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Bangladesh J. Sci. Ind. Res. **60(4)**, 297-306, 2025

BCSIR

BANGLADESH JOURNAL OF SCIENTIFIC AND INDUSTRIAL RESEARCH

ISSN. 0304-9809

Temporal variation of selected soil fertility indicators under organic amendments in contrasting soils

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ARTICLE INFO

Received: 28 August 2025

Revised: 19 October 2025

Accepted: 02 November 2025

eISSN 2224-7157/© 2025 The Author(s). Published by Bangladesh Council of Scientific and Industrial Research (BCSIR).

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DOI: https://doi.org/10.3329/bjsir.v60i4.83957

Abstract

A laboratory incubation study evaluated the effects of alternate wetting-drying cycles on soil properties using an acid soil (Dinajpur), a calcareous soil (Faridpur), and their 1:1 mixture. Three organic amendments, namely vermicompost, tricho-compost, and burnt poultry litter, were applied at 5 and 10 t ha^{-1} in a completely randomized design with three replicates over 90 days. In the acid soil, pH increased from 5.42 to 7.09; in the calcareous soil, pH decreased from 8.01 to 7.43; while the 1:1 mixture maintained an intermediate pH. Electrical conductivity increased markedly in both soils during the first 15 days and declined after day 30, while organic carbon peaked at day 45 and then gradually decreased. Cation exchange capacity increased significantly over the 90 days of incubation. The combined effects of soil types and organic amendments showed synergistic advantages. The results indicate that locally available organic fertilizers can effectively improve soil health and support sustainable agriculture.

Keywords: Acid soil; Calcareous soil; Incubation; Organic fertilizers; Soil fertility

Introduction

Soil fertility degradation presents a considerable challenge to sustainable agriculture globally, especially in South Asia. The excessive intensification of crop production, excessive use of chemical fertilizers, and limited organic matter return to the soil in Bangladesh have contributed to a consistent deterioration in soil health (Haque *et al.* 2021; Akter *et al.* 2025). Key factors influencing soil fertility include soil reaction (pH), organic matter content (OC), electrical conductivity (EC), and cation exchange capacity (CEC). These elements collectively regulate nutrient dynamics, microbial activity, and overall soil health (Brady and Weil, 2016). Soils across various agroecological zones in Bangladesh exhibit distinct chemical limitations. Acidic soils are common in northwestern districts such as Dinajpur, while calcareous soils dominate southern regions like Faridpur (Rahman *et al.* 2018; Hossain *et al.* 2017). The identified soil types restrict the availability of essential nutrients and require corrective management to ensure long-term productivity. Some soil health indicators in acid soils are the basis for productivity, while these level indicators are required by calcareous soils. If the two were mixed, the combination could perform synergistically (Saha *et al.* 2021).

The use of organic fertilizers has been widely recommended as a sustainable soil amendment strategy due to their ability to enhance soil structure, buffer pH, improve water retention, and increase nutrient availability (Adhikari and Hartemink, 2020; Manna *et al.* 2005). The utilization of organic fertilizers as soil nutrient inputs is currently on the rise, aimed at sustaining profitable vegetable production while minimizing environmental contamination and enhancing food quality (Naznin *et al.* 2024). Organic materials such as vermicompost, tricho-compost, and poultry litter have shown effectiveness in improving soil organic carbon and nutrient retention capacity (Azeez and Van Averbeke, 2012; Li *et al.* 2022).

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The breakdown and transformation of organic fertilizers happen in a dynamic way in rice-based cropping systems, where soils often experience alternating periods of wetting and drying. These moisture fluctuations can significantly affect the temporal changes in soil chemical properties (Xie *et al.* 2021).

Some research has investigated the short-term effects of organic amendments on specific soil parameters; most focus on either a single soil type or overlook the temporal progression of changes under moisture fluctuation. Moreover, there is limited information on how the combination of contrasting soil types (acidic and calcareous) behaves when amended with organic inputs over time. This reveals an important research gap regarding how mixing soils with different properties and applying amendments under alternate wetting and drying conditions may lead to synergistic or antagonistic effects.

