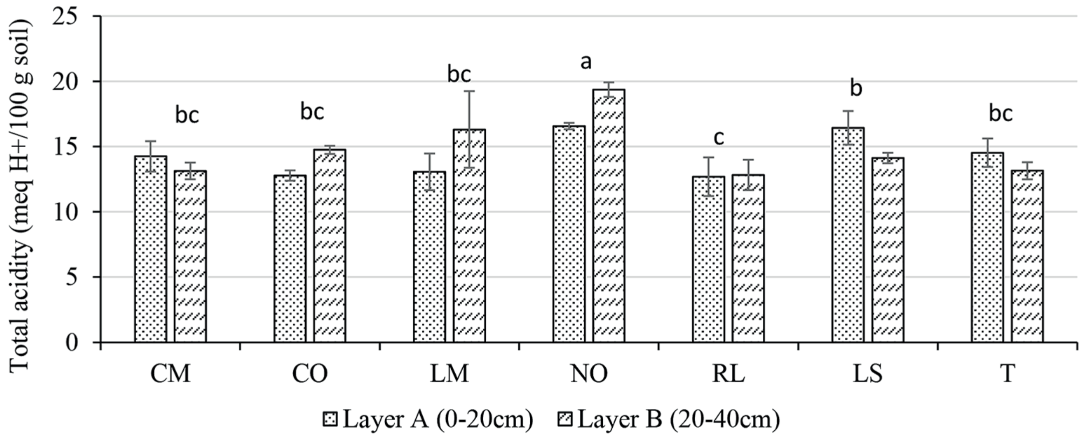

Figure 3. Changes in total acidity in soil in different habitats

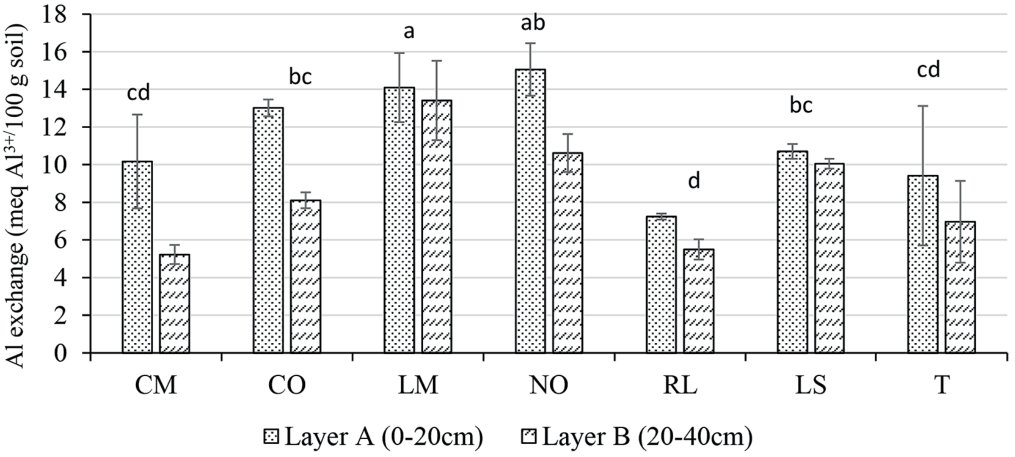

Figure 4. Changes in exchanged Al^{3+} in different habitats

recorded a relatively large difference in soil quality between LM and RL habitats. When comparing the Al^{3+} in Tram Chim National Park in 2015 fluctuated around 10.1–20 meqAl^{3+}/100g (Sum et al., 2015), the Al^{3+} at the time of the study tended to decrease. However, exchangeable Al^{3+} in habitats (except Rice field and Melaleuca habitats) remained high when values were in the range of 10–20 meq Al^{3+}/100g (Hung et al., 2004).

