

SOIL DEGRADATION DUE TO LONG-TERM CITRUS CULTIVATION IN THE UPPER VIETNAMESE MEKONG DELTA

Nguyen Thi Phuong¹, Ho Nguyen^{1,2,✉}

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Abstract

This study investigated the impact of tree age on soil properties in citrus orchards in the upper Vietnamese Mekong Delta province, examining orchards of four age groups (< 10, 10–20, 21–30, and over 30 years) at two soil depths (0–20 cm and 20–50 cm). Findings indicate notable variations in soil physico-chemical properties with age and depth. In older orchards (over 20 years), bulk density increased and soil pH decreased, with overall low pH values (3.5–5.0) observed. Electrical conductivity remained consistent across all ages. Key nutrients such as nitrogen (N), phosphorus (P), potassium (K), soil organic carbon (SOC), and cation exchange capacity (CEC) generally decreased with the age of the orchards. These trends were consistent across both soil layers. The study highlights the influence of prolonged cultivation on soil health and provides insights for developing strategies to enhance productivity and sustain agricultural practices in citrus orchards.

Key words: fruits cultivation, physico-chemical properties, soil depth, organic carbon, agricultural production, Mekong Delta

Introduction. The Vietnamese Mekong Delta (VMD) stands as a fertile and lush plain, serving as the primary agricultural region of Vietnam. The VMD is widely recognized for its cultivated orchard regions, particularly favourable for

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citrus fruits, accounting for about 35% of Vietnam's total production. The area of fruit-bearing tree cultivation in the Mekong Delta has experienced rapid growth over the past few decades [1]. Specifically, the area dedicated to orchards for citrus fruit trees has seen significant expansion. Fruit-growing areas in the VMD are concentrated in provinces along the Mekong River, such as An Giang, Dong Thap, Hau Giang, Vinh Long, Tien Giang, Ben Tre, and Soc Trang. In Dong Thap alone, a province located in the upper VMD region, the total fruit-growing area reached 40 919 hectares by 2022, with the area dedicated to citrus covering 6536 hectares, accounting for 16% of the total fruit area in the province [2].

However, the primary challenge in developing fruit tree cultivation currently is the low productivity and limited farming techniques among farmers. Continuous use of orchard lands, with some fruit trees planted as far back as the 1980s and 1990s, leads to signs of decline and decreasing yields. In some regions, numerous orchards exhibit signs of deterioration, ageing, and diminishing yields with each harvest season, rendering approximately 20–30% of the area no longer exploitable [3]. Research indicates that soil physical, chemical, and biological properties in long-term cultivated orchards contribute to productivity decline and fruit quality reduction [4]. The decrease in soil fertility is considered a crucial factor that reduces crop yield on various types of land. Additionally, intensive farming practices, coupled with minimal organic amendments to the soil, alter chemical and physical properties in the long term. Organic nitrogen contents can decrease by 25% within 20 years of cultivation and by 35% within 60 years of cultivation. Continuous cultivation for 50 years can result in a loss of over 50% of organic matter in the soil [5]. Reducing the organic matter content in the soil gradually decreases natural soil fertility over time, leading to a decline in crop productivity and yield [6]. Furthermore, Soil Organic Carbon (SOC) represents a significant portion of the total terrestrial carbon storage, with approximately 1500 to 4800 Pg C found in the top 100 cm of soil. Therefore, as the SOC content in the surface layer decreases, it leads to an overall reduction in the total carbon content in the soil [6, 7].

The sustainability and productivity of agricultural systems greatly depend on the quality of the underlying soil. In the context of Dong Thap Province in the upper VMD, renowned for its fruit production, understanding the soil's health and environmental conditions becomes crucial for informed decision-making for farmers as well as policymakers. This study aims to evaluate the effects of long-term cultivation of citrus orchards on soil physicochemical properties and identify issues contributing to soil degradation in Dong Thap province, thereby supporting informed land management and sustainable agricultural development in the VMD.