This study examines the effects of three organic fertilizers, viz. vermicompost, tricho-compost, and burnt poultry litter on acid, calcareous, and mixed soils. A 90 days of incubation under alternate wetting and drying conditions was conducted to monitor temporal changes in pH, EC (electrical conductivity), organic carbon (OC), and cation exchange capacity (CEC). The objectives of this study were to: (a) assess the influence of different organic amendments under alternate wetting and drying conditions; (b) compare the efficiency of the three fertilizers in modifying the soil properties; and (c) identify optimal soil and fertilizer combinations for improving fertility in problematic soils of Bangladesh. The outcomes provide evidence-based guidance for sustainable use of locally available organic inputs to enhance soil quality, reclamation, and agricultural productivity in diverse soil systems.

Materials and methods

Sampling site description: Soils were collected from two locations for the incubation study based on low and high soil pH levels. Acidic soil with a low pH was obtained from Binnapara, a village in the Chehelgazi Union of Dinajpur Sadar upazila (25°42'52.58" N and 88°39'36" E), which is situated in AEZ-1 (Old Himalayan Piedmont Plain). The calcareous soil was collected from the village of Parchar of Krishnanagar Union, upazila of Faridpur Sadar (23°35'01" N and 89°46'01" E), which is situated under AEZ-12 known as the Lower Ganges River Floodplain (Fig. 1). The collected acid and calcareous soils were combined manually at a ratio of 1:1 to make the mixed soil in the Department of Soil, Water and Environment before the setup of the experiment.

Incubation study: An incubation study was conducted using the two surface (0-15 cm depth) soils (acid and calcareous) and their mixture (1:1), to investigate the effect of incubation time on the selected soil health parameters under wetting and drying cycles during the period of March to June, 2021 of about 90 days. An amount of 500 g air-dry processed and sieved (2mm) soil was measured and placed in plastic containers (10 × 8cm) to mix with the organic fertilizers (Vermicompost, Tricho-compost, Burnt Poultry Litter) thoroughly at a rate of 5 and 10 t ha^{-1} respectively. The fertilizers were mixed with the soils on a dry weight basis (Table I). The organic fertilizers were collected from

Table I. Treatment number, denotations and details of the experiment

Treatment No.			Treatment denotations	Description
Acid soil (S_1)	Calcareous soil (S_2)	Mixed soil (S_3)		
S_1T_0	S_2T_0	S_3T_0	$V_0TC_0BPL_0$	No fertilizers were used (Absolute Control)
S_1T_1	S_2T_1	S_3T_1	V_5	Vermicompost was applied @ 5t ha^{-1}
S_1T_2	S_2T_2	S_3T_2	V_{10}	Vermicompost was applied @ 10 t ha^{-1}
S_1T_3	S_2T_3	S_3T_3	TC_5	Tricho-compost was used @ 5t ha^{-1}
S_1T_4	S_2T_4	S_3T_4	TC_{10}	Tricho-compost was used @ 10 t ha^{-1}
S_1T_5	S_2T_5	S_3T_5	BPL_5	Burnt Poultry Litter was applied @ 5t ha^{-1}
S_1T_6	S_2T_6	S_3T_6	BPL_{10}	Burnt poultry Litter was applied @ 10 t ha^{-1}

the local vendor. Moreover, the poultry litter was burned (90-130℃) manually. The litter was burned to get rid of some toxic substances. The composition and relevant status of organic fertilizers used in the experiment are given in Table III. The soil samples were incubated at ambient temperature (~28℃). The moisture was maintained at field moist capacity condition (~50%) by using distilled water for 15 days and then left for air drying condition for the next 15 days. Again, the soil turned into field moist condition for the respective 15 days. Soil samples were taken at intervals of 15, 30, 45, 60, 75, and 90 days of incubation. Soil samples were obtained using the destructive method. So, a total of 63 plastic containers were utilized throughout the incubation experiment (7 × 3 × 3= 63). Plastic containers were organized in a completely randomized way. The results were reported on a dry weight basis.

Soil preparation for laboratory analyses: Collecting the soil samples from the incubation experiment on each sampling date, the samples were air-dried and subjected to sieving through a 2 mm mesh. Other gathered samples were similarly prepared for chemical analyses.

