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COMPARATIVE ASSESSMENT OF SOIL PROPERTIES IN ORGANIC, CONVENTIONAL, AND ABANDONED VEGETABLE CULTIVATION SYSTEMS IN VEGETABLE-GROWING AREAS OF HANOI

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Abstract. The application of fertilizers and agrochemicals in crop cultivation can significantly affect the physicochemical properties and nutrient composition of vegetable soils. In this study, soil samples were collected from eighteen vegetable fields managed under organic farming, conventional farming, and abandoned land-use systems across four specialized vegetable-producing communes in southern Hanoi. Results indicated that the cultivated soils were mainly loamy and sandy loam soils, both suitable for vegetable production. Physical, chemical, and nutrient parameters varied among cultivation systems. Organic farming soils showed the best quality in terms of physicochemical properties, organic matter content, and macro- and micronutrient contents. Conventional farming soils contained higher concentrations of macro- and micronutrients compared to abandoned fields, but exhibited lower organic matter content. Organic farming soils have BD: 1.08 g/cm^3, PD: 2.62 g/cm^3, OC: 1.34%, N: 0.12%, P_2O_5: 0.21%, K_2O: 0.95, CEC: 13.07 cmol/kg of air-dried soil. Conventional farming soils exhibited BD: 1.18 g/cm^3, PD: 2.47 g/cm^3, OC: 1.09%, N: 0.10%, P_2O_5: 0.35%, K_2O: 0.74, CEC: 11.87 cmol/kg of air-dried soil. The cultivation of organic vegetables not only ensures a safe and health-promoting food supply for humans but also contributes to environmental protection and the improvement of soil quality. This practice represents a sustainable approach to soil utilization and should be actively promoted for wider adoption.

Keywords: vegetable-cultivated soils, soil properties, farming systems.

1. Introduction

Vegetable cultivation has measurable impacts on soil quality. Cultivated soils tend to accumulate less organic matter than uncultivated soils, and prolonged cultivation leads to a greater decline in organic matter content [1]. Land management and utilization practices strongly influence soil organic matter levels [2]. Organic and conventional vegetable farming systems differ in their effects on local soil quality: the application of organic fertilizers enhances soil quality by supplying nutrients to a wide range of soil organisms, thereby improving fertility, soil structure, and increasing porosity, nutrient availability, and oxygenation [3]. In contrast, conventional farming systems rely primarily on inorganic fertilizers, especially nitrogen-based fertilizers, which can negatively affect nitrogen-fixing bacteria such as Rhizobium spp., decrease soil pH, alter soil structure, increase bulk density, and reduce soil microbial diversity [4]. Long-term use of inorganic fertilizers also poses a risk of heavy metal accumulation in soils [5].

Several studies have investigated the effects of chemical inputs in vegetable cultivation on soil quality in peri-urban areas of Hanoi. Soil environmental quality gradually declines toward the southern districts of Hanoi, as indicated by elevated heavy metal concentrations [6]. In the vegetable-growing soils of Gia Lâm, Đông Anh, and Thanh Trì, nutrient levels (N, P, K) were frequently low, while concentrations of certain heavy metals (Zn, Pb, Cu) exceeded permissible limits at some sites [7]. In Tien Le (Hoai Duc), an area designated for safe vegetable production, most soils were contaminated with arsenic at 1.11- 1.49 times higher than the allowable amount [8]. Similarly, in Yen Nghia, Ha Dong, total arsenic concentrations exceeded permissible limits by 1.14–2.86 times [9]. Despite existing findings, comparative research on the impacts of different vegetable cultivation practices on soil quality remains scarce. Moreover, investigations into the physical and chemical properties of vegetable-growing soils in Hanoi are still notably limited.

