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Long-term cultivation effects on soil physicochemical properties in Dong Thap Province, Vietnamese Mekong Delta

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ABSTRACT

In many agricultural regions, long-term intensive cultivation has raised concerns about soil degradation and declining soil fertility, particularly in tropical lowland areas. This situation highlights the need to understand better how continuous cropping affects soil properties over time. This study aimed to investigate how prolonged continuous cultivation influences the physical and chemical characteristics of agricultural soils. Effect of 4 different long-term cultivation (<5, 5 - 10, 11 - 15, and over 15 years) on soil physico-chemical properties of farmers' two rice - one cash crop in Dong Thap province. A total of 66 soil samples at two depths (0 - 20 and 20 - 50 cm) were randomly collected from the intensive crop area. Data showed that bulk density was higher after over 10 years of cultivation, and the soil texture of Silty Clay was observed across all crops. The results showed that the chemical properties of the soils were characterised by the low to rather low pH values (4.0 - 6.0) of the topsoil and tended to decrease gradually with depth and intensive cultivation. Unimpacted electrical conductivity (EC) in rice-crop field was recorded, while total N, P, K, soil organic carbon and CEC tended to decrease with cropping time and depths. Electrical conductivity (EC) remained largely unaffected by long-term cropping. In contrast, total nitrogen (N), phosphorus (P), potassium (K), soil organic carbon (SOC), and cation exchange capacity (CEC) showed a declining trend as cultivation time and depth increased. Overall, these results demonstrate that prolonged continuous cultivation contributes to the gradual degradation of soil quality and fertility, emphasizing the need for improved soil management strategies in the region.

1. INTRODUCTION

Dong Thap is one of the upstream provinces of the Mekong River Delta, playing a vital role in ensuring regional food security and contributing to the country's agricultural exports. As of 2022, the province has a total natural land area of approximately 338,228 hectares, of which 277,039 hectares are used for agricultural development and aquaculture. Within the agricultural land, the area dedicated to annual crops is 206,835 hectares, accounting for over 89% (People's Committee of Dong Thap Province, 2023).

Short-term crops, particularly food crops in Dong Thap Province, were developed in the 1980s when the 60-02 Program helped alleviate flooding, improve water quality, drain acidic soils, and reclaim land that rehabilitated hundreds of thousands of hectares in the region. In addition, the establishment of dike systems has partially reduced flooding, allowing the area for crop production to expand. However, the creation of these dikes has also limited the deposition of alluvial soil. According to Vu et al., (2021) alluvial soil is a vital source of essential nutrients, as it contains a balanced composition of macronutrients, secondary nutrients, and trace elements required by crops. Therefore, the decline in sediment from alluvial soil also reduces the nutritional supply for plants (Livsey et al., 2021). Furthermore, intensive production practices and increased cropping cycles contribute to the ongoing degradation of soil quality, negatively impacting agricultural production (Huu, 2011).

For long-term cultivation, farmers rarely care about the addition of organic fertilizers or returning agricultural by-products to the soil, which can lead to soil depletion due to compaction and structure degradation beneath the cultivated layer, leading to a deficiency of organic matter and macronutrients in the soil (Ly et al., 2022; Shrivastava et al., 2022)

Therefore, assessing the variability of soil characteristics in Dong Thap province is essential for evaluating trends in soil quality over the cultivation period, enabling people to adopt more appropriate and sustainable farming methods.

2. MATERIALS AND METHOD

2.1. Study area

Dong Thap province, located upstream of the Vietnamese Mekong Delta (VMD), features a tropical climate and fertile soil primarily composed of fluvial deposits, ideal for food crop cultivation (Figure 1). Its favorable environmental conditions contribute significantly to the agricultural productivity of the province. Food crop cultivation primarily occurs in Gleysols and Fluvisols, which are noted for their thick surface layers and high nutrient content from the accumulation of fluvial material (refer to Figure 1). These soils are well drained to a depth of 50 cm and show little variation in texture throughout the profile. Despite the accumulation of organic matter in the surface layer, the soils remain acidic, which may be attributed to the oxidation of sulfur-bearing materials, the production of organic acids during residue decomposition, and the depletion of exchangeable base cations through prolonged cultivation and leaching processes. Gleysols and Fluvisols are characterized by prolonged water saturation, leading to aeration problems. Consequently, Crops are often planted on raised beds with dike systems or an irrigation canal system for drainage.