The results showed that OM in the habitats in A and B layers were from low to moderate levels according to the rating scale of Metson (1961) with a range of 5.03 ± 0.49 – 8.28 ± 0.28% and 3.81 ± 1.01 – 6.73 ± 1.55%, respectively (Figure 5). The figures are relatively consistent with the study of Hung et al. (2004) when the soil in the Mekong Delta usually has medium OM content. In addition, the OM content in the habitats is also within the limits of TCVN 7376:2004 – acidic soil (2.15 – 8.32%). The rice field habitat in layer A was noted with the highest concentration of OM. The reason may be due to the amount of decomposed plant residues and accumulated in situ during the cultivation process, which created the OM content (Nga and Thuy, 2012). In addition, because of the characteristics of acid sulfate soil, this has made difficult for microorganisms to decompose OM, limiting the release of nutrients in the soil (Hoa, 2007). Besides that, most habitats have higher OM in layer A than that in layer B; the decline in OM content in different habitats is due to the amount of fallen materials in different habitats (Anh et al., 2013), typically in the RL habitat and the CO habitat. However, there was an opposite trend in RL and LS habitats, which could be explained by the activities of microorganisms that slowly degrade OM compounds. Moreover, in the annual LM habitats, there is a collection and burning of LM biomass in the dry season, the burning of fields affects the activity of decomposing microorganisms in the soil. On the other hand, the average concentration of OM in the soil tended to decrease over the years when compared with the research results of Sum et al. (2015), the

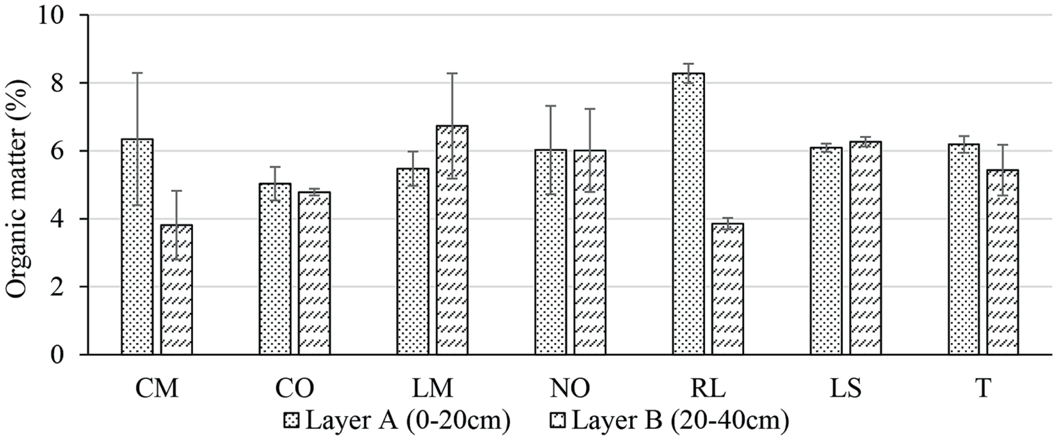

Figure 5. Changes in organic matters in different habitats

OM content has an average value ranging from 10–30% reaching the rich level. This decline can be attributed to the annual vegetation collection plan and the water retention regime of the TCNP leading to a slower decomposition of OM.

Similar to the OM content in the soil, the analysis results of the TN content in the A layer (0–20 cm) and the B layer (20–40 cm) ranged from 0.08 ± 0.06 – 0.19 ± 0.06% and 0.04 ± 0.02 – 0.1 ± 0.05%, respectively (Figure 6) and tended to decrease with depth of soils; this is similar to the results in the study of Anh et al. (2013). In which, the RL and LM habitats had the highest average TN content in the A and B layers and the lowest in the CM and melaleuca habitats, respectively. The accumulation of nitrogen in fertilizers due to agricultural practices contributed to an increase in the TN content of the soil. On the other hand, the remaining habitats are affected by the inundation regime and the activities of microorganisms in the soft soil that reduce the TN content in the soil. However, the study did not find a statistically significant difference between soil quality in the habitats ($p>0.05$). Compared with TCVN 7373:2004 – acidic soil (0.145–0.42%N), the TN content in most habitats is lesser than the standard limit except for weeds and rice fields in the A layer. In general, the amount of TN in the two soil layers in the habitats ranges from poor to good according to Hung (2005) scale. In addition, according to the study of Sum et al. (2015) in TCNP, the TN content was recorded ranging from 0.1–0.15%N; This can be seen that the TN content tends to decrease compared to the present study time. This change may be influenced by the nature of heavily acidic soil and the inundation regime in the TCNP as well as the lack of appropriate soil and water management.