The communes of Hong Van, Chuong Duong, Thuong Tin, and Thuong Phuc (formerly part of Thuong Tin district, Hanoi) are major suppliers of vegetables for Hanoi and surrounding provinces. Multiple farming systems coexist in these areas, including organic vegetables, VietGAP-certified vegetables, safe vegetables, and conventional vegetables. These systems can be broadly classified into two cultivation methods: (i) organic farming, which avoids the use of agrochemicals, and (ii) conventional farming, which employs fertilizers and pesticides (including VietGAP, safe vegetables, and traditional cultivation systems). In addition, many abandoned vegetable fields colonized by spontaneous wild vegetation are also present. Land management practices, including soil amendment and crop care, strongly influence environmental conditions and soil quality. Therefore, this study compares key soil properties under different cultivation methods (organic farming, conventional farming, and abandoned land) to assess soil quality. This study represents a novel research direction and provides a basis for the sustainable planning and development of vegetable production areas in Hanoi.

2. Content

2.1. Materials and methods

**** Materials***

Several characteristics of cultivated soils were examined in vegetable-growing areas across four communes: Hong Van, Chuong Duong, Thuong Tin, and Thuong Phuc, Hanoi, including: Soil texture composition; Physicochemical properties: bulk density, particle density, porosity, soil acidity (pH), electrical conductivity (EC), and organic matter content (percentage of organic carbon - %OC, percentage of organic matter - %OM); Cation exchange capacity (CEC) and exchangeable cations: K^+, Na^+, Ca^{2+}, Mg^{2}; Nitrogen, phosphorus, and potassium contents.

Sampling locations are presented in Table 1 and Figure 1. The study focused on vegetable cultivation soils, so sampling sites were selected in specialized vegetable-producing areas of the localities.

Table 1. Soil sampling locations of the study

Location on the map	Sample code		Location
1	RHC 1 - 6		Hoang Gia Farm, Tu Van Hamlet, Chuong Duong Commune (20°50'04.1"N 105°53'31.4"E)
2		RH 4	Loc Du, Thuong Phuc Commune (20°50'41.3"N 105°51'14.7"E)
3	RTT 3	RH 2	Tho Giao, Thuong Phuc Commune (20°50'12.8"N 105°50'33.8"E)
3	RTT 4		Trieu Dong, Thuong Phuc Commune (20°50'03.4"N 105°50'21.1"E)
3		RH 1	Phu Luong, Thuong Phuc Commune (20º50’03.4”N 105º50’55.55”E)
4	RTT 1		Ha Hoi, Hong Van Commune (20°51'33.7"N 105°52'37.4"E)
4	RTT 2		Hoa Luong, Hong Van Commune (20°52'40.0"N 105°53'07.5"E)
5	RTT 5	RH 3	Yen Phu, Thuong Tin Commune (20°52'45.5"N 105°52'44.0"E)
6		RH 6	Tien Phong, Thuong Tin Commune (20°51'04.3"N 105°49'48.8"E)
7	RTT 6	RH 5	Phu My, Chuong Duong Commune (20°51'36.1"N 105°54'25.6"E)

RHC: organic fields; RTT: conventional fields; RH: abandoned fields

Figure 1. Location of the study area (Source: Google Map)

**** Methods***

- Sampling and preservation methods:

Soil samples were collected using the diagonal method, with each composite sample taken from five points within the same field. Samples were obtained from the cultivation layer at a depth of 0 - 30 cm, with an approximate weight of 1 kg per sample. A total of eighteen soil samples were collected across three land-use types:

(1) Organically cultivated vegetable fields (sample codes RHC 1 to RHC 6): These fields are managed without the use of chemical fertilizers and synthetic pesticides. Instead, compost, vermicompost, and green manure are applied to supply nutrients and enhance soil quality. Pest management relies on biological measures, including natural enemies and plant-based extracts (e.g., garlic, chili, ginger), while weeds are controlled through mechanical methods or mulching.

(2) Conventionally cultivated vegetable fields (sample codes RTT 1 to RTT 6): These fields are managed primarily with chemical fertilizers and pesticides. In addition, farmers may incorporate green manure and animal manure, while weeds are controlled manually.

(3) Abandoned vegetable fields (sample codes RH 1 to RH 6): These fields are left uncultivated, allowing vegetables to grow spontaneously without management or care.

Soil samples from each field were collected three times in three different crops (winter crop, summer crop, and spring crop), yielding a total of 54 soil samples.