Materials and methods. Study area. Dong Thap province, located upstream of the VMD, features a tropical climate and fertile soil primarily composed of alluvial deposits, ideal for fruit tree cultivation (Fig. 1). Its favourable environmental conditions contribute significantly to the agricultural productivity of the

province. Citrus cultivation primarily occurs in Gleysol and Cambisol soils, noted for their thick surface layers and high nutrient content from river silt accumulation (refer to Fig. 1). These soils are well-drained at a depth of 50 cm without texture change from the topsoil. Despite a thick organic matter layer on the surface, the soil pH is low. Gleysols are characterized by prolonged water saturation, leading to aeration issues. Consequently, orchards are often planted on raised beds with water pumps or an irrigation canal system for drainage.

Soil sample collection. Soil samples were collected from citrus orchards in Dong Thap from June to July 2022, at two depths (0–20 cm and 20–50 cm) around the tree basin, where the majority of citrus feeder roots are found. Five samples from different positions around each tree were combined to create a composite sample for each depth, which was then stored for chemical analysis. Orchards were selected randomly, ensuring each had a minimum area of 2000 m² and sampling points were at least 200 meters apart. For each soil depth, 10 samples were collected, resulting in 20 samples per tree age group.

Selection of tree age group. Citrus trees were categorized into four age groups (< 10, 10–20, 20–30, and over 30 years) to assess the impact of tree age on soil properties. These groups represent different growth stages of citrus trees, from initial fruiting to post-peak productivity.

Measurement of soil physico-chemical properties. The pH and electrical conductivity (EC) of the soil samples were determined using a pH meter and a conductivity meter, respectively. The measurements were conducted with a soil to 1N KCl ratio of 1:5 for pH and a soil to water ratio of 1:5 for EC [8]. Soil texture was assessed using hydrometer analysis [9]. Bulk density was measured with a 100 cm³ cylinder, oven-dried at 105 °C for 24 h [10]. Porosity was measured by the thermo-TDR technique. Soil organic matter (% C) was quantified through the dry combustion method [11]. Furthermore, the Kjeldhal method was used to determine the content of total nitrogen, while total phosphorus content was measured calorimetrically using phosphomolybdate with SnCl₂ as an agent at 890 nm [8,12]. Potassium content was determined by an atomic absorption spectrometer through the emission method (AES) [13]. Cation exchange capacity (CEC) was analysed and extracted with 0.1 M BaCl₂, followed by titration with 0.01 M EDTA [14].

Statistical analysis. Data were analysed using Analysis of Variance (ANOVA) in a Completely Randomized Design (CRD) framework. Differences between means were evaluated using the Duncan test ($P < 0.05$). All statistical analysis were carried out using SPSS software version 22.0.

Results and discussion. Soil physical characteristics of citrus orchard. The research results indicate that the bulk density of the cultivation layer (0–20 cm) fluctuated between 1.07–1.19 g/cm³ and exhibited an increasing trend with soil depth (ranging from approximately 1.18–1.23 g/cm³), corresponding to the orchard tree's age. This suggests that for orchards with tree ages ranging