Chemical Analyses: The physicochemical properties of the soil and fertilizer samples were determined following standard procedures. pH was measured electrochemically using a glass electrode pH meter (MW150MAX) at a sample-to-water ratio of 1:2.5 and electrical conductivity (EC) was assessed with a glass electrode conductivity meter (EUTECH Instrument CON 700) using a soil-to-water ratio of 1:5 (Jackson, 1973). Organic carbon (OC) content was determined in which organic carbon is oxidized by chromic acid (derived from potassium dichromate), and the remaining unreacted chromic acid is titrated with standard ferrous sulfate solution to calculate the amount of oxidized carbon (Walkley and Black, 1934). Organic carbon in fertilizer samples was determined in the same procedur. Cation exchange capacity (CEC) was measured by saturating the sample with 1N ammonium acetate solution at pH 7.0, followed by the removal of excess salts using alcohol, displacement of ammonium with acidified 1N sodium chloride, and quantification through Kjeldahl distillation (Chapman, 1965).

Statistical Analyses of Data: The results of the experiment were calculated and graphically evaluated using Microsoft Excel 2019. All statistical analyses were performed with Minitab version 20.

Results and discussion

Soil pH: Soil pH is crucial for the solubility of nutrient availability and microbial activity (Neina, 2019). The pH responses exhibited significant variation across different soil types throughout the 90-day incubation period ($p \leq 0.05$). Organic amendments resulted in notable changes in soil pH, indicative of their specific composition and decomposition processes.

Organic amendments increased pH in acid soil compared to the untreated soil, with the effect becoming more pronounced over time. The greatest improvement was observed in S_1T_4 (TC_{10}), followed by vermicompost (V_{10}) and burnt poultry litter (BPL_{10}) (Fig. 2). The pronounced rise in pH suggests a strong buffering capacity of tricho-compost because of its higher base cation content and humified organic compounds. These cations neutralize exchangeable acidity by exchanging ion with Al^{3+} and Fe^{3+} and forming complexes with them. This causes the pH to