The soil sampling procedure followed TCVN 4046:1985 [10]. Samples were placed in cloth or plastic bags tightly sealed at the mouth; the outside was labeled with the sample code, and inside each bag, a data sheet was included (indicating sample code, date of collection, location, depth, etc.). Samples were air-dried, ground, and sieved through 0.5 mm and 2 mm meshes before being placed into labeled bags for subsequent analyses.

For the determination of bulk density, particle density, and porosity, intact samples were collected using core cylinders and then sealed.

- Sample analysis methods:

The analysis of soil parameters was conducted following Circular No. 24/2017/TT-BTNMT [11], Selected Methods of Environmental Analysis [12], and Methods for the Analysis of Soil, Water, Fertilizers, and Crops [13].

Indicators of soil texture, bulk density, particle density, porosity, pH, EC, and the concentrations of nitrogen, phosphorus, potassium, sodium, calcium, and magnesium were analyzed at the Environmental Chemistry Laboratory, Institute for Agricultural Environment.

- Data processing methods

The data presented in the results section represent mean values of three replicates. Analytical results were processed using Microsoft Excel 2016. Tukey's Honestly Significant Difference in this study was performed in the R language.

2.2. Results and discussion

2.2.1. Soil texture

According to the United Nations (UN) soil particle size classification [13], the cultivated soils at the study sites were predominantly classified as loam (14 out of 18 sampling points), while four sites (RTT2, RTT3, RTT4, RTT5) were identified as sandy loam; however, the sand proportion was not high (below 65%). All soils at the investigated sites were suitable for the cultivation of various vegetable species [14].

Table 2. Soil texture composition of vegetable-cultivated soils in the study area

Location	Clay	Silt	Fine sand	Coarse sand	Soil type
RHC	18.52 ± 1.48	29.82 ± 2.11	47.21 ± 1.59	4.45 ±1.12	Loam
RTT	14.97 ± 0.65	24.24 ± 1.23	55.84 ± 1.16	4.95 ± 1.19	Loam, Sandy loam
RH	17.37 ± 0.55	25.11 ± 1.30	52.83 ± 2.16	4.69 ±1.02	Loam

Unit: %

The soil samples from the RHC and RH habitats contained higher proportions of clay and silt compared to those from the RTT habitat. Clay and silt enhance the soil's ability to retain nutrients. Long-term chemical cultivation in the RTT area tends to reduce soil pH, leading to soil compaction, weakened cohesion among soil colloidal particles, and consequently, finer particles such as clay and silt become more susceptible to leaching than sand. Visually, soils in RTT appeared looser, more desiccated, and lacking structural cohesion compared with RHC and RH soils, as the proportions of clay and silt decreased while the sand fraction increased over time. It can thus be concluded that chemical cultivation affects soil texture by decreasing the percentage of clay and silt while increasing the sand fraction, thereby altering soil structure, reducing water- and nutrient-holding capacity, and ultimately decreasing vegetable yield.

2.2.2. Physicochemical properties of vegetable-cultivated soils in the study area

The physicochemical indicators of soil reflect soil quality and its capacity to supply nutrients to crops, thereby providing a basis for determining appropriate cultivation and soil improvement practices. The results of the analysis of physicochemical properties of vegetable-cultivated soils in the study area are presented in Table 3.

Table 3. Physicochemical properties of cultivated soils in the study area

Sample code	Bulk density	Particle density	Porosity	EC	pH H_2O	pH KCl	OC	OM	CEC	K^+	Na^+	Ca^{2+}	Mg^{2+}
RHC 1	1.07	2.64	59.50	0.42	7.41	7.04	1.29	2.22	12.67	0.405	0.627	9.75	1.60
RHC 2	1.09	2.62	58.44	0.36	7.37	7.18	1.27	2.19	12.71	0.475	0.658	9.54	1.61
RHC 3	1.05	2.60	59.66	0.41	7.26	6.93	1.45	2.49	13.72	0.442	0.413	10.32	2.09
RHC 4	1.11	2.58	56.98	0.37	7.47	7.22	1.32	2.28	12.92	0.639	0.717	9.13	2.04
RHC 5	1.11	2.65	58.11	0.39	7.08	6.81	1.32	2.28	12.86	0.499	0.452	10.12	1.46
RHC 6	1.07	2.62	59.16	0.39	7.31	7.02	1.40	2.42	13.51	0.642	0.408	10.81	1.35
RTT 1	1.20	2.44	50.63	0.34	6.71	6.61	1.22	2.11	12.44	0.401	0.282	9.87	1.52
RTT 2	1.18	2.53	53.38	0.3	6.97	6.43	1.29	2.22	12.77	0.433	0.394	9.70	1.84
RTT 3	1.16	2.41	52.04	0.31	6.55	6.28	0.92	1.59	10.94	0.285	0.328	8.82	1.29

