


Assessing Soil Fertility and Challenges in Organic Vegetable Farms: A Case Study in the Philippines

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Abstract

Organic agriculture is gaining momentum in the Philippines as consumers become more health- and environment-conscious. This study investigated soil fertility based on soil chemistry and biological properties of organic vegetable farms in Sariaya, Quezon Province and Los Baños, Laguna Province, with the aim of developing organic agriculture in the Philippines. We utilized the SO-FIX (Soil Fertility Index) technology, which is designed to evaluate soil fertility by focusing on the activity and diversity of microbial communities in the soil. This technology provides a scientific assessment of soil health, aiming to contribute to sustainable agriculture and environmental conservation. Soil fertility parameters from four different farms cultivating outdoor organic vegetables were below the recommended values for organic production. Essential macronutrients like nitrogen, phosphorus, and potassium and total carbon content, which is indicative of soil organic matter, were insufficient. Bacterial biomass for soil organic matter decomposition, and nitrogen and phosphorus circulation was inadequate. These results indicated that organic plots lack the fertility needed for optimal organic crop growth. The poor fertility of these organic plots could be attributed to their recent shift from conventional cultivation, which used synthetic pesticides and chemical fertilizers, to organic cultivation approximately seven years ago. This shift may harm soil microorganisms, leading to decreased fertility, nutrient availability and hindering the ability to sustain organic production. Overall, the findings of this case study emphasize the significant soil fertility challenges on organic vegetable farms. Therefore, farmers and agricultural practitioners must adopt appropriate soil management practices to improve soil fertility, microbial populations, nutrient availability, and overall soil health for successful organic production.

Keywords

Outdoor Organic Vegetables, Microorganisms, Nitrogen Circulation Activity, Phosphorus Circulation Activity

1. Introduction

In recent years, there has been an increasing awareness of the detrimental effects of conventional farming practices on the environment, human health, and biodiversity. In response to these challenges, sustainable organic agriculture has emerged as a balanced and regenerative approach to food production. Organic agriculture has been implemented in the Philippines since the 1980s [1]. In 1999, the country had only nine organic farms, covering 95 acres [2]. However, in 2005, the Philippine government achieved significant progress by incorporating organic agriculture into its policy through Executive Order 481, titled “Promotion and Development of Organic Agriculture in the Philippines.” Subsequently, the Philippine government took a major step forward in 2010 by enacting the Organic Agriculture Act, or Republic Act 10068. This legislation aimed to promote the growth and development of the country’s organic agricultural sector by establishing an organic certification program and providing farmers with technical guidance and financial support, thereby encouraging the widespread adoption of organic farming.

Organic farming in the Philippines has gained momentum with the increasing health and environmental awareness of consumers. The Philippine government, in collaboration with its Department of Agriculture and other relevant authorities, has launched various programs and incentives to promote and encourage organic farming. These initiatives aim to improve agricultural sustainability, advocate for organic products, and provide technical assistance to organic farmers. Furthermore, efforts to promote organic agriculture have extended beyond the government sector. Non-governmental organizations (NGOs) and private companies have been actively promoting organic farming in this region. They have helped organic farmers by providing valuable training, organizing workshops, and enabling market access.

The country’s tropical climate and abundant agricultural resources provide ideal conditions for organic agriculture. Among the regions adopting this sustainable approach, Quezon Province stands out owing to its strong agricultural presence, and organic farming is gaining popularity among farmers and consumers. As the demand for organic products increases and environmental awareness grows, more farmers in Quezon Province are transitioning toward organic farming practices. Notable examples of this shift can be seen in farms such as Yumi’s Farm, PJ’s Plantation, and Bee Farm, all located in Sariaya Town. Although these farms are smaller and possess fewer resources than commercial enterprises, they play a crucial role in promoting sustainable, community-oriented organic agriculture.

These farms grow a variety of crops and employ traditional agro-ecological methods to cultivate their produce. Furthermore, these small private organic farms have adopted a direct-to-market approach. They sell their organic products directly to local markets and consumers, fostering close connections between producers and consumers. Additionally, they actively participate in farmers' markets and community-supported agriculture (CSA) programs, strengthening their sense of community and mutual support in the region.

Despite its adoption of government policies, organic farming continues to face challenges in the Philippines. A significant challenge is the limited number of studies on the impact of organic farming on soil quality and the environment. Studies conducted in various provinces have demonstrated that organic farms show notable improvements in soil properties compared with non-organic farms. For instance, in the Benguet Province, organic farms had higher levels of soil organic matter, total nitrogen, and available phosphorus than non-organic farms [3]. Similarly, in the Laguna Province, organic vegetable farms had greater levels of soil organic matter, total nitrogen, and available phosphorus than their non-organic counterparts [4]. Moreover, research conducted in the Nueva Ecija Province revealed that organic rice farms had higher levels of soil organic matter, microbial biomass, and microbial diversity than non-organic farms [5].