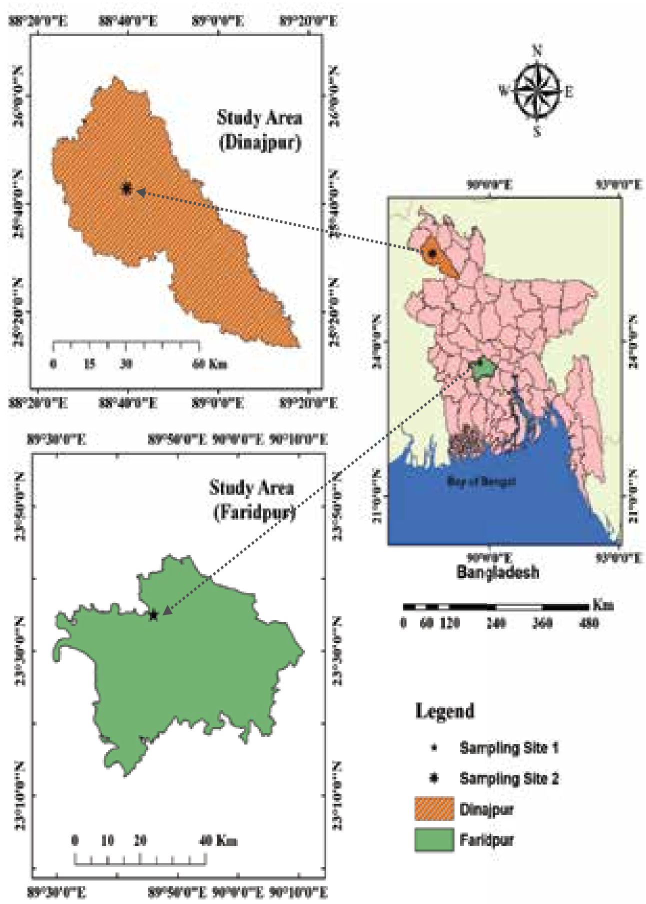

Fig. 1. Map of the sampling site

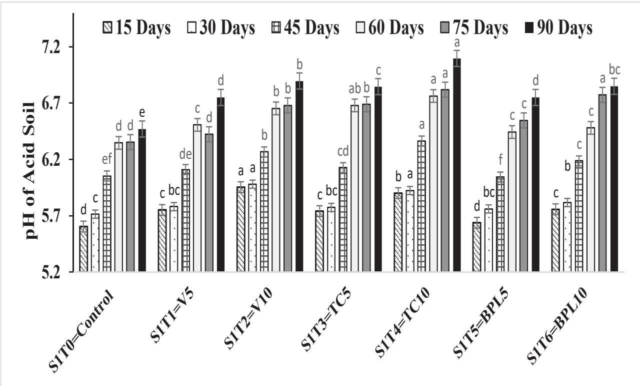

Fig. 2. Changes in pH values in acid soil at different time intervals as influenced by the application of different organic fertilizers in the incubation study

slowly rise (Akter and Hossain, 2025). The relatively high alkalinity of tricho-compost (Table III) likely enhanced this neutralizing effect and improved soil conditions for nutrient uptake.

In contrast, calcareous soil exhibited a gradual decline in pH during incubation, with the most pronounced decrease under S_2T_4 (TC_{10}) ($p \leq 0.05$) (Fig. 3). This mild acidification is agronomically favorable, as it moderates excessive alkalinity and enhances nutrient availability. The reduction in pH likely resulted from microbial decomposition of organic matter and the release of organic acids by Trichoderma spp., which promote carbonate dissolution (Barka *et al.* 2018). Similar observations have been reported where organic amendments slightly acidify calcareous soils through increased micro-

Table II. Selected properties of the initial acid, calcareous and mixed soils

Properties	Acid soil (S_1)	Calcareous soil (S_2)	Mixed soil (S_3) (Acid soil: Calcareous soil= 1:1)
USDA Soil Taxonomy	Typic Eutrochrepts	Aeric Endoaquapts	-
Texture	Sandy clay loam	Loam	Loam
pH (Soil reaction)	5.42	8.01	6.09
EC (µS cm^{-1})	26.65	24.04	44.2
CEC (cmol kg^{-1})	3.60	20.05	13.05
Organic carbon (%)	0.29	0.70	0.54

Table III. Relevant status of the fertilizers used in the incubation study

Characteristics	Vermicompost (V)	Tricho -compost (TC)	Burnt poultry litter (BPL)
pH (Soil reaction)	6.35	7.63	6.27
EC (µS cm^{-1})	3.19	2.16	10.11
CEC (cmol kg^{-1})	70	72	50
OC (%)	3.55	7.18	9.33
OM (%)	6.12	12.38	16.08
Total N (%)	3.5	4.28	1.93
Total P (%)	0.635	0.875	0.818
Total K (%)	0.7	1.15	0.26

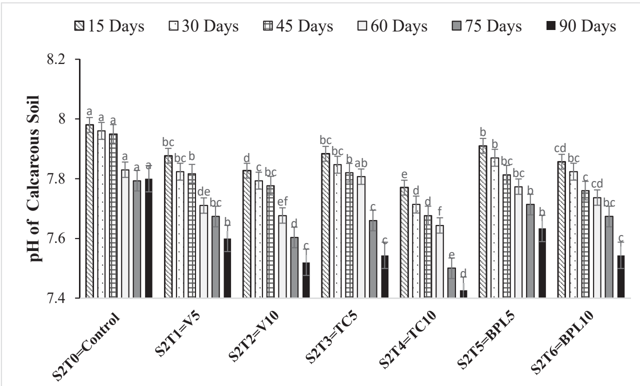

Fig. 3. Changes in pH values in calcareous soil at different time intervals as influenced by the application of different organic fertilizers in the incubation study

bial respiration, and facilitate carbonic acid formation (El-Nagar *et al.* 2022).

In the mixed soil, which initially exhibited near-neutral pH, minor increases were recorded with all organic amendments (Fig. 4). The treatment S_3T_4 again performed best, followed by V_{10} and BPL_{10}. The mixed soil's balanced composition may have buffered both acidic and alkaline components and maintained pH near optimal levels for nutrient availability. Overall, tricho-compost demonstrated superior efficacy in moderating soil pH across soil types. It raised pH in acidic soil, lowered it slightly in calcareous soil, and stabilized it in mixed soil. These findings emphasize its potential as a multifunctional amendment for managing soil reaction and enhancing long-term soil health.