Sample code	Bulk density	Particle density	Porosity	EC	pH H_2O	pH KCl	OC	OM	CEC	K^+	Na^+	Ca^{2+}	Mg^{2+}
RTT 4	1.21	2.51	51.79	0.29	6.70	6.37	1.18	2.03	12.35	0.418	0.284	9.78	1.53
RTT 5	1.14	2.45	53.47	0.27	7.26	7.06	0.88	1.53	10.89	0.321	0.347	8.77	1.23
RTT 6	1.20	2.49	51.81	0.32	6.92	6.25	1.05	1.82	11.83	0.348	0.258	9.66	1.31
RH 1	1.24	2.44	49.06	0.26	6.31	6.06	1.12	1.93	10.36	0.187	0.183	8.37	1.12
RH 2	1.30	2.45	46.94	0.25	6.19	5.87	1.25	2.16	11.57	0.141	0.102	9.44	1.33
RH 3	1.23	2.39	48.51	0.21	6.49	6.21	1.08	1.86	10.29	0.138	0.240	7.98	1.26
RH 4	1.27	2.43	47.74	0.24	6.18	5.92	1.23	2.11	11.32	0.184	0.192	8.75	1.57
RH 5	1.23	2.45	49.80	0.23	5.79	5.58	1.33	2.29	11.67	0.125	0.136	9.38	1.40
RH 6	1.25	2.32	46.12	0.26	5.99	5.79	1.32	2.28	11.16	0.204	0.193	8.87	1.23

Notes. The unit of measurement for CEC, K^+, Na^+, Ca^{2+}, and Mg^{2+} is cmol/kg of air-dried soil; The unit of measurement for bulk density and particle density is g/cm³; The unit of measurement for porosity, as well as OC and OM contents, is %; The unit of measurement for EC is mS/cm

Bulk density is an indicator of the degree of soil compaction and is influenced by soil texture, structure, porosity, and organic matter content. The bulk density of RHC soils ranged from 1.05 to 1.11 g/cm³, with an average of 1.08 g/cm³, a level typical of cultivated soils. In RTT soils, bulk density varied between 1.14 and 1.21 g/cm³, while RH soils exhibited the highest values, ranging from 1.23 to 1.32 g/cm³. According to Katrinski, bulk densities between 1.1 and 1.39 g/cm³ are classified as medium density, indicating moderately compacted soils [13]. Loose and well-aerated soils provide favorable conditions for root nutrient uptake and the activity of aerobic microorganisms. In the study area, soil bulk density was primarily determined by organic matter (OC, OM) content; despite having higher proportions of clay and silt, RHC soils exhibited lower bulk density than RH and RTT soils. In RTT areas, farmers often applied chemical nematicides containing active ingredients such as Chlorpyrifos ethyl (removed from the list of permitted pesticides in 2021) and carbosulfan, which unintentionally killed earthworms, crickets, termites, and other soil fauna that burrow and enhance soil porosity and structure. The decline in these organisms is one of the reasons why RTT soils became less friable and poorly aerated.

Particle density is defined as the weight of soil particles tightly packed together (without pore spaces) in a unit volume under oven-dry conditions. In the study area, particle density decreased in the order of RHC - RTT - RH. The particle density of RHC soils ranged from 2.58 to 2.65 g/cm³, higher than that of RTT soils (2.41 - 2.53 g/cm³), due to the higher proportion of fine particles (clay and silt) in RHC compared with RTT soils. Although RH soils contained higher clay and silt proportions than RTT soils, they exhibited lower particle density. This can be explained by the higher organic matter content in RH soils, since abundant organic matter reduces soil particle density.