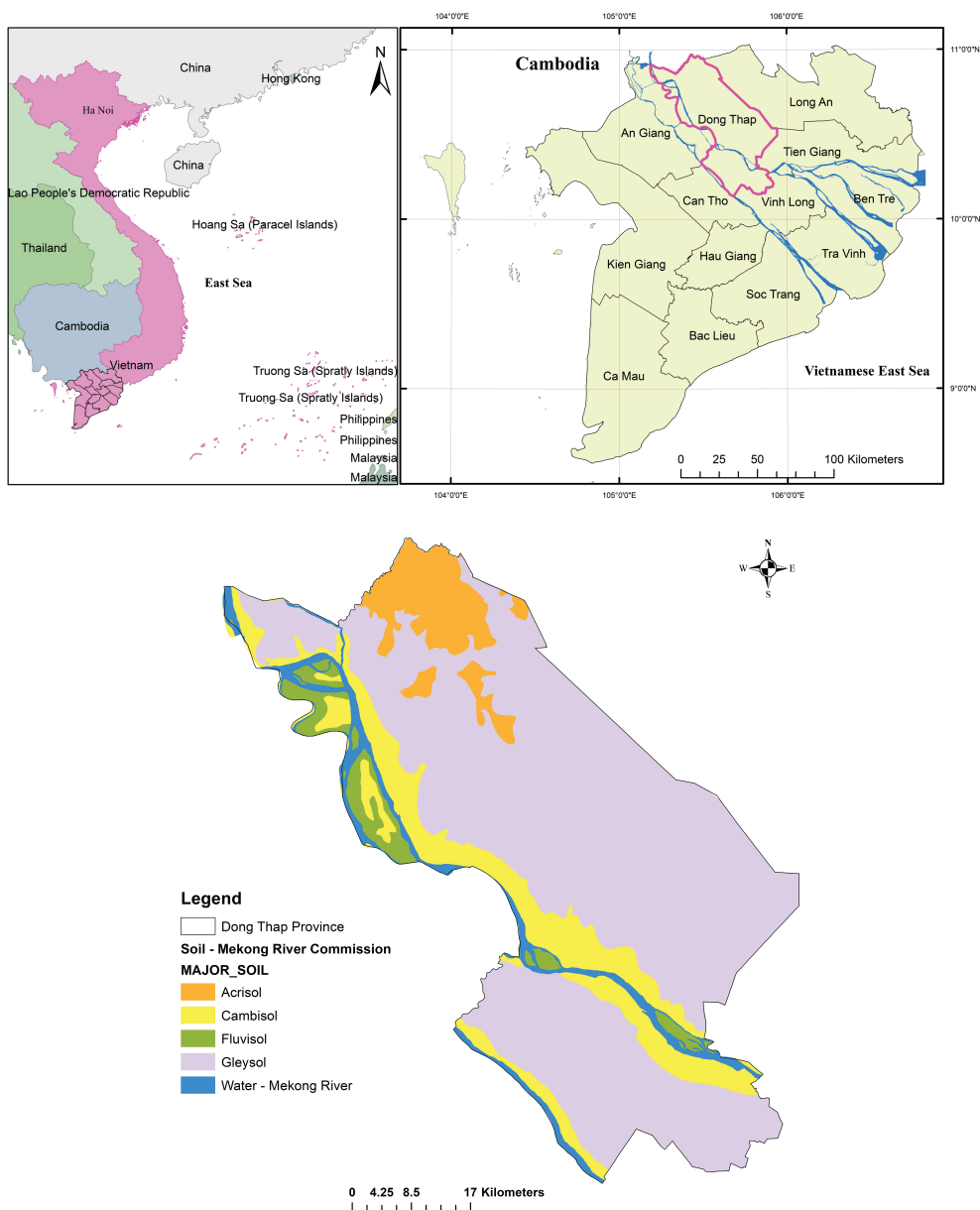


Fig. 1. Study area – Dong Thap province in the Vietnamese Mekong Delta (above), and soil map (below), with soil types extracted from the soil map of the Mekong River Commission (MRC)

from 10 to 30 years, the bulk density tends to increase with the depth of the cultivation layer, without significant variation in bulk density concerning age and cultivation depth ($P > 0.05$). Soil porosity also showed a similar trend to bulk density. Surface layer porosity ranged from approximately 46.87% to 52.95%, and 47.14% to 51.49% at the depth of 20–50 cm. Thus, these values indicate that bulk density and porosity do not exert significant negative effects on the development of grafted citrus trees. However, data from Table 1 demonstrates an increasing trend in bulk density with depth and cultivation time. Therefore, to ensure optimal root activity, alongside stabilizing soil bulk density, it is essential to enhance soil management techniques, such as ploughing and organic matter supplementation, to maintain soil porosity and prevent soil compaction.