The total phosphorus content in habitats ranged from 0.02 ± 0 – 0.03 ± 0 %P_2O_5 (layer A) and 0.01 ± 0 – 0.02 ± 0 %P_2O_5 (layer B). In which, the habitats of RL and LS were recorded with the highest concentrations in A and B layers; it was the lowest in the CM habitat and significantly different from the other habitats (except CO habitat) ($p<0.05$) (Figure 7). Moreover, the TP content tended to decrease sharply from the A to B layer in all habitats, especially the RL habitat. The use of fertilizers during cultivation may have led to this difference in soil content in the A layer of the study area. In addition, TP in soil was divided into two forms including organic phosphorus and inorganic phosphorus. Total phosphorus content tended to increase with depth and organic phosphorus content is relatively high in the topsoil (Tisdale and Nelson, 1975). This factor has also contributed to the difference between the two soil layers because the soil structure in the study area is mainly clay (clay composition > 40%), this has limited the increase of phosphorus content in the soil layer B (Tien, 2018). In addition, compared with TCVN 7374:2004 – acidic soil (0.03–0.08 % P_2O_5), the TP content in the habitats is lower than the specified value. The low phosphorus content in the soil is due to the fact that phosphorus is immobilized on acidic soils by Fe and Al oxides, which can increase the toxicity of Fe^{3+} (Astrom, 1998). In addition, the habitats in Tram Chim National Park mainly grow naturally and there is no addition of phosphorus to the soil, so the TP content is low.

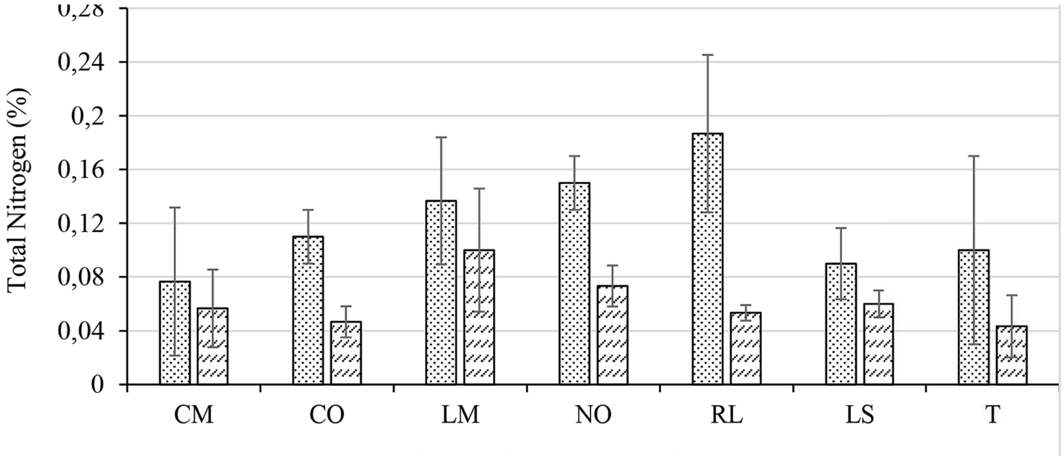

Figure 6. Changes in total nitrogen in different habitats

In general, the TP content in Tram Chim National Park is at a very poor level when all habitats have %P_2O_5 < 0.03 (Can, 1978). This result is consistent with the study of Ren (1999) that the TP content in the Mekong Delta soil is made up of poor minerals. However, the low phosphorus content in the soil has raised many concerns for soil nutrients; specifically, this nutrient tends to decrease over time. The previous research by Sum et al. (2016) showed that the TP content ranged from 0.04 – 0.1% in the average range.