2.2. Soil sample collection

Soil samples were collected from each rice–crop field at two depths (0–20 cm and 20–50 cm), corresponding to the cultivated topsoil and subsurface layers, respectively (Edwards et al., 2024). All samples were taken randomly according to a diagonal rule, selecting 5 points: 4 corners and an intersection point from the observed area plot. Samples from the same plot were combined into a representative sample weighing at least 1.5 kg, labelled, and brought to the laboratory. Once transferred to the laboratory, the soil samples were air-dried under ambient conditions until reaching a stable moisture content, then crushed and passed through a sieve with a 2 mm mesh size. A portion of the soil was used to determine soil texture, while the remainder was further sieved through a 1 mm mesh to analyze the remaining chemical and physical soil properties. A total of 66 soil samples were collected from vegetable-cultivated fields at two depths (0–20 cm and 20–50 cm), representing the topsoil and subsoil layers, respectively.

2.3. Measurement of soil physico-chemical determinants

All analytical indicators are described in detail in Table 1 below.

Table 1. Methods and principal procedures of analyzed determinants

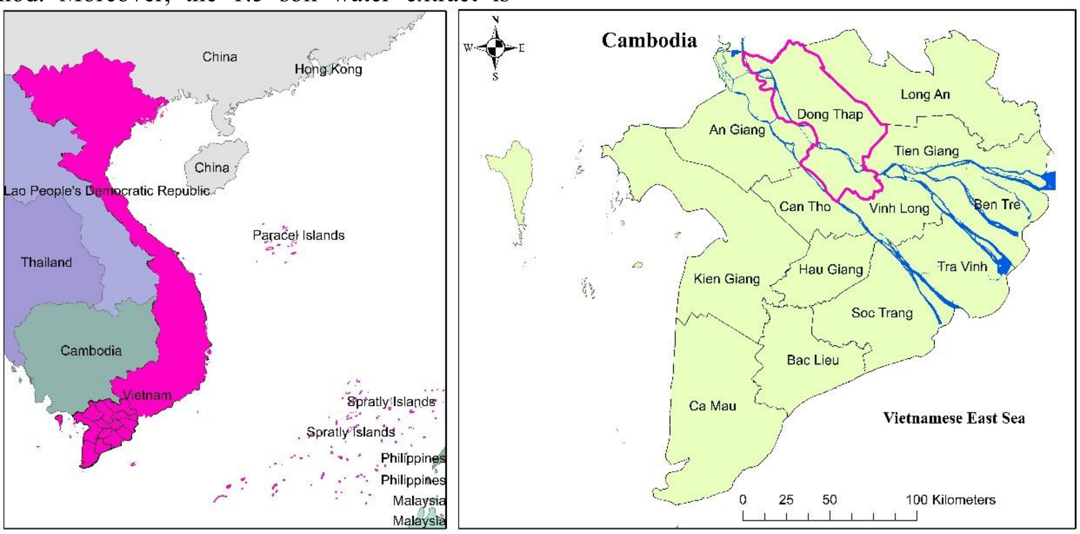
No	Analyzed determinant	Unit	Methods and principal procedures
1	Bulk density	g cm^{-3}	Determined using the core method with a 100 cm^3 cylinder; samples were oven-dried at 105°C for 24h before weighing (European Center for Standardization, 2014).
2	Soil texture	% sand, silt, clay	Particle-size distribution was determined using the hydrometer method after dispersion of soil aggregates (Ashworth et al., 2001).
3	Porosity	%	Determined using the thermo–time domain reflectometry (thermo-TDR) technique (Ochsner et al., 2001).

No	Analyzed determinant	Unit	Methods and principal procedures
4	Soil pH	—	Measured in a 1:5 soil-to-1N KCl suspension using a pH meter (Landon, 2014; Reeuwijk, 2002).
5	Electrical conductivity (ECw)	dS m^{-1}	Measured in a 1:5 soil-to-water suspension following Landon (2014) and Reeuwijk (2002).
6	Soil organic carbon	% C	Determined by the dry combustion method (Ramamoorthi & Meena, 2018).
7	Total nitrogen	% N	Analyzed by the Kjeldahl digestion method (Reeuwijk, 2002).
8	Total phosphorus	mg kg^{-1}	Measured colorimetrically using phosphomolybdate with $SnCl_2$ as the reducing agent at 890 nm (Pierzynski, 2000).
9	Total potassium	mg kg^{-1}	Determined using an atomic absorption spectrometer via emission method (AES) (Angelova et al., 2021).
10	Cation exchange capacity (CEC)	meq 100 g^{-1}	Extracted with 0.1 M $BaCl_2$ and titrated with 0.01 M EDTA (Gillman, 1979).