Electrical conductivity (EC): Electrical conductivity reflects the measure of soluble ions and indicates the soil's salinity and nutrient availability. In this study, EC varied significantly ($p \leq 0.05$) among soil types and incubation periods. It illustrated the dynamic influence of organic amendments under alternate wetting and drying conditions.

The initial EC was recorded at 26.65 µS cm^{-1} in acid soil (Table II). EC increased progressively with the application of organic fertilizers and reached its peak values between 35.03 and 103.96 µS cm^{-1} at 60 days, before stabilizing toward the end of incubation. The highest EC values occurred in treatment S_1T_2 (V_{10}), indicating enhanced solubilization of salts and organic ions. Conversely, Tricho-compost (TC) consistently maintained the lowest EC values (Table IV) due to its lower inherent salt content and slower mineralization rate compared with vermicompost (V) and burnt poultry litter (BPL). This slow rise in EC shows that nutrients are being mineralized and ions are being released from organic matter that is breaking down.

In calcareous soil, the initial EC (24.04 µS cm^{-1}) rose sharply after 15 days of incubation (70.2-216.83 µS cm^{-1}), followed by a gradual decline. The early spike likely resulted from rapid mineralization and the release of soluble salts, particularly in burnt poultry litter and vermicompost-treated soils. This slow rise in EC shows that nutrients are being mineralized and ions are being released from organic matter that is breaking down. The relatively lower EC in tricho-compost amended soils further supports its slower nutrient release and lower salt load. Similar transient EC patterns after organic amendment application have been documented by Diacono and Montemurro (2010), Loper *et al.* (2010), and Akpa *et al.* (2016).

For the mixed soil (1:1 acid and calcareous), the initial EC (44.20 µS cm^{-1}) was increased significantly (124.33 to 177.2 µS cm^{-1}) after 15 days, peaking early and declined gradually thereafter. EC values ranged from 39.07 to 70.53 µS cm^{-1} after 90 days. (Table IV). Treatment S_3T_6 (BPL_{10}) recorded the highest EC, reaffirming the salinity-enhancing potential of BPL due to its high EC content. The gradual decrease in EC across all soils suggests that decomposed organic matter is becoming more stable, ions are being immobilized by microbes, and leaching may be happening when moisture levels change. Overall, the EC dynamics

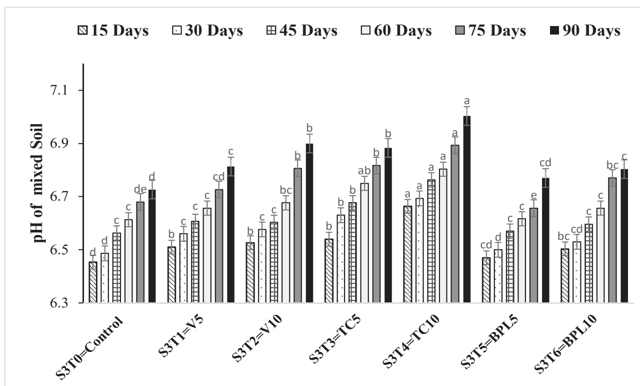

Fig. 4. Changes in pH values in mixed soil (1:1) at different time intervals as influenced by the application of different organic fertilizers in the incubation study

Table IV. Changes in EC (µS cm^{-1}) values in different soils at different time intervals as influenced by the application of different organic fertilizers in the incubation study