The analysis results showed that the average total iron content in the layers A and B ranged from 0.76 ± 0.28 – 1.45 ± 0.08% and 0.45 ± 0.1 – 1.74 ± 0.12%, respectively (Figure 8). The total iron content in habitats decreased with depth of soil, however, the LM and CO habitats with soil layer B had an average value of 1.41 ± 0.19% and 1.74 ± 0.12%, respectively, higher than that of layer soil A (0.05–0.29%). In addition, the habitats of CM, CO, and LM were determined to have a statistically significant difference compared with the habitats of LM, LS and melaleuca ($p<0.05$). This difference may be due to the influence of the oxidation process that produces H^+ ions or the presence of many acidic functional groups due to the accumulation of OM in the soil. On the basis of the rating scale of Landon (1984), the iron content in the area is assessed as medium to high. Compared to 2015 the total iron value fluctuated by about 0.67% (Sum et al., 2016), showing that the total iron content in the soil in the TCNP over the years has not changed much. However, with the current total iron content, it will easily directly affect the life of plants and animals.

Spatial variation of soil quality at various depth

Soil quality of the A layer (0–20 cm) (Figure 9) and B layer (20–40 cm) (Figure 10) in

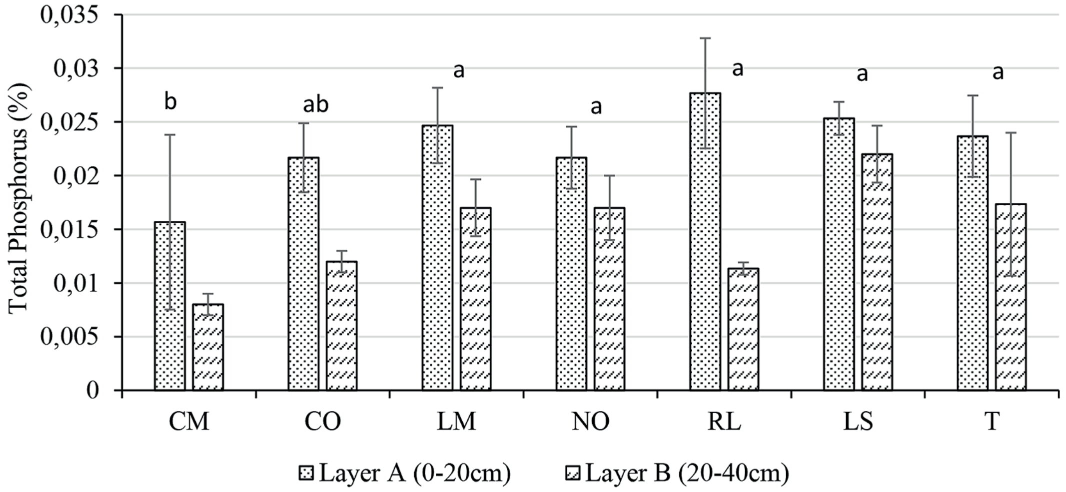

Figure 7. Changes in total phosphorus in different habitats

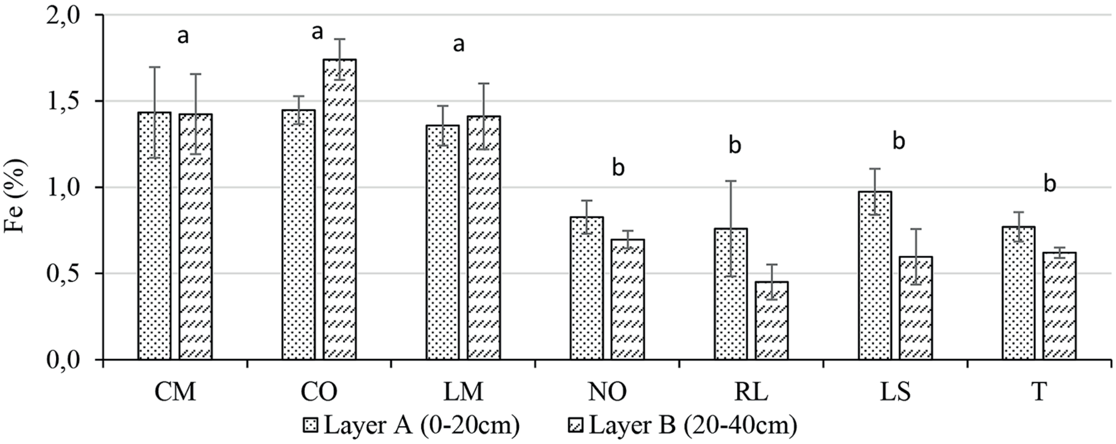

Figure 8. Changes in total iron in different habitats

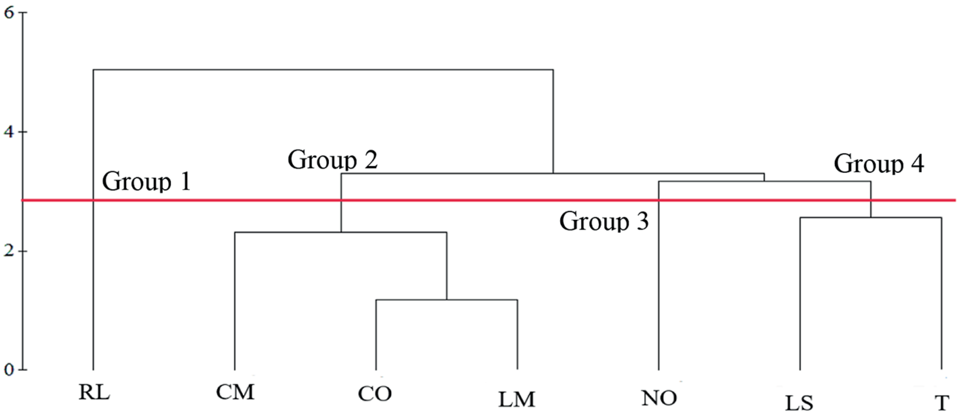

Figure 9. Clustering soil quality at layer A (0 – 20 cm)