Soil porosity is the percentage of void spaces within the soil relative to its total volume. The average porosity of RHC soils was 58.64%, corresponding to very good quality cultivated soils. RTT soils had an average porosity of 52.19%, which meets the requirements for the cultivation layer [13]. Soil porosity depends on bulk density, particle density, and soil structure; in addition, it is strongly influenced by cultivation practices such as plowing, harrowing, and tilling. Consequently, RH soils exhibited lower porosity than the two cultivated vegetable systems, with an average porosity of 48.03%, which does not meet the cultivation-layer requirements. However, this average porosity of 48.03% can be readily improved, indicating that porosity could be enhanced if RH soils are returned to cultivation.

Active acidity (pH H_2O) and *exchangeable acidity* (pH KCl) are determined by the presence of free H^+ ions or H^+ and Al^{3+} ions exchanged from soil colloids. Based on both measurements, RHC soils were classified as neutral; RTT soils ranged from slightly acidic to neutral; and RH soils were slightly acidic. The pH values of RHC and RTT vegetable-cultivated soils were relatively suitable for a wide variety of vegetable crops. Cultivation practices generally lead to gradual soil acidification [15], but farmers actively apply lime to raise soil pH. The lime used in local vegetable fields was primarily dolomite ($CaMg(CO_3)_2$). RH soils, which were not managed with fertilization, irrigation, or protective coverings, tended to dry out quickly under intense sunlight and high temperatures, causing reduced soil moisture and thereby affecting soil pH. The findings of this study are consistent with those of Suja (2013), who reported that organic management in vegetable cultivation improved soil water retention and porosity, increased the availability of soil moisture and water-holding capacity, raised soil pH (by 0.46–0.77 units), and enhanced organic carbon as well as the availability of N, P, and K [16] with increases of 0.69 in pH H_2O and 0.59 in pH KCl.

Electrical conductivity (EC) is an indicator of the total concentration of dissolved ions in the soil solution. A high EC value corresponds to high nutrient content in the soil; however, if EC is too high, plant water uptake is inhibited, necessitating additional irrigation and reduced fertilizer application. Conversely, a low EC value indicates low nutrient availability for poor nutrient retention in the soil, in which case fertilizer application, especially organic fertilizer, is necessary to improve nutrient-holding capacity. All soil samples collected from the three habitats in the study area exhibited EC values within the favorable range for crop growth (0.2 - 1.2 mS/cm). The average EC values decreased in the order of RHC (0.39 mS/cm) - RTT (0.31 mS/cm) - RH (0.24 mS/cm). In RHC soils, all samples were loam with good drainage and nutrient retention due to a suitable proportion of soil colloids and pore spaces, resulting in EC values ranging from 0.36 to 0.42 mS/cm. In RTT soils, two loam samples corresponded to the highest EC values (0.34 and 0.32 mS/cm), while the four sandy loam samples exhibited lower EC values, ranging from 0.27 to 0.31 mS/cm. In this study, EC was influenced not only by soil texture but also by the amount of fertilizer applied. This explains why RH soils, despite all being loam, had the lowest EC values among the three habitats.

Soil organic matter was assessed through the total organic carbon (OC) content. Organic carbon decreased in the order of RHC - RH - RTT. In RHC soils, besides the application of organic fertilizers, biofertilizers were also added, which promoted microbial decomposition and contributed to higher OC levels [17]. Total organic carbon in RHC soils ranged from 1.27 to 1.45%, with an average of 1.34%, corresponding to a medium level. Although RH soils were not managed or fertilized, they still contained relatively high organic matter, ranging from 1.08 to 1.33%, with an average of 1.33%. This can be explained by the spontaneous growth of vegetables and wild plants (mainly herbaceous species). In RTT soils, OC content ranged from 0.88 to 1.29%, corresponding to low to medium levels.