Treatment	Incubation days					
S_1T_0=Control	22.50 g	31.23 e	32.33 f	35.03 g	41.40 g	43.50 g
S_1T_1=V_5	28.23 f	35.83 d	39.00 e	40.46 e	42.80 f	53.40 f
S_1T_2=V_{10}	34.23 d	40.20 c	52.56 b	61.13 c	63.00 b	67.17 d
S_1T_3=TC_5	31.40 e	35.50 d	37.97 e	38.43 f	47.03 e	58.97 e
S_1T_4=TC_{10}	36.17 c	41.17 b	45.03 d	52.00 d	52.80 d	88.00 a
S_1T_5=BPL_5	41.10 b	47.63 b	51.10 c	67.07 b	57.77 c	70.23 c
S_1T_6=BPL_{10}	58.73 a	70.57 a	97.80 a	103.97 a	94.70 a	77.50 b
S_2T_0=Control	70.20 f	69.23 g	68.73 f	56.90 g	48.27 g	39.73 f
S_2T_1=V_5	137.83 d	90.03 e	76.77 e	68.83 e	62.23 e	53.40 e
S_2T_2=V_{10}	139.30 d	84.20 f	78.73 d	72.40 d	64.73 d	57.40 d
S_2T_3=TC_5	202.80 c	117.43 d	77.43 de	62.20 f	58.47 f	57.23 d
S_2T_4=TC_{10}	216.83 a	122.60 c	92.77 c	83.37 c	79.13 b	69.93 c
S_2T_5=BPL_5	133.17 e	155.73 b	259.37 b	93.8 b	77.13 c	74.17 b
S_2T_6=BPL_{10}	205.03 b	159.93 a	423.77 a	145.27 a	106.43 a	89.83 a
S_3T_0=Control	127.67 e	70.80 f	52.57 f	49.27 f	47.70 f	39.07 e
S_3T_1=V_5	160.73 g	83.43 c	71.23 c	61.30 d	55.2 e	51.40 b
S_3T_2=V_{10}	137.40 d	68.16 g	55.23 e	50.77 e	46.47 g	42.67 d
S_3T_3=TC_5	148.80 c	74.53 e	64.13 d	61.73 d	57.80 d	47.80 c
S_3T_4=TC_{10}	159.90 b	81.77 d	72.13 c	69.30 c	62.37 c	46.87 c
S_3T_5=BPL_5	124.33 f	109.27 b	183.20 b	88.70 b	79.33 b	69.70 a
S_3T_6=BPL_{10}	177.20 a	137.13 a	238.83 a	93.20 a	81.53 a	70.53 a

Different letters in the same column indicate significant ($p \leq 0.05$) statistically differences by Tukey's Range Test.

observed across soils suggest that organic amendments, particularly BPL and vermicompost, temporarily elevate soil salinity due to enhanced mineralization and ion release, followed by stabilization as decomposition proceeds. Tricho-compost, by contrast, exerts a milder effect on EC owing to its lower soluble salt content and controlled mineralization rate. These results emphasize that it's important to balance short-term nutrient availability with potential salinity effects when applying organic fertilizers to different soil types.

Organic carbon (OC): The temporal changes of soil organic carbon are characterized by an increase up to 45 days followed by a gradual decline. It reflects the interplay between carbon inputs from organic amendments and microbial decomposition. Initially, the addition of organic fertilizers supplies labile carbon, which increases measured soil OC. As incubation progresses, microbial activity metabolizes the labile carbon, releases CO_2 and causes a gradual decline in OC. Simultaneously, a portion of the carbon may become stabilized in recalcitrant fractions or temporarily immobilized within microbial biomass which has contributed to the observed trends.

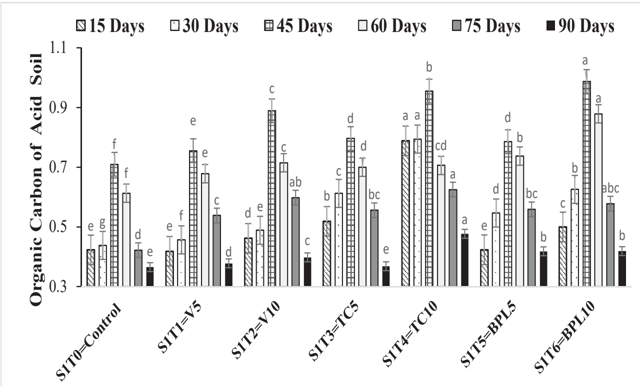

Fig. 5. Changes in organic carbon content in acid soil at different time intervals as influenced by the application of different organic fertilizers in the incubation study