the habitats was classified into four groups. Soil at layer A and layer B in rice field habitat is influenced directly by human activities; therefore, soil quality in this habitat was classified into separate groups (Group 1 and Group 3). In which, this division is due to the presence of high pH, OM, TN, and TP; while TA and Al^{3+} in layer A were the lowest in all habitats showing a marked change in soil quality compared to other habitats. Similarly in the B horizon, this difference is also shown by the significant difference in pH, Al^{3+}, TA; however, the content of nutrients in the soil in the B layer did not clearly show the difference between the habitats. The similarity of Al^{3+} and TA content in soil quality of A layer has classified NO habitat into a separate group (Group 3).

It can be seen that the soil quality was heavily contaminated with acid sulfate soil and very acidic. The habitats of CM, CO and LM had similar characteristics and were classified in Group 2. These habitats had high total Fe content and low pH compared to the studied habitats. At layer B, the LM habitat had similar soil quality characteristics to the NO habitat (Group 1) with both TA and Al^{3+} content at very high levels compared to other habitats. In addition, Group 4 was formed by the LS and Melaleuca habitats in both layer A and B. This can be concluded that the soil quality in the two habitats LS and Melaleuca does not degrade in terms of natural soil quality.

In general, the soil quality in the habitats hardly changed significantly. Specifically, the soil quality in Tram Chim National Park can be divided into three areas, including the CM and CO habitats (Group 1), RL and NO (Group 2); RL, LS and Melaleuca (Group 3) (Figure 11). The grouping of the habitats was mainly based on the values of total acidity, Fe, pH and exchangeable aluminum, in which, Group 1 had low pH, Fe and total acidity values were relatively high compared to other habitats, group 2 represented soil properties with high value of TA and $Al^{3+,}$ whereas, group 3 had a relatively high content of nutrients.