Recent advancements in soil health assessment technologies have further underscored the benefits of organic farming. A study employing the Soil Fertility Index (SOFIX) methodology demonstrated significant improvements in critical soil health indicators on various organic farms across Japan. The results revealed notable enhancements in total carbon content, bacterial biomass, nitrogen circulation activity, and phosphorus circulation activity. These metrics are indicative of improved soil fertility, enhanced microbial activity, and more efficient nutrient cycling, all of which contribute to the long-term sustainability of agricultural productivity. The SOFIX methodology provides a systematic and quantitative approach to soil health evaluation, offering actionable insights for farmers. By tailoring organic farming practices to the specific conditions of their soil and environment, farmers can optimize productivity while maintaining ecological balance. This approach highlights the potential of integrating advanced soil assessment tools with organic agricultural practices to achieve sustainable and resilient farming systems. Kai *et al.* [6] demonstrated the significant role of organic farming in improving soil microbial communities. His study highlighted that organic farms showed higher diversity and abundance of beneficial soil microorganisms, which play a key role in nutrient cycling and pest management. Kai *et al.* [7] provided evidence that organic farming practices enhance the activity of nitrogen-fixing bacteria and phosphate-solubilizing microbes, leading to improved soil fertility and plant growth. These findings underscore the synergistic relationship between organic farming practices and soil microbial health, emphasizing the potential for long-term agricultural sustainability.

Hence, this study aimed to investigate the physical, chemical, and biological

properties of soil in organic plots growing vegetables in open fields in the Philippines to assess the soil fertility of the organic plots.

2. Materials and Methods

2.1. Study Sites and Plant Materials

The study sites are listed in **Table 1**. Plots A and B are located in Laguna Province, whereas plots C and D are located in Quezon Province, Philippines. The study's research sites included four organic plots that produced open-field vegetables (tomatoes, eggplants, mung beans, lettuce, and okra). Soil samples were collected in plot A from the tomato, eggplant, and mung bean cropping zones (sites 1 - 3). In organic plots B (sites 4 - 6) and C (sites 7 - 9), soil samples were collected from tomato-, eggplant-, and lettuce-cropping areas. In organic field D, soil samples were collected from the eggplant, lettuce, and okra cropping areas (sites 10 - 12). Soil samples were collected between February 27 and March 1, 2023. Composite soil samples of the top 15 cm (excluding the surface crust of 2 - 3 cm) were collected from around the base of three randomly selected plants and analyzed for chemical and biological parameters. To maintain microbial activity, the composite samples were packed in sealed plastic bags containing air. Prior to fresh soil analysis, the soil was sieved through a 2 mm sieve to remove plant roots and stones. All fresh soil was used within two weeks for physical, chemical, and biological analyses, and the fresh soil was never dried.

Table 1. List of the study sites (organic farming).

No	Study sites	Province	Fertilizer	Pesticide
1				
2	A		None	None
3		Laguna		
4				
5	B		Compost (banana leave, etc.)	None
6				
7				
8	C		Chicken manure, carabao manure, vermicompost, mukosaku, bee propolis	None
9		Quezon		
10				
11	D		Chicken dung compost, rice straws	None
12				

2.2. Analysis of Physical and Chemical Properties of Soil

Fresh soil samples were analyzed for ammonium-nitrogen (NH_4^+ -N) and nitrate-nitrogen (NO_3^- -N) using 1 M KCl extraction. NH_4^+ -N was quantified via the indophenol blue method, and NO_3^- -N was measured using the brucine method,

following the protocol of Nicholas and Nason [8]. Water-soluble phosphorus (SP) and potassium (SK) were extracted by shaking a soil-water suspension (1:20, w/v) at 100 rpm for 1 hour. SP was determined using the molybdenum blue method [9], while SK was analyzed via atomic absorption spectrophotometry. Total carbon (TC) was measured with a total organic carbon analyzer (SSM-5000A, Shimadzu, Kyoto, Japan). Total nitrogen (TN), phosphorus (TP), and potassium (TK) were estimated from the amounts of NH_4^+ -N, SP, and SK in soil digests prepared using H_2SO_4 and H_2O_2 in a Kjeldatherm digestion unit (Gerhardt, Königswinter, Germany).

Soil pH and electrical conductivity (EC) were measured in a soil–water suspension (1:2.5, w/v) using a pH meter (HM-30R, TOA DKK, Tokyo, Japan) and an EC meter (CM-30R, TOA DKK, Tokyo, Japan), respectively. The volumetric moisture content of the soil was determined by calculating the percentage mass loss after oven drying at 110°C for at least 24 hours, or until a constant mass was achieved. The mass loss was expressed as a proportion of the total soil mass before drying.

2.3. Soil Biological Properties Analysis

Various biological properties were analyzed to evaluate the soil microbial biomass and its capacity for nutrient cycling. Total bacterial biomass was estimated by quantifying endogenous DNA (eDNA) following the method described by Aoshima *et al.* [10]. Nitrogen cycling activity was assessed based on the soil's ability to convert organic nitrogen into nitrate (NO_3^-), as described by Matsuno *et al.* [11] and Adhikari *et al.* [12]. Organic nitrogen is transformed through a series of decomposition processes involving proteins, peptides, amino acids, ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). Specific microbial groups mediate these processes, with NH_4^+ oxidation ($\text{NH}_4^+ \rightarrow \text{NO}_2^-$) and NO_2^- oxidation ($\text{NO}_2^- \rightarrow \text{NO}_3^-$) carried out by distinct bacterial communities. Nitrogen cycling activity was quantified by plotting NH_4^+ oxidation activity, NO_2^- oxidation activity, and total microbial biomass on a triangular graph. The area of the triangle was used as an index, with larger areas indicating higher nitrogen cycling activity in the soil. Phosphorus cycling activity was evaluated by incubating soil samples for three days and measuring the amount of water-soluble phosphorus (P) released from organic phosphorus compounds, specifically phytic acid. The phosphorus cycling score was calculated on a scale from 0 to 100, where a score of 100 indicated complete conversion of phytic acid to water-soluble phosphorus without adsorption by soil minerals, and a score of 0 indicated no detectable water-soluble phosphorus.