From the measured total organic carbon content, the total organic matter (OM) content of the soil was calculated. Results showed that OM values in RHC soils ranged from 2.19 to 2.49%, classified as high; RTT soils had OM values from 1.53 to 2.22%, corresponding to medium to high levels; and RH soils contained OM ranging from 1.86 to 2.29%, also falling within the medium to high category. To improve vegetable yields, farmers practicing conventional cultivation should apply organic fertilizers to increase organic matter content, thereby enhancing soil structure, water-holding capacity, and infiltration. This, in turn, reduces surface runoff, nutrient leaching, and soil erosion. In addition, biofertilizers should be applied to promote the decomposition and stabilization of organic matter in the soil, contributing to improved soil structure, fertility, and friability.

The cation exchange capacity (CEC) of soil represents the total number of cations adsorbed by soil colloids, including exchangeable base cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) as well as NH_4^+, H^+, and Al^{3+}. Among the three habitats, RHC soils exhibited the highest CEC values, ranging from 12.67 to 13.72 cmol/kg of soil, corresponding to the medium CEC group. CEC is dependent on soil texture and is positively correlated with clay percentage, organic carbon, and total nitrogen content. The mean concentrations of exchangeable cations K^+, Na^+, Ca^{2+}, and Mg^{2+} in RHC soils were 0.517, 0.546, 9.95, and 1.69 cmol/kg of air-dried soil, respectively. Organic vegetable farmers reported that, during cultivation, they supplemented K, Ca, and Mg by applying wood ash, green manure, and well-decomposed animal manure, as well as crushed eggshells and oyster shell powder to enhance Ca content. Oyster shells contain approximately 96% $CaCO_3$, with the remainder comprising Na_2O, P_2O_5, SiO_2, MgO, Al_2O_3, SrO, and SO_3, of which Na_2O accounts for the highest proportion at about 1%. Elevated Na concentrations in soil can adversely affect soil structure by causing surface crusting. According to TCVN 9236-3:2012 [18], the average Na^+ content of Red River alluvial soils is 0.47 cmol/kg of air-dried soil, indicating that Na^+ levels in RHC soils were slightly higher, potentially due to the application of oyster shell powder.

In RTT soils, the cation exchange capacity ranged from 10.89 to 12.77 cmol/kg of air-dried soil, classified as medium. These values were lower than those observed in RHC soils but higher than those in RH soils. The application of fertilizers during vegetable cultivation contributed additional exchangeable base cations, thereby increasing the CEC of RTT soils, even though the clay content, organic carbon content, and total nitrogen were lower than those of RH soils.

It can be observed that in the soil samples from the study area, Na^+ content was inversely proportional to Ca^{2+} content, meaning that soils with higher Na^+ concentrations had lower Ca^{2+} levels, and vice versa. The ratio of K^+, Na^+, Ca^{2+}, and Mg^{2+} within the CEC strongly influences the potential soil structure, since these positively charged ions act as binding agents that hold soil particles together while maintaining adequate pore spaces. The optimal ratio of these ions in the CEC follows the principle: calcium > magnesium > potassium, with ideal proportions being Ca^{2+}: 65–80%, Mg^{2+}: 10–15%, K^+: 1–5%, Na^+: 0–1%, and Al^{3+}: 0%. Therefore, the proper application of fertilizers and lime will help improve soil structure.

2.2.3. NPK nutrient content in soils

For agricultural soils in general and vegetable-cultivated soils in particular, the NPK content is an important indicator for evaluating soil quality. Nitrogen (N), phosphorus (P), and potassium (K) are essential macronutrients required for the growth and development of crops. The NPK contents of vegetable-cultivated soils in the study area are presented in Table 4 below.

Table 4. Total NPK content in vegetable-cultivated soils in the study area

Sample code	N%	P_2O_5 %	K_2O %	Sample code	N%	P_2O_5 %	K_2O %	Sample code	N%	P_2O_5 %	K_2O %
RHC 1	0.108	0.217	0.773	**RTT 1**	0.111	0.376	0.72	**RH 1**	0.099	0.170	0.696
RHC 2	0.103	0.176	0.881	**RTT 2**	0.122	0.405	0.813	**RH 2**	0.108	0.165	0.725
RHC 3	0.132	0.200	0.898	**RTT 3**	0.089	0.262	0.632	**RH 3**	0.098	0.191	0.66
RHC 4	0.109	0.225	1.097	**RTT 4**	0.105	0.331	0.769	**RH 4**	0.100	0.129	0.767
RHC 5	0.115	0.197	0.944	**RTT 5**	0.086	0.371	0.687	**RH 5**	0.118	0.131	0.611
RHC 6	0.125	0.218	1.102	**RTT 6**	0.095	0.330	0.801	**RH 6**	0.112	0.145	0.717