The results presented in Table 1 also show that the sand component in the soil is relatively low compared to the silt and clay components. The clay content varies from 30.37 to 38.58%, and the silt content ranges from 55.41 to 60.66% in the 0–20 cm soil layer; 32.49–38.75% for clay and 52.63–63.08% for silt in the 20–50 cm depth. Based on the USDA soil texture triangle [15], the soil in the citrus orchard belongs to the group of soils with a medium texture of silty clay loam (Table 1). In general, due to the relatively high clay content, the soil in citrus orchards has the capacity to supply and retain abundant nutrients, exhibit good water retention capabilities. However, in areas with high clay content, it may lead to disadvantages in water permeability and runoff during periods of high rainfall or irrigation.

Soil chemical properties of citrus orchard. pH. The pH analysis results of the soil are presented in Fig. 2, showing that the pH values for the four orchard age groups varied from 3.5 to 4.58 at the depth of 0–20 cm and 3.38 to 4.48 at the depth of 20–50 cm, which is lower than the optimal pH range for grafted citrus [16]. Citrus trees can thrive at a pH ranging from 5 to 8, with the optimal range being 6 to 7 [16]. Soils with a pH below 4.5 can be unfavourable for the growth and development of grafted citrus, leading to less available nutrients and reduced activity of beneficial microorganisms. Comparing pH values among orchard age groups in the study area, pH decreased gradually with increasing cultivation age, with orchards over 30 years exhibiting significantly lower pH compared to the other age groups (Fig. 2). These findings are consistent with previous research on mango orchards [4]. Specifically, citrus orchards with grafted trees aged 33 years had a very low pH, around 3.5 [3]. The pH decrease over time can be attributed to the gradual loss of organic matter, reduction in useful base cations due to plant absorption, leaching, excessive fertilization without proper inorganic balance, and the accumulation of H^+ ions from various chemical and biological processes in the soil.

Soil organic matter (SOM). The organic matter content in the soil of the citrus orchard across different tree ages is illustrated in Table 2. Soils with orchards aged less than 10 years were assessed to have rich organic matter con-

T a b l e 1

Soil physical properties of citrus orchard according to tree ages in different soil depths

Tree ages (years)	Bulk density	Porosity	Soil texture			Type of soil texture (USDA Soil taxonomy)
			%Sand	%Silt	% Clay	
	0–20 cm					
< 10	1.07 ^{ns}	51.47 ^{ns}	4.31	58.80	36.89	Silty Clay Loam
10–20	1.08 ^{ns}	52.95 ^{ns}	5.43	58.43	36.14	Silty Clay Loam
21–30	1.19 ^{ns}	47.96 ^{ns}	8.97	60.66	30.37	Silty Clay Loam
> 30	1.19 ^{ns}	46.87 ^{ns}	5.01	55.41	38.58	Silty Clay Loam
CV (%)	15.02	21.86				
Tree ages (years)	20–50 cm					
	< 10	1.21 ^{ns}	48.25 ^{ns}	4.43	63.08	32.49
10–20	1.18 ^{ns}	50.30 ^{ns}	8.62	52.63	38.75	Silty Clay Loam
21–30	1.23 ^{ns}	47.14 ^{ns}	7.54	56.51	35.95	Silty Clay Loam
> 30	1.18 ^{ns}	51.49 ^{ns}	7.96	53.88	38.16	Silty Clay Loam
CV (%)	10.66	11.90				

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

tent at the depth of 0–50 cm, while the remaining orchard age groups displayed moderate to high organic matter content. A significant decline in organic matter content in the soil was observed in orchards aged 10 to 20 years. There was no difference in organic matter content between orchards aged 10 to 20 years and 20 to 30 years at the depth of 0–20 cm ($P > 0.05$). However, at the depth of 20–50 cm, the organic matter content exhibited variation and differences between different tree ages (Table 2). This indicates that, under orchard soil conditions, the decomposition of organic matter occurs rapidly. Additionally, the habitual lack of annual organic matter supplementation by most citrus orchard owners has led to a significant reduction in soil organic matter over time [17]. Thus, the organic matter content of citrus orchard soil in Dong Thap province demonstrates a trend similar to the overall cultivation practices in the VMD region [19,20]. Specifically, the organic matter content tends to decrease with the age of cultivation and the depth of cultivation. The primary cause is the lack of emphasis on restoring or replenishing natural organic matter to the soil [4]. 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 [17]. Therefore, to help stabilize and maintain