2.4. Statistical Analysis

Data for soil parameters were analyzed using Excel Statistics 2018 for Windows (Social Survey Research Information Co., Ltd., Tokyo, Japan). The normality of the data was assessed using the Shapiro-Wilk test, and homogeneity of variances

was evaluated using Levene's test. To compare the mean values of different treatment groups, one-way analysis of variance (ANOVA) was performed. If significant differences were detected ($p < 0.05$), post hoc comparisons were conducted using Fisher's least significant difference (LSD) test to identify specific group differences. All statistical analyses were conducted at a significance level of $p < 0.05$.

3. Results

3.1. Soil Physical and Chemical Properties

The physical and chemical properties of soils from 12 sampling sites across four organic plots (A-D) are summarized in **Table 2**. The recommended values for the physical and chemical properties of SOFIX soils are shown in **Table 3**. These values serve as guidelines for maintaining soil health and enhancing crop productivity. They are derived from a comprehensive evaluation of the soil's physical, chemical, and biological properties, aiming to sustain and improve soil fertility. Total carbon (TC) ranged from 7,430 to 21,830 mg kg^{-1} , below the recommended $\geq 25,000 \text{ mg kg}^{-1}$. Total nitrogen (TN) levels varied between 574 and 1,898 mg kg^{-1} , with only two sites meeting the $\geq 1,500 \text{ mg kg}^{-1}$ threshold. Total phosphorus (TP) levels ranged from 474 to 1,410 mg kg^{-1} , exceeding the $\geq 1,300 \text{ mg kg}^{-1}$ benchmark at two sites. Total potassium (TK) ranged from 978 to 1,741 mg kg^{-1} , below the recommended 2,500 - 10,000 mg kg^{-1} at all sites. The carbon-to-nitrogen (C/N) ratio (8.7 - 15.4) was within the optimal range of 10 - 25 at most sites. Despite adequate C/N ratios, low TC and TN levels indicate insufficient carbon and nitrogen for microbial activity. Overall, macronutrient levels were suboptimal in these soils.

Nitrate nitrogen ($\text{NO}_3^- \text{-N}$) ranged from 5 to 35 mg kg^{-1} , meeting the $\geq 10 \text{ mg kg}^{-1}$ threshold at all but one site. Ammonium nitrogen ($\text{NH}_4^+ \text{-N}$) levels (2 - 31 mg kg^{-1}) met the $\geq 10 \text{ mg kg}^{-1}$ benchmark at six sites. Soluble phosphate (SP) levels (17 - 957 mg kg^{-1}) exceeded the $\geq 100 \text{ mg kg}^{-1}$ threshold at 10 sites, while exchangeable potassium (SK) levels (289 - 901 mg kg^{-1}) met the $\geq 100 \text{ mg kg}^{-1}$ benchmark at all sites. Soil pH (6.1 - 7.9) fell within the recommended 5.5 - 6.1 range at three sites. Electrical conductivity (EC) values (0.08 - 0.26 mS cm^{-1}) met the 0.2 - 1.2 mS cm^{-1} range at six sites. Soil moisture content (22 - 36%) exceeded the $\geq 20\%$ benchmark at all sites.

Table 2. Physical and Chemical Properties of the soil in upland fields.

No	Study sites	Cropping system	TC (mg kg^{-1})	TN (mg kg^{-1})	TP (mg kg^{-1})	TK (mg kg^{-1})	C/N Ratio	$\text{NO}_3^- \text{-N}$ (mg kg^{-1})	$\text{NH}_4^+ \text{-N}$ (mg kg^{-1})	Soluble P (mg kg^{-1})	Soluble K (mg kg^{-1})
1	A	Tomato	9,902	688	639	1,608	14.4	19	4	402	739
2		Eggplant	7,430	574	673	1,741	12.9	15	3	146	754
3		Mung bean	9,781	748	492	1,674	13.1	11	2	43	582
4	B	Tomato	11,620	1,036	474	1,126	11.2	14	9	17	352
5		Eggplant	13,470	1,155	1,107	1,646	11.7	5	5	103	486

Continued

6	B	Head lettuce	15,210	1,389	1,128	1,598	11.0	21	14	152	444
7		Tomato	12,910	1,485	1,362	1,040	8.7	30	7	273	588
8	C	Eggplant	19,830	1,635	808	983	12.1	25	13	295	289
9		Head lettuce	20,300	1,437	738	1,321	14.1	30	15	178	791
10		Eggplant	16,370	1,060	916	1,140	15.4	35	12	957	901
11	D	Head lettuce	21,830	1,898	1,410	1,207	11.5	28	31	455	615
12		Okra	20,040	1,353	808	978	14.8	18	14	478	424

pH	EC (mS cm ⁻¹)	Volume moisture content (%)
7.6	0.10	24
7.4	0.11	22
7.0	0.07	26
6.2	0.11	30
7.4	0.08	22
7.3	0.12	25
6.1	0.26	33
7.2	0.20	30
6.5	0.21	33
7.5	0.26	33
7.0	0.23	36
7.5	0.21	30

Table 3. Recommended values for the physical and chemical properties of organic farm soil in upland fields.