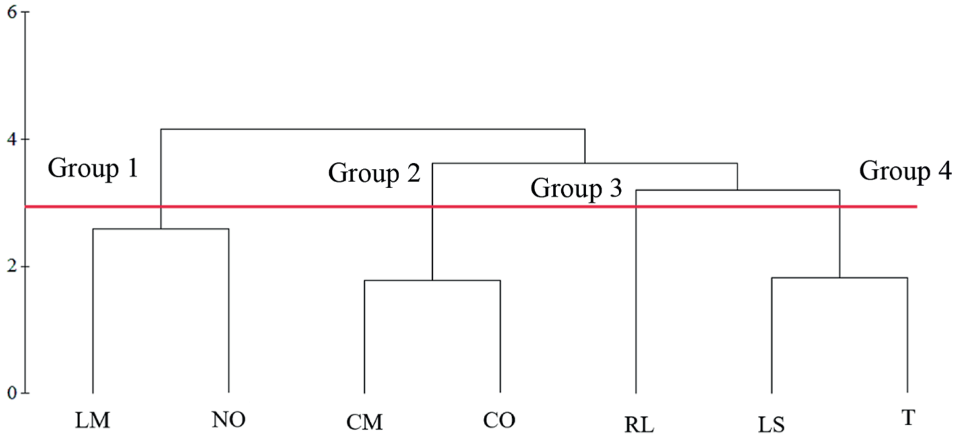

Figure 10. Clustering soil quality at layer B (20–40 cm)

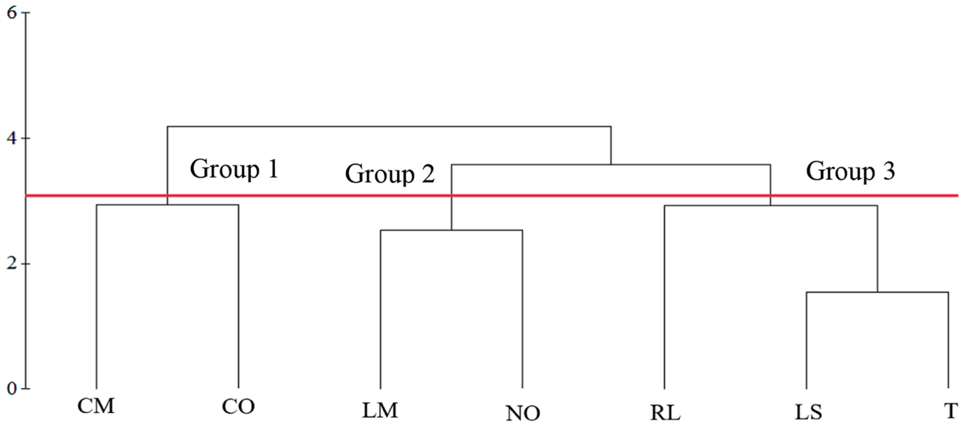

Figure 11. Clustering soil quality of the mean values of both soil layers

Key parameters influencing soil quality at TCNP

The analysis of key parameters affecting soil quality in the study area was carried out and the results were shown in Table 2. The main parameters affecting soil quality in layer A (0–20 cm) include PC1, PC1 and PC3, since the Eigenvalues coefficients of these components were greater than 1. However, the high correlation of TP with PC4 (0.74) showed that agricultural factors affected the TP content in the soil through the addition of phosphate fertilizers. The PC1 composition was explained by the contribution of most soil quality evaluation parameters related to soil physics and chemistry, such as pH (-0.49), Al^{3+} (-0.40), OM (-0.47) and TP (-0.42). PC2 showed a high correlation with TA (-0.83), while the PC3 factor was contributed and explained by TN (0.77). Moreover, in the A layer, total Fe had the most correlation with PCs, so it can be seen that Fe made an important contribution and is the fundamental factor leading to the changes of other soil quality evaluation parameters. Because the study area is very acidic soil, the total Fe is derived from the natural characteristics of the study area.