The measurements were performed using a soil-to-solution ratio of 1:5, with 1N KCl used for determining soil pH and distilled water used for measuring electrical conductivity (ECw), following the procedures described by Landon (2014) and Reeuwijk (2002). In this study, ECw (electrical conductivity of the soil–water suspension) was used instead of ECe (electrical conductivity of the saturated paste extract) because the soils in the study area are non-saline alluvial soils with generally low soluble salt contents. Under such conditions, ECw provides a reliable relative indicator of soluble ion concentration and soil chemical status without requiring the more time-consuming saturated paste method. Moreover, the 1:5 soil–water extract is widely used in tropical soil research and environmental monitoring, providing greater comparability across large sample sets and sufficient sensitivity to detect changes resulting from long-term cultivation.

2.4. Statistical analysis

Data were analyzed using analysis of variance (ANOVA) under a completely randomized design (CRD). Mean comparisons were performed using Duncan's multiple range test at a significance level of $P < 0.05$. All statistical analyses were conducted using IBM SPSS Statistics version 22.0.



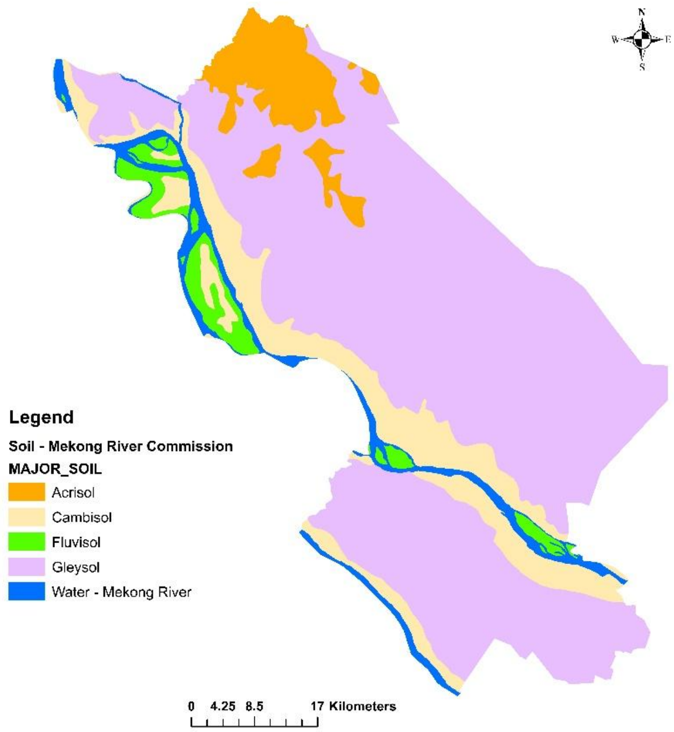


Figure 1. Study area – Dong Thap province in the Vietnamese Mekong Delta (above), and soil map (below), with soil types extracted from the soil map of the Mekong River Commission (MRC)

Note: On June 12, 2025, the National Assembly of Vietnam issued Resolution No. 202/2025/QH15, which amended certain administrative boundaries, effective July 1, 2025. Throughout this study, provincial and district names/boundaries are presented as they existed before that Resolution to ensure consistency across historical datasets.

3. RESULTS AND DISCUSSION

3.1. Physical soil characteristics

The research results indicated that the bulk density of the tillage layer (0 – 20 cm) ranged from 0.9 to 1.12 g/cm³ and tended to increase with soil depth (approximately 1.04 – 1.22 g/cm³), corresponding to the duration of cultivation. This indicates that in areas where annual crops are grown, bulk density tends to increase with soil depth, but there is no significant variation in bulk density with land-use time or cultivation depth ($P>0.05$). Soil porosity also showed a similar trend to bulk density.

The porosity of the topsoil (0-20 cm) fluctuated from 48.16% to 61.87%, while the subsoil of 20-50 cm ranged from 46.6% to 57.18%. Given these values of bulk density and porosity, there appears to be no adverse impact on crop growth. However, data indicate that bulk density tends to increase with depth and cultivation time. Therefore, to mitigate potential soil compaction that could restrict root activity and nutrient uptake, it is essential to adopt improved soil management practices such as appropriate tilling, incorporation of organic matter, and maintenance of soil structure through sustainable cultivation techniques

The results presented in Table 1 also indicate that the sand content in the soil is relatively low compared to that of silt and clay. The clay content ranges from 42% to 57%, while the silt content varies from 41% to 54% in the 0 – 20 cm soil layer, and from 41% to 53% and 46% to 50% for clay and silt at depths of 20 – 50 cm, respectively. Based on the United States Department of Agriculture (USDA), (1993) the soil colour belongs to the silty clay soil group (Table 2). In general, due to the high clay content, this soil in Dong Thap has the potential to supply and retain a lot of nutrients, and the subsoil of 20-50 cm has high soil water capacity.