Survey items	Recommended value
TC (mg kg ⁻¹)	≥25,000
TN (mg kg ⁻¹)	≥1,500
TP (mg kg ⁻¹)	≥1,300
TK (mg kg ⁻¹)	2,500 - 10,000
C/N Ratio	10 - 25
NO ₃ ⁻ -N (mg kg ⁻¹)	≥10
NH ₄ ⁺ -N (mg kg ⁻¹)	≥10
Soluble P (mg kg ⁻¹)	≥100
Soluble K (mg kg ⁻¹)	≥100
pH	5.5 - 6.5
EC (mS cm ⁻¹)	0.2 - 1.2
Volume moisture content (%)	0.21

3.2. Soil Biological Property

The biological properties of soils from 12 sampling sites across four organic plots (A-D) are summarized in **Table 4**, with recommended values for comparison in **Table 5**. Total bacterial biomass, a key indicator of soil health, ranged from 2.9×10^8 to 6.8×10^8 cells g^{-1} , with 10 sites below the threshold of $\geq 6.0 \times 10^8$ cells g^{-1} . Nitrogen (N) circulation activity, indicative of organic nitrogen transformation, varied from 6 to 60 points, with 9 sites failing to meet the benchmark of ≥ 49 points. Phosphorus (P) circulation activity ranged from 3 to 26 points, with 3 sites below the recommended ≥ 11 points. These results reveal widespread deficiencies in microbial activity and nutrient cycling efficiency.

The average evaluation values for nitrogen (N) circulation activity across crops are presented in **Figure 1**, while those for phosphorus (P) circulation activity are shown in **Figure 2**. Mung beans and okra were surveyed at a single location. For reference, mung beans exhibited a nitrogen cycling activity value of 58 points and a phosphorus circulation activity value of 7 points, whereas okra recorded 8 points for nitrogen circulation activity and 21 points for phosphorus circulation activity. Among tomatoes, eggplants, and lettuce, nitrogen circulation activity varied, with tomatoes showing the highest value (38 points), followed by eggplants and lettuce (24 points each). Similarly, phosphorus circulation activity differed, with tomatoes, eggplants, and lettuce recording 13, 10, and 23 points, respectively. However, no significant differences in N or P circulation activity were observed among the crops, suggesting comparable nutrient cycling efficiencies.

Table 4. Biological Property of the soil in upland fields.

No	Study sites	Cropping system	Bacterial biomass ($\times 10^8$ cells g^{-1})	NH_4^+ oxidation activity (Point)	NO_2^- oxidation activity (Point)	N circulation activity (Point)	P circulation activity (Point)
1		Tomato	5.5	63	59	49	11
2	A	Eggplant	3.9	33	35	18	3
3		Mung bean	3.8	67	100	58	7
4		Tomato	4.4	25	88	35	14
5	B	Eggplant	3.8	7	38	10	8
6		Head lettuce	4.0	0	43	10	26
7		Tomato	5.0	14	82	31	13
8	C	Eggplant	2.9	3	33	6	25
9		Head lettuce	4.1	7	83	22	20
10		Eggplant	6.8	68	67	60	5
11	D	Head lettuce	6.6	0	99	33	22
12		Okra	4.4	0	32	8	21

Table 5. Recommended values for the biological property of organic farm soil in upland fields.

Survey items	Recommended value
Bacterial biomass ($\times 10^8$ cells g^{-1})	$\geq 25,000$
NH_4^+ oxidation activity (Point)	$\geq 1,500$
NO_2^- oxidation activity (Point)	$\geq 1,300$
N circulation activity (Point)	2,500 - 10,000
P circulation activity (Point)	0.21