In the layer B, most of the soil quality change depends on the processes occurring in the surface layer (layer A), so there are only two main factors affecting the soil quality in all habitats (explained 82.40%). In addition, PC3 and PC4 could be considered as secondary factors affecting soil quality and have explained about 15.30% of soil quality variation in layer B. PC3 and PC4 had average correlation coefficients with total nitrogen (-0.58) and total acidity (-0.62), respectively. Except for total pH and Fe, PC1 was correlated with most of the parameters, this factor was related to the growth of flora (absorption of basic cations and excretion of H^+ from the root system), nitrification, long-term leaching and microbial activities affected soil quality in the layer B. Meanwhile, PC2 was explained by pH (-0.58) and total Fe (0.67) showed that this factor could originate from the topography and the water holding capacity of the soil. In general, the

Table 2. Key parameters affecting soil quality of layers A and B in Tram Chim National Park

PCs / Parameters	Layer A (0 – 20cm)					Layer B (20 – 40 cm)				
	PC1	PC2	PC3	PC4	PC5	PC1	PC2	PC3	PC4	PC5
pH	-0.49	-0.02	-0.12	0.18	-0.43	-0.19	-0.58	-0.51	-0.20	-0.37
Al^{3+}	-0.40	-0.18	0.51	0.38	-0.03	0.50	-0.03	-0.24	0.04	-0.41
TA	-0.03	-0.83	0.01	0.04	0.35	0.41	0.10	0.47	-0.62	-0.29
OM	-0.47	0.10	0.05	-0.27	0.68	0.47	-0.20	-0.03	0.38	-0.25
TN	-0.27	0.26	0.77	0.14	0.10	0.41	0.15	-0.58	-0.38	0.56
TP	-0.42	-0.12	-0.19	0.74	0.07	0.40	-0.38	0.23	0.40	0.41
Fe_t	-0.37	0.43	-0.30	0.43	0.46	0.06	0.67	-0.28	0.35	-0.27
Eigenvalues	3.89	1.39	1.03	0.46	0.21	3.83	1.94	0.64	0.43	0.15
% Variation	55.50	19.90	14.70	6.60	3.00	54.70	27.80	9.10	6.20	2.10
Cum.%Variation	55.50	75.40	90.10	96.70	99.70	54.70	82.40	91.60	97.70	99.90

soil quality in two soil layers in TCNP is mainly affected by the physicochemical processes occurring in nature, soil and hydrological characteristics of the study area.

The PCA results revealed that at least five influencing components explaining 99.7% and 99.9% of soil quality variation in soil layers A and B. The Al^{3+}, TA, OM, and TP parameters were the main influence on soil quality of layer A. Meanwhile, the pH, Al^{3+}, TA, TN, and Fe_t indicators have influence on soil quality of layer B. These indicators need to be future surveyed.

CONCLUSIONS

The results showed that soil quality in Tram Chim National Park habitats does not have a large variation between the habitats. Soils are acidic in nature, because they contain many ions that affect the low pH value of the soil, and the TA, Al^{3+} and Fe_t were relatively high. The OM content was assessed at medium level, the TN and TP levels were very low and low, respectively. Most of the soil quality indicators tended to decrease with the depth of soil (except for total acidity). The results of CA analysis showed that there was almost no major change in soil quality between the two soil layers, however, the soil quality in the rice field habitat is also noted to have little similarity with other habitats because the process of adding fertilizers/pesticides to the soil environment during cultivation. It was found from the PCA's results that Al^{3+}, TA, OM, and TP significantly influenced the soil quality of layer A, while pH, Al^{3+}, TA, TN, Fe_t drastically impacted on soil quality of layer B. These indicators need to be surveyed in the future.

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