However, a high clay ratio may lead to reduced water permeability and increased runoff during heavy rainfall or irrigation.

Table 2. Physical soil characteristics in croplands

Cultivation time (years)	Bulk density (g/cm^3)	Porosity (%)	*Soil particle distribution*			Classification of soil texture (USDA Soil taxonomy)
			%Sand	%Silt	% Clay	
			0-20 cm			
<5	1.01^{ns}	48.16^{ns}	2	41	57	Silty Clay
5-10	1.12^{ns}	53.31^{ns}	7	47	46	Silty Clay
11-15	0.90^{ns}	61.87^{ns}	8	49	43	Silty Clay
>15	1.11^{ns}	51.67^{ns}	4	54	42	Silty Clay
CV (%)	23.53	0.51				
Cultivation time (years)			*20-50 cm*			
<5	1.04^{ns}	46.60^{ns}	4	50	46	Silty Clay
5-10	1.04^{ns}	57.18^{ns}	1	46	53	Silty Clay
11-15	1.22^{ns}	47.24^{ns}	3	50	47	Silty Clay
>15	1.22^{ns}	47.08^{ns}	10	49	41	Silty Clay
CV (%)	23.53	23.58				

Note: Different lowercase letters indicate significant differences at P < 0.05; ns: not significant

3.2. Chemical soil characteristics

The analytical results for the chemical characteristics of the soil in the cropland, presented in Table 3, show that the pH_{KCl} values are classified as strongly acidic (ranging from approximately 3.56 to 4.79 in the topsoil and from 4.29 to 4.35 in the subsoil), which may affect crop growth. Despite slight variations, no significant differences (P > 0.05) in pH_{KCl} values were detected among cultivation durations or between soil depths within the intensive crop cultivation areas.

The results of the EC analysis show a significant impact of cultivation duration on EC values; however, the EC values remain within permissible limits and do not yet affect crop growth potential, ranging from 131.88 to 236.25 (µS/cm). Although current EC values do not affect crop growth and development, the results indicate that intensive farming practices have led to higher EC values in the deeper layer. Therefore, if continuous intensive cropping is implemented, it may increase soil EC, hindering crop development (Table 3).

The organic matter content in the topsoil of cultivated land is assessed as high, ranging from 6.58% to 8.8% (Table 3). This value tends to decrease significantly with depth and cultivation duration. The soil organic matter content tends to decrease in some cultivated lands after more than 15 years of cultivation. This indicates that long-term cultivation, coupled with continuous enclosure by a closed dyke system, degrades the soil's organic matter. In addition, numerous studies have indicated that organic matter content can decrease by 25% under continuous cultivation for over 20 years without additional organic fertilizer supplementation and can decrease by up to 50% after cultivation for more than 50 years with little to no organic fertilizer supplementation (Emiru & Gebrekidan, 2013; Zhuo et al., 2018). Therefore, farmers need to supplement with more organic fertilizer to maintain and stabilize nutrients for cultivated land.

The total nitrogen content is highest in areas cultivated for less than 5 years and lowest in those cultivated continuously for over 15 years, with values of 0.37% N and 0.19% N for the 0-20 cm layer, and 0.25% N and 0.15% N for the depth of 20-50 cm, respectively. However, the total nitrogen content in the topsoil of cultivated cropland at the surveyed locations is assessed as high. Nitrogen levels decrease with soil depth and duration of cultivation, showing a significant difference (P<0.05) (Table 2).

The longer the cultivation period, the lower the soil nitrogen content. Therefore, farmers need to pay attention to maintaining the number of chemical fertilizers and should combine them with organic fertilisers to stabilise organic matter and nitrogen in the soil.

The total phosphorus content is recorded at a level ranging from poor to moderate, with values of approximately 0.07 - 0.16% P_2O_5 for the topsoil and 0.02 - 0.16% P_2O_5 for the subsoil, showing a statistically significant difference over the duration of cultivation. In contrast, the total potassium content in crop soils is assessed as moderate to rich across both sampling layers and does not show a significant difference by cultivation duration in the surface layer of crop soils in the province.