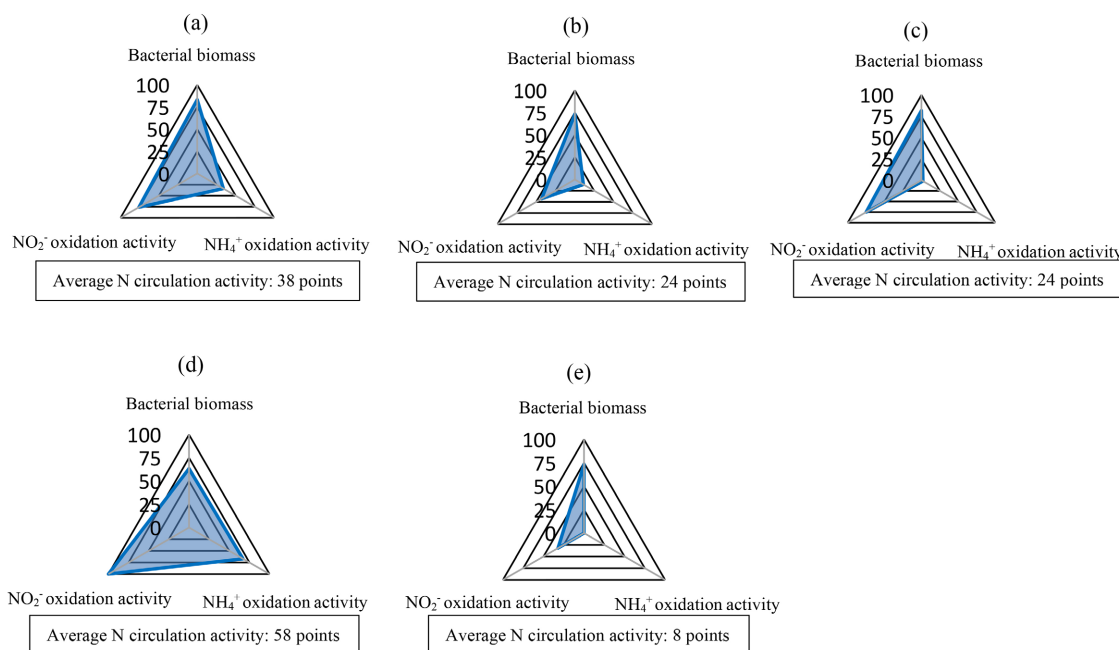


Figure 1. Radar charts of average N circulation activity in soil samples from (a) tomato (n = 3), (b) eggplant (n = 4), (c) head lettuce (n = 3), (d) mung bean (n = 1), and (e) okra (n = 1).

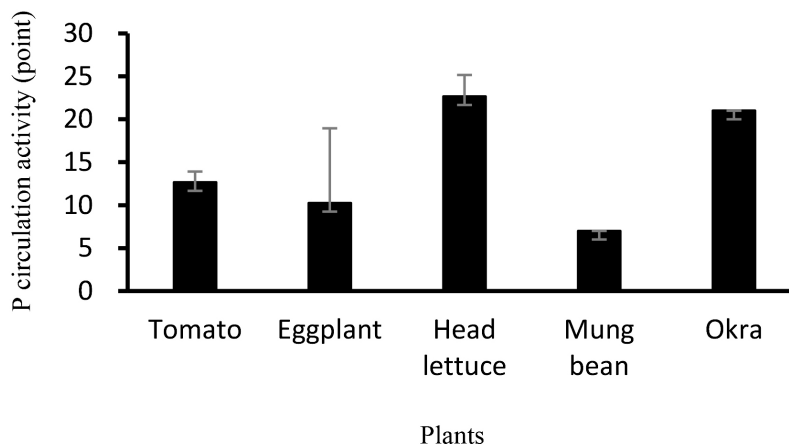


Figure 2. Average Phosphate (P) circulation activity in (a) tomato (n = 3), (b) eggplant (n = 4), (c) head lettuce (n = 3), (d) mung bean (n = 1), and (e) okra (n = 1) soils.

3.3. Correlation between Total Carbon (TC) and Total Nitrogen (TN)

Figure 3 shows a significant positive correlation between TC and TN ($R^2 = 0.76$) in the studied soils. The average TN content and C/N ratio in the organic plots were 1,210 mg kg^{-1} and 12.6, respectively. In contrast, upland field soils in Japan require minimum TC and TN levels of 25,000 mg kg^{-1} and 1,500 mg kg^{-1} , with a C/N ratio of 10 - 20 for effective nutrient cycling [13]. These findings suggest that while organic amendments, such as manure and unfermented materials, align with typical practices, further optimization is needed to achieve sustainable nutrient thresholds.

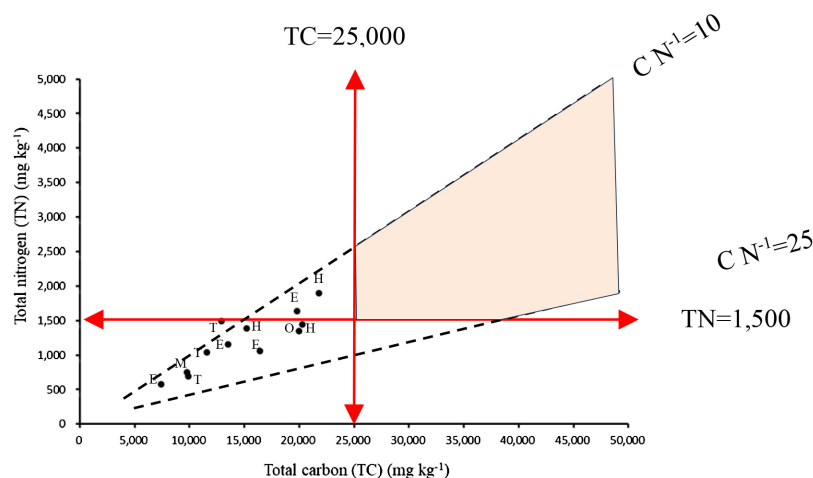


Figure 3. The correlation between total carbon (TC) and total nitrogen (TN) in upland fields of tomato (T), eggplant (E), mung bean (M), head lettuce (H), and okra (O). The dashed lines indicate the recommended values for the C/N ratios.

3.4. Correlation between Total Carbon (TC) and Total Phosphorus (TP)

Figure 4 illustrates the relationship between total carbon (TC) and total phosphorus (TP) in the studied soils. The average TP concentration and C/P ratio in the organic plots were approximately 880 mg kg^{-1} and 18.0, respectively. While a positive correlation was observed between TC and TP ($R^2 = 0.18$), the relatively low coefficient of determination suggests a weaker association between these two parameters compared to the relationship between TC and total nitrogen (TN). The variability in the C/P ratios across the field soils may reflect differences in the sources and decomposition rates of organic materials applied in the organic plots.