Nitrogen (N) is a vital macronutrient for crops in general and particularly for leafy vegetables; nitrogen deficiency leads to stunted growth, poor leaf greenness, and reduced development. Total nitrogen in RHC soils ranged from 0.103 to 0.125%, corresponding to medium nitrogen levels. RTT soils had total nitrogen contents ranging from low to medium (0.086 - 0.122%). In RH soils, total nitrogen values ranged from 0.098 to 0.118%, falling within the low to medium category. Total nitrogen content in soils is largely dependent on organic matter, with more than 90% of nitrogen in the surface layer of most soils being in organic form [19]. The results indicated that total nitrogen content was positively correlated with OC, with both OC and total nitrogen decreasing in the order of RHC - RH - RTT. Available nitrogen is prone to losses through leaching or volatilization; thus, in conventional farming systems, nitrogen is primarily supplemented as inorganic fertilizer form, leaving limited residual nitrogen in the soil. In RH soils, although nitrogen was not directly applied through management practices, considerable nitrogen inputs originated from the decomposition of plant and animal residues, as well as biological nitrogen fixation by certain wild leguminous species (e.g., *Sesbania* and *Arachis pintoi*)

Phosphorus (P) plays a crucial role in plant life, influencing root development, the formation of new plant organs, and serving as a key factor in flowering, fruit set, and the ripening of fruits and seeds. Soils in the study area were rich in phosphorus (%P_2O_5) at all sampling sites: RHC soils contained 0.176 - 0.225%, while RH soils had the lowest values among the three habitats (0.129 - 0.191%). Notably, RTT soils exhibited very high phosphorus levels, ranging from 0.262 to 0.405% P_2O_5, with an average of 0.346%. In fact, 5 out of 6 conventional vegetable fields (RTT1, 2, 4, 5, and 6) across three cropping seasons had total phosphorus contents exceeding the upper threshold for alluvial soils in Vietnam (0.3%) [20].

Given the naturally phosphorus-rich condition of local soils, rational fertilizer application should be carefully considered to avoid unnecessary costs and the risk of phosphorus toxicity in vegetables, which may reduce yields.

Although *potassium* (K) is not a structural component of plant tissues, it plays a crucial role in their development. Potassium enhances yield and improves the quality of agricultural products in general and vegetables in particular. Among the three habitats, RHC soils had the highest total potassium content (%K_2O), ranging from 0.773 to 1.102%, classified as medium. The relatively high K levels in RHC soils can be explained by the higher silt content in this habitat, as silt contains abundant primary minerals rich in potassium; additionally, the high organic matter content helps reduce nutrient leaching, including potassium.

RTT and RH soils had total potassium contents ranging from 0.632 - 0.813% K_2O and 0.611 - 0.767% K_2O, respectively. Although no potassium was directly supplemented in RH soils by human management, the total K content was not much lower than that of RTT soils (average values of 0.696% compared with 0.737% K_2O). This may be attributed to the higher silt and organic matter contents in RH soils compared with RTT soils.

2.2.4. Comparison of soil properties in three study habitats

The results of the comparison of soil properties across the three habitats are presented in Table 5.