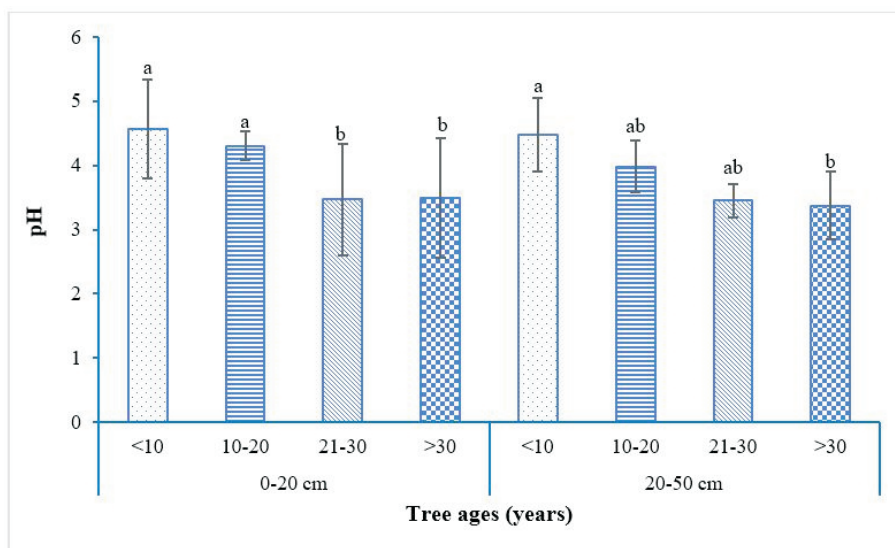


Fig. 2. Change of pH value with tree age at two soil depths

Note: Different lowercase letters indicate significant differences at $P < 0.05$ within tree age at each soil depth

the soil's desirable characteristics, farmers need to supplement additional organic fertilizer to restore the soil's current state.

Total nitrogen. Across the four age groups of orchards, the total nitrogen content in the surface soil layer was assessed as moderate to rich, ranging from 0.17% to 0.27%, with statistically insignificant differences between the age groups ($P > 0.05$) (Table 2). According to MARSCHNER [18], 95% of total nitrogen in the soil is related to the soil's organic matter. Organic matter in the soil typically contains about 5% nitrogen, so high organic matter content in the soil often corresponds to rich total nitrogen. The decrease in total nitrogen content in the soil is evident in orchards over 20 years old, aligning with the findings of GUONG [19] that the total nitrogen content in the surface soil layer of citrus orchards decreases with tree age.

Total phosphorus (P). The total phosphorus content is assessed as poor to moderate (0.04–0.10% P_2O_5), with no statistically significant differences observed between the two cultivation depths (0–20 cm and 20–50 cm) for all four age levels of orchards ($P > 0.05$) (Table 2). The low total phosphorus content may be attributed to farmers applying mixed phosphate fertilizers only in amounts sufficient to stabilize soil pH (since pH values were found to be acidic to very acidic ($pH < 5.5$, Fig. 2). Our field survey also revealed that farmers rarely supplement with lime, leading to phosphorus deficiency in orchard soil. This observation aligns with EMIRU and GEBREKIDAN [7], who argued that under low soil pH conditions,

Table 2

Total Nitrogen, Phosphorus and Potassium, SOM, and CEC contents at two soil depths in citrus orchards' soils