3.5. Relationship between Total Carbon (TC) and Bacterial Biomass

Figure 5 presents the relationship between total carbon (TC) and bacterial biomass in the studied soils. In Japanese upland field soils, the average TC and total bacterial biomass are reported to be 33,120 mg kg^{-1} and 8.0×10^8 cells g^{-1} , respectively [14]. By comparison, the mean TC and total bacterial biomass values in the Philippine upland field soils examined in this study were 14,891 mg kg^{-1} and 4.6×10^8 cells g^{-1} ,

respectively. These values represent approximately 40% and 58% of the corresponding values observed in Japanese upland field soils. Despite the relatively lower TC and bacterial biomass levels in the Philippine soils, the observed bacterial biomass in the organic plots aligns with expectations for recently transitioned organic farming systems. The lower TC levels likely reflect the relatively short duration (approximately seven years) since the transition from conventional cultivation, during which synthetic fertilizers and pesticides were heavily utilized.

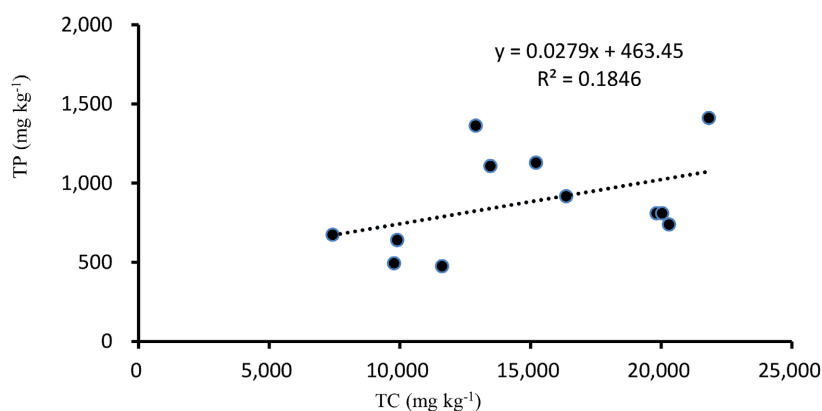


Figure 4. The correlation between total carbon (TC) and total phosphorus (TP).

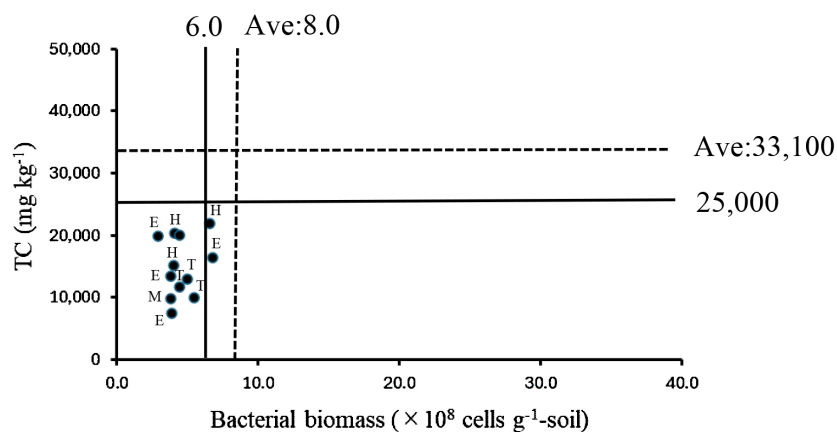


Figure 5. The correlation between total carbon (TC) and bacterial biomass in tomato (T), eggplant (E), mung bean (M), head lettuce (H), and okra (O) in upland fields.

In this study, no significant differences were observed in TC, TN, TP, bacterial biomass, nitrogen (N) circulation activity, or phosphorus (P) circulation activity among the cropping zones for tomato, eggplant, and lettuce. This lack of variation suggests that the soil properties and microbial activities in these organic plots are influenced more by overall field management practices than by specific crop types.

4. Discussion

4.1. Analysis of Soil Physical and Chemical Properties

The analysis of soil physical and chemical properties reveals that, while certain

parameters such as nitrate nitrogen, soluble phosphate, exchangeable potassium, and volumetric moisture content meet the recommended thresholds, the overall levels of key macronutrients—total carbon (TC), nitrogen (TN), phosphorus (TP), and potassium (TK)—are suboptimal for organically managed soils. Specifically, the TC and TN levels were significantly lower than the recommended values, which suggests that organic matter inputs may be insufficient or decomposition rates may be too slow, potentially limiting microbial activity and nutrient availability [13] [14].

The results of the nitrogen and phosphorus circulation activity indicate moderate microbial activity in the soils, with no significant differences observed among the tested crops. This suggests that while nutrient cycling processes are functional, they may not be operating at their optimal capacity. Similar findings have been reported by researchers who noted that low nutrient availability can limit microbial efficiency, particularly in organic systems where nutrient cycling is heavily reliant on microbial activity [15] [16]. Although the carbon-to-nitrogen (C/N) ratios were mostly within the recommended range, the low levels of TC and TN suggest that the organic matter may not be sufficient to support robust microbial communities necessary for efficient nutrient cycling and soil health [17].