***Table 5.* The results of the comparison of soil properties in the study area**

No.	Property	Habitat		
		RH Soil	***RHC Soil***	***RTT Soil***
1	Bulk density (g/cm^3)	1.25^a	1.08^b	1.18^c
2	Particle density (g/cm^3)	2.41^a	2.62^b	2.47^c
3	Porosity (%)	48.03^a	58.64^b	52.19^c
4	EC (mS/cm)	0.24^a	0.39^b	0.31^c
5	pH H_2O	6.16^a	7.32^b	6.85^c
6	% Clay	17.37^a	18.52^b	14.97^c
7	% Silt	**25.11^a**	29.82^b	**24.24^a**
8	% Sand	57.52^a	51.66^b	60.79^c
9	OC %	1.22^a	1.34^b	1.09^c
10	CEC (cmol/kg air-dried soil)	11.06^a	13.07^b	11.87^c
11	N%	**0.11^a**	0.12^b	**0.10^a**
12	P_2O_5 (g/100g soil)	18.62^a	29.92^b	63.1^c
13	P_2O_5 %	0.16^a	0.21^b	0.35^c
14	K_2O (g/100g soil)	6.36^a	20.16^b	14.34^c
15	K_2O %	**0.70^a**	0.95^b	**0.74^a**
16	K^+ (cmol/kg air-dried soil)	0.16^a	0.52^b	0.37^c
17	Na^+ (cmol/kg air-dried soil)	0.17^a	0.55^b	0.32^c
18	Ca^{2+} (cmol/kg air-dried soil)	8.8^a	9.94^b	9.43^c
19	Mg^{2+} (cmol/kg air-dried soil)	1.32^a	1.69^b	1.45^c

Values with different letters (a, b, c) indicate statistically significant differences between treatments ($p < 0.05$) according to Tukey's Honestly Significant Difference *(number of observations n = 54).*

The results presented in the table indicate that the proportions of silt, total nitrogen, and total potassium differ significantly between RHC and RTT soils, as well as between RHC and RH soils ($p < 0.05$). However, no significant differences in these parameters were observed between RTT and RH soils. The remaining indicators exhibited clear variations among the three habitats. These findings highlight the distinction between cultivated and uncultivated soils, and between organic and conventional vegetable cultivation systems. Notably, organic cultivation contributes positively to soil improvement and supports sustainable farming practices, underscoring the need for its wider adoption. Conversely, conventional cultivation should reduce reliance on chemical inputs and place greater emphasis on organic fertilizers and environmentally friendly pest management strategies.

It can be concluded that cultivation methods significantly influence the quality of vegetable-growing soils, with organically managed soils exhibiting superior overall quality compared to conventionally managed soils. It is likely that, because organically cultivated vegetable soils were well improved, adequately supplied with nutrients, and free from the adverse effects of agricultural chemicals, certain local wild plant species occurred exclusively in this habitat and were absent from both conventionally cultivated and abandoned fields [21]. Organic vegetable cultivation not only provides a safe food source for humans but also contributes to soil conservation and biodiversity protection, in alignment with Sustainable Development Goals, thereby warranting wider adoption.

3. Conclusions

Vegetable-cultivated soils in the four communes of Hong Van, Chuong Duong, Thuong Tin, and Thuong Phuc (Hanoi) were predominantly loam, with the remainder classified as sandy loam; both soil types are suitable for various vegetable crops. Conventional (chemical-based) cultivation reduced the proportions of clay and silt while increasing the sand fraction, thereby altering soil structure and reducing its capacity to retain water and nutrients. RHC soils exhibited favorable bulk density and porosity for cultivation, whereas RH and RTT soils were moderately compacted. The pH values of RHC and RTT soils were higher than those of RH soils, as farmers intentionally applied lime during cultivation to increase soil pH. All soil samples collected from the three habitats in the study area exhibited EC values within the optimal range for crop growth (0.2 - 1.2 mS/cm).

Organic matter content and total nitrogen decreased in the order of RHC - RH - RTT; nitrogen levels ranged from low to medium, while OC was classified from medium to high. Cation exchange capacity (CEC), exchangeable base cations (K^+, Na^+, Ca^{2+}, Mg^{2+}), and total potassium decreased in the order of RHC - RTT - RH, as RHC and RTT soils were regularly supplemented with fertilizers. Phosphorus content in all three soil types was at high to very high levels.

Compared with RTT and RH soils, RHC soils exhibited the best quality in terms of soil texture, physicochemical properties, and mineral nutrient contents. Therefore, management authorities should encourage farmers to transition from conventional to organic farming by promoting the application of appropriate scientific and technical measures.

These include the use of greenhouses for vegetable cultivation, the adoption of Passlite non-woven sheets instead of nylon coverings, and the increased application of organic fertilizers and biological pesticides as alternatives for chemical inputs.

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