Tree ages (years)	Total nitrogen (%N)	Total phosphorus (%P ₂ O ₅)	Total potassium (%K ₂ O)	SOM (%)	CEC (meq/100 g)
0–20 cm					
< 10	0.27 ^{ns}	0.10 ^{ns}	2.14 ^{ns}	9.15 ^a	14.70 ^b
10–20	0.25 ^{ns}	0.06 ^{ns}	2.02 ^{ns}	6.58 ^b	20.68 ^a
21–30	0.17 ^{ns}	0.09 ^{ns}	2.02 ^{ns}	6.10 ^b	17.23 ^{ab}
> 30	0.20 ^{ns}	0.10 ^{ns}	1.92 ^{ns}	4.53 ^c	11.58 ^c
CV (%)	13.22	12.18	15.73	16.26	10.47
20–50 cm					
< 10	0.15 ^{ns}	0.04 ^{ns}	2.23 ^{ns}	9.03 ^a	11.20 ^{ns}
10–20	0.17 ^{ns}	0.06 ^{ns}	1.81 ^{ns}	6.96 ^{ab}	14.40 ^{ns}
21–30	0.16 ^{ns}	0.07 ^{ns}	1.49 ^{ns}	5.95 ^b	13.94 ^{ns}
> 30	0.13 ^{ns}	0.06 ^{ns}	1.85 ^{ns}	4.25 ^c	14.06 ^{ns}
CV (%)	17.75	11.29	17.00	15.84	9.18

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

phosphorus content in the soil decreases. Thus, low soil pH over cultivation time and soil depth might have reduced the availability of phosphorus [4, 19]. The result is an increasing phosphorus deficiency in orchard soil at both depths and over cultivation time. Therefore, farmers are recommended to apply balanced chemical fertilizers, and supplement lime and organic fertilizer to increase pH and enhance phosphorus availability in orchard soil.

Total potassium (K). The total potassium content in citrus orchards' surface soil ranges from 1.92% to 2.14% K₂O, evaluated as moderate to rich. Meanwhile, this content at the accumulation layer (20–50 cm) is assessed as average to rich (1.49% to 2.23% K₂O). However, the total potassium content shows no statistically significant differences for all four age levels corresponding to the two soil depths (Table 2). Overall, the total potassium content of orchard soil is less affected by cultivation time and soil depth. Nevertheless, according to various studies, long-term cultivation contributes to fluctuations in total potassium content along with a decrease in the stability of potassium levels in the soil [20]. Therefore, we recommend that farmers maintain balanced potassium fertilizer application for their orchard soil to mitigate phosphorus deficiency over the tree's age.

Cation exchange capacity (CEC). The results presented in Table 2 show that the cation exchange capacity (CEC) of the soil in all four age groups ranges from moderate to high, varying from 11.1 to 20.68 meq/100 g. This CEC value is evaluated as low to moderate at the surface layer (0–20 cm). The cation exchange capacity in orchards over 30 years old is statistically significantly reduced compared to orchards aged 10 to 20 years and orchards less than 10 years old.

Additionally, the CEC content in the subsoil layer (20–50 cm) ranges from 11.2 to 14.4 meq/100 g, evaluated as low, with no statistically significant differences ($P > 0.05$) among the four tree age levels. However, in general, the CEC values in the experimental soil samples fall within the range of CEC values in various types of soil in Vietnam (CEC ranging from 5–30 meq/100 g) [19, 20].

Conclusion. This study evaluated the effects of long-term cultivation on soil properties in an upstream province of the Vietnamese Mekong Delta. Findings reveal that intensive cultivation with limited organic matter input has contributed to soil degradation over time, both physically and chemically. Soil pH and phosphorus levels in the four orchard age groups were generally lower than what is ideal for citrus trees. Potassium levels were found to be excessive in orchards under 10 years but deficient in those over 20 years. Total nitrogen and potassium were abundant, with moderate cation exchange capacity (CEC) across all orchards. Notably, orchards aged 20–30 years and over 30 years showed significant soil degradation, particularly in pH, organic matter, total nitrogen, and CEC. Based on these findings, it is recommended that farmers use lime or bio-organic fertilizers to mitigate soil degradation and implement restorative practices for prolonged cultivation periods.

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¹*Department of Land management, Dong Thap University,
870000 Cao Lanh City, Dong Thap, Viet Nam
e-mails: ntphuong@dthu.edu.vn/nguyenho@dthu.edu.vn
<https://orcid.org/0009-0008-8678-733X>*

²*Institute of Landscape Ecology, University of Münster, 48149 Münster, Germany
e-mail: ho.nguyen@uni-muenster.de, <https://orcid.org/0000-0002-2991-0011>*