These findings highlight the need for further optimization of organic amendments and crop rotation practices to enhance nutrient cycling and improve soil fertility. Previous studies have emphasized that organic farming systems, especially those in the transition phase, often face challenges related to nutrient deficiencies due to the reduced use of synthetic fertilizers [18]. The relatively recent transition from conventional to organic farming practices in the study area may have contributed to the observed deficiencies in soil fertility. Increased organic matter inputs, such as compost and green manure, are widely recognized as essential strategies to improve nutrient availability and microbial activity in organic systems [18] [19]. Moreover, crop rotation practices can help maintain soil fertility by preventing nutrient depletion and supporting diverse microbial populations [20].

In conclusion, while the soils in the study plots exhibit some positive characteristics, such as adequate moisture content and exchangeable potassium levels, the overall nutrient levels and microbial activity are insufficient for optimal organic farming. These results align with previous studies that have demonstrated the importance of soil management strategies, including the application of well-composted organic materials and crop rotation, to improve soil quality and promote sustainable agricultural practices [16] [21]. Future research should focus on the long-term effects of these interventions on soil health and crop productivity, with an emphasis on the sustainability of organic farming systems under varying climatic and management conditions.

4.2. Analysis of Soil Biological Activity and Nutrient Cycling

The results of the soil biological properties analysis reveal critical limitations in

microbial activity and nutrient cycling in the studied soils. The total bacterial biomass, which serves as a key indicator of soil microbial health, was below the recommended threshold at most sites. This suggests that microbial populations in these soils are suboptimal, potentially limiting the soil's capacity to decompose organic matter and cycle nutrients efficiently [17]. The failure to meet the recommended bacterial biomass values at 10 of the 12 sites points to a deficiency in microbial populations that are essential for maintaining soil fertility in organic farming systems [16].

The nitrogen cycling activity values observed in this study also point to inefficiencies in nitrogen transformation processes. With 9 out of 12 sites recording values below the recommended threshold, the results suggest that these soils have limited capacity to convert organic nitrogen into plant-available forms, which could hinder plant growth and nutrient uptake [19]. Previous studies have similarly shown that nitrogen cycling efficiency in organic soils can be affected by insufficient microbial activity, leading to slower nutrient turnover and reduced availability of nitrogen for crops [15] [16].

Phosphorus cycling activity, which is crucial for the availability of phosphorus to plants, also fell below the recommended values at some sites. The observed range of 3 to 26 points suggests that phosphorus release from organic matter is suboptimal in these soils, potentially limiting plant access to this essential nutrient. Deficiencies in phosphorus availability have been reported in organic farming systems, particularly in soils with low microbial activity and insufficient organic matter inputs [18] [19]. The limited phosphorus cycling observed in this study may be linked to the relatively low microbial populations, which are necessary for the mineralization of organic phosphorus compounds [22].

To address these deficiencies, tailored soil management practices are essential. Increasing organic matter inputs, such as compost and green manure, could enhance microbial populations and nutrient cycling efficiency [18]. Additionally, the use of cover crops could improve microbial diversity and support nutrient cycling by providing organic matter and fostering favorable soil conditions [20]. Adjustments to soil pH and moisture levels may also create more conducive conditions for microbial activity, further enhancing nutrient transformation processes [17].

In conclusion, the findings of this study underscore the need for targeted soil management strategies to address the limitations in microbial activity and nutrient cycling. By improving soil microbial health through organic amendments and other management practices, it is possible to enhance nutrient availability and overall soil fertility, supporting more efficient and sustainable organic farming systems.

4.3. Correlation between TC and TN

The observed positive correlation between total carbon (TC) and total nitrogen (TN) in the soils of the Philippine organic plots ($R^2 = 0.76$) suggests that the organic

amendments applied, such as manure and unfermented organic materials, have a similar carbon-to-nitrogen ratio. This finding aligns with previous studies that report similar ratios in organic farming systems, where organic materials are often applied to enhance soil fertility [23]. The strong relationship between TC and TN in this study reflects the efforts of farmers to incorporate organic amendments into the soil, which is a typical practice in organic farming systems. However, the relatively low concentrations of TC and TN in the soils, compared to recommended thresholds for high nutrient cycling efficiency [13], suggest that these practices may not be sufficient to fully replenish soil nutrients in the short term.

The lower fertility observed in the organic plots in the Philippines can likely be attributed to the relatively recent transition from conventional farming practices, which involved the use of synthetic pesticides and chemical fertilizers. This transition, which occurred approximately seven years prior to the study, may have resulted in reduced organic matter content and a decline in microbial activity, as the soil's biological and chemical properties were likely altered by the previous use of chemical inputs [24]. Studies have shown that soils transitioning from conventional to organic farming often exhibit lower nutrient levels and microbial biomass in the early stages due to the absence of synthetic fertilizers and the time required for organic matter to accumulate and decompose [20].

The results suggest that while the organic amendments used in the study align with typical organic farming practices, further optimization of these inputs may be necessary to meet the recommended nutrient thresholds for sustainable productivity. The application of additional organic matter, such as compost, and the integration of green manure crops could help increase the TC and TN concentrations in the soil, thus improving nutrient cycling efficiency and microbial activity [18]. Furthermore, improving soil management practices, such as crop rotation and cover cropping, may enhance the long-term fertility of these soils by increasing the availability of essential nutrients and fostering a more diverse microbial community [16].