The high total potassium content in the soil may be attributed to the main crop studied, which is chili, as farmers increase the number of inorganic fertilizers, especially potassium, to ensure fruit quality. This leads to greater accumulation of potassium in the cultivated soil, increasing total potassium levels. Additionally, the regions cultivating cash crops in the province often grow in newly formed silt banks where the nutrient content in the soil remains high. However, the results partially indicate that long-term cultivation has led to fluctuations in soil potassium levels. Specifically, high potassium content (2.74% K_2O) is found in areas cultivated for less than 5 years, decreasing to 1.8% K_2O in areas cultivated for over 15 years. This gradually reveals the soil's disadvantages, as nutrient levels tend to decline under intensive cultivation.

The results showed that prolonged cultivation led to a noticeable decline in the soil's exchange capacity (CEC) as soil depth and cultivation duration increased. The CEC values ranged from approximately 13.75 to 20.51 meq/100 g in the surface layer (0–20 cm) and decreased to 11.46–13.38 meq/100 g at 20–50 cm depth. Although these values are at the lower end of the expected range for Gleysols and Fluvisols developed from alluvial silty clay deposits, they remain within plausible limits for such soils under intensive, long-term cultivation. The relatively low CEC may be attributed to the combined effects of organic matter depletion, soil acidification, and oxidation–reduction dynamics that promote the accumulation of Fe and Al oxides, which possess fewer permanent exchange sites. Furthermore, repeated wetting and drying cycles typical of these hydromorphic soils may have altered the surface charge characteristics of clays, reducing their effective CEC (Brady & Weil, 2013; FAO, 2022; Sposito, 2008) (Brady & Weil, 2017; Blume et al., 2016; FAO, 2022). Collectively, these processes reflect a gradual decline in the soil's capacity to retain and supply nutrients, consistent with the observed signs of fertility degradation under prolonged continuous cropping.

Table 3. Chemical soil characteristics in croplands

Cultivation time (years)	**pH**	**EC** (µS/cm)	**SOM (%)**	**Total Nitrogen** (%N)	**Total phosphorus** (%P_2O_5)	**Total potassium** (%K_2O)	**CEC** (meq/100g)
							0 – 20 cm
<5	4.64 ^{ns}	190.00 ^{ns}	6.58 ^{ns}	0.37 ^{a}	0.16 ^{a}	2.37 ^{ns}	13.70 ^{b}
5-10	4.35 ^{ns}	156.00 ^{ns}	8.04 ^{ns}	0.24 ^{b}	0.14 ^{b}	2.15 ^{ns}	15.15 ^{b}
11-15	4.79 ^{ns}	226.50 ^{ns}	8.80 ^{ns}	0.21 ^{b}	0.08 ^{c}	2.33 ^{ns}	15.25 ^{b}
>15	3.56 ^{ns}	218.38 ^{ns}	7.45 ^{ns}	0.19 ^{b}	0.07 ^{c}	2.26 ^{ns}	20.51 ^{a}
CV (%)	***20.12***	***29.30***	***29.01***	***16.71***	***18.23***	***15.81***	***23.92***
Cultivation time (years)				***20 – 50 cm***			
<5	4.35 ^{ns}	236.25 ^{a}	8.93 ^{a}	0.25 ^{a}	0.16 ^{a}	2.74 ^{a}	12.40 ^{ns}
5-10	4.29 ^{ns}	137.38 ^{b}	7.49 ^{ab}	0.17 ^{b}	0.12 ^{b}	2.16 ^{b}	11.46 ^{ns}
11-15	4.35 ^{ns}	131.88 ^{b}	4.87 ^{b}	0.16 ^{b}	0.07 ^{c}	1.96 ^{b}	13.38 ^{ns}
>15	4.23 ^{ns}	197.25 ^{ab}	6.92 ^{ab}	0.15 ^{b}	0.04 ^{d}	1.80 ^{b}	12.64 ^{ns}
CV (%)	***15.18***	***25.27***	***27.80***	***23.99***	***10.00***	***29.69***	***7.60***

Note: Different lowercase letters indicate significant differences at $P < 0.05$; ns: not significant.

4. CONCLUSIONS

The soil used for croplands showed little variability in physical characteristics at the time of the survey across the two depths studied and different cultivation stages, except for the soil's chemical characteristics. The organic matter content, nitrogen, phosphorus, potassium, and CEC all decrease with soil depth and cultivation time. In areas where crops have been continuously cultivated for more than 10 years, symptoms of physical and chemical soil degradation were evident, including increased bulk density, surface compaction, reduced soil organic carbon, nutrient depletion, and a decline in cation exchange capacity. Therefore, more appropriate cultivation measures are needed, such as applying organic fertilizers to maintain nutrients, as well as to improve the physical characteristics supporting sustainability in land utilization types

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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