In conclusion, while the positive correlation between TC and TN indicates that organic amendments are being applied in a manner consistent with organic farming practices, the observed low nutrient levels highlight the need for further optimization of soil management strategies. Long-term improvements in soil fertility will require a more comprehensive approach, including the application of additional organic inputs, optimized crop management practices, and continuous monitoring of soil health.

4.4. Relationship between TC and TP

The observed positive correlation between total carbon (TC) and total phosphorus (TP) in the organic plots ($R^2 = 0.18$) suggests that, while there is a relationship between these two parameters, it is relatively weak compared to the stronger correlation between TC and total nitrogen (TN). This finding aligns with previous studies that have reported weaker correlations between carbon and phosphorus

compared to carbon and nitrogen, particularly in soils where phosphorus availability is influenced by a range of factors beyond microbial processes [25].

Unlike nitrogen, which is closely linked to carbon through microbial processes such as mineralization and immobilization, phosphorus availability in soil is more complex. It is influenced by factors such as mineral adsorption, chemical precipitation, and microbial immobilization [26]. These processes can limit the availability of phosphorus for plant uptake, which may explain the weaker correlation observed in this study. For instance, phosphorus in soils is often bound to minerals like iron, aluminum, or calcium, which can reduce its bioavailability [27]. Furthermore, the decomposition rates of organic materials, which contribute to both carbon and phosphorus inputs, can vary significantly, leading to greater variability in the C/P ratios across the field soils.

These findings underscore the need for targeted soil management practices to optimize phosphorus availability in organic farming systems. Practices such as the application of organic amendments rich in phosphorus, like bone meal or composted manure, could help improve phosphorus cycling in soils with low phosphorus availability [28]. Additionally, adjusting soil pH to enhance phosphorus solubility and employing crop rotation strategies to increase microbial diversity may help improve phosphorus cycling efficiency [29].

Further research is needed to investigate the specific mechanisms governing phosphorus dynamics in these soils. Identifying the key factors that control phosphorus availability, such as mineral interactions and microbial processes, will provide valuable insights into how phosphorus cycling can be enhanced in organic farming systems, aligning phosphorus inputs with carbon management practices.

4.5. Analysis of Bacterial Biomass in Relation to Total Carbon

The observed relationship between total carbon (TC) and bacterial biomass in the Philippine upland soils reveals a significant difference when compared to Japanese upland field soils. The mean TC content ($14,891 \text{ mg kg}^{-1}$) and bacterial biomass ($4.6 \times 10^8 \text{ cells g}^{-1}$) in the Philippine soils were approximately 40% and 58% of the corresponding values in Japan, respectively [14]. This discrepancy is likely attributed to the relatively recent transition (approximately seven years ago) from conventional to organic farming in the study area. Previous studies have shown that organic farming systems, especially those transitioning from conventional practices, typically exhibit lower soil organic matter (SOM) levels and microbial biomass in the early stages due to the reduced use of synthetic fertilizers and pesticides [30].

In the Philippine organic plots, the observed bacterial biomass aligns with what is expected for systems that have recently transitioned to organic practices. The lower TC levels are consistent with the reduced organic matter inputs typically associated with the early stages of organic farming. This finding supports the notion that the duration of organic management significantly influences soil microbial communities, with longer-term organic systems showing improved microbial

biomass and nutrient cycling efficiency [31] [32].

Interestingly, no significant differences were observed in TC, TN, TP, bacterial biomass, or nutrient cycling activities (nitrogen and phosphorus) among the cropping zones for tomato, eggplant, and lettuce. This lack of variation suggests that microbial activity and soil properties in these organic plots are influenced more by overall management practices than by the specific crops grown. The consistent application of organic amendments and crop rotation practices may have contributed to this uniformity, emphasizing the importance of holistic soil management in organic farming systems [33].

These findings highlight the need for ongoing soil management strategies to enhance microbial biomass and nutrient cycling, particularly in soils with a history of conventional farming. The use of organic amendments, such as compost and green manure, and adjustments to soil pH and moisture can help accelerate the recovery of microbial populations and improve nutrient cycling. Further studies are warranted to explore the long-term effects of organic farming on soil microbial communities and nutrient dynamics, particularly in systems transitioning from conventional to organic practices.

5. Conclusion

This study underscores the substantial soil fertility challenges faced by organic vegetable farms in the Philippines. The results indicate insufficient levels of key macronutrients, including total carbon, nitrogen, phosphorus, and potassium, as well as reduced bacterial biomass and nutrient cycling activities compared to benchmarks for sustainable organic farming systems. These limitations are likely attributable to the relatively recent transition from conventional farming, characterized by the historical use of synthetic fertilizers and pesticides, to organic farming practices. To address these soil fertility constraints and foster a more sustainable organic agricultural system, the adoption of targeted soil management practices is imperative. Key strategies include the application of well-composted organic materials to replenish soil organic matter, the implementation of diverse crop rotations to enhance nutrient cycling, and the use of green manures to improve soil structure and fertility. Additionally, regular monitoring of soil biological, chemical, and physical parameters through advanced analytical techniques can provide actionable insights for optimizing soil management practices. By adopting these measures, organic vegetable farms can overcome existing limitations, enhance soil health, and achieve more efficient and sustainable production. Such efforts not only support the resilience of organic farming systems but also contribute to global initiatives aimed at promoting environmentally sustainable and economically viable agriculture.

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Conflicts of Interest

The authors declare no conflicts of interest associated with the publication of this article.

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