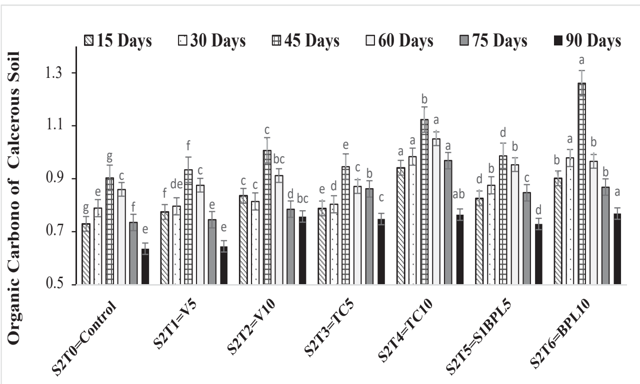

Fig. 6. Changes in organic carbon content in calcareous soil at different time intervals as influenced by the application of different organic fertilizers in the incubation study

In acid soil, the initial OC content (0.29%) increased sharply during the first 45 days. It reached 0.70-0.98% across treatments before decreasing to 0.30-0.37% by day 90. The highest OC value was recorded in S_1T_6 which indicated greater carbon accumulation under high organic inputs (Fig. 5). Similar declining trends in OC have been reported in acid soils amended with organic materials, primarily due to enhanced microbial mineralization, which can lead to temporary immobilization of nutrients and carbon loss (Ano and Agwu, 2005).

The initial OC in calcareous soil was 0.70% (Table II). After 15 days of incubation, OC levels increased across all treatments compared to the control, continuing to rise up to 45 days. The OC values ranged from 0.73-0.94% at 15 days, 0.78-0.98% at 30 days, 0.90-1.20% at 45 days, followed by a slight decrease to 0.86-1.05% at 60 days, 0.73-0.96% at 75 days, and finally 0.63- 0.77% at 90 days. Treatments S_2T_4 and S_2T_6 consistently maintained higher organic carbon levels throughout the incubation, particularly at the 90-days of incubation (Fig. 6). The transient accumulation followed by reduction suggests that organic carbon from amendments was rapidly mineralized under favorable pH and moisture conditions.

In the mixed soil, the initial value of organic carbon content was 0.54%. The contrast between the ranges of organic carbon content was 0.21%, 0.2%, 0.335%, 0.349 %, 0.218% and 0.25% during 15, 30, 45, 60, 75, and 90 days of incubation, respectively. Practically every one of the treatments showed excellent outcomes in the event of mixed soils. The higher content of organic carbon after the 45 days of incubation was recorded by the treatment S_3T_6=BPL_{10} which dropped down after the end of the incubation study (Fig. 7). The pattern shows an initial accumulation of decomposable organic matter, followed by microbial breakdown and stabilization. The higher organic carbon observed in treatments receiving burnt poultry litter is consistent with their greater content of decomposable organic matter. Tricho-compost induced comparatively lower OC increases due to its slower decomposition rate and lower labile carbon content. These patterns are consistent with previous studies documenting short-term increases in OC followed by gradual declines under incubation conditions, which reflects microbial mineralization and carbon cycling dynamics (Aboukila *et al.* 2024). These findings emphasize that repeated or continuous application of organic amendments may be necessary to

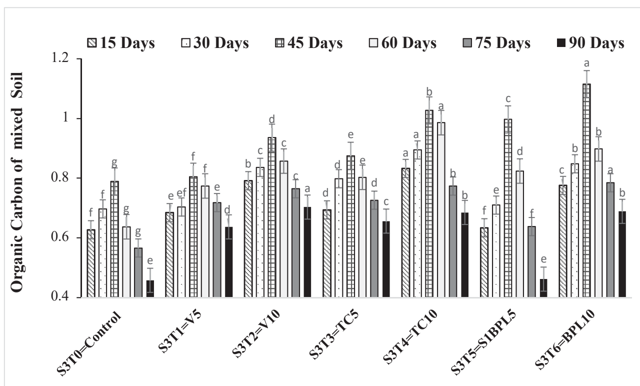

Fig. 7. Changes in organic carbon content in mixed soil at different time intervals as influenced by the application of different organic fertilizers in the incubation study

maintain higher soil OC over time, particularly in soils subject to alternating wetting and drying cycles.

Cation exchange capacity (CEC): Cation exchange capacity is a key soil property that reflects the ability of soil colloids to retain and supply essential cations, directly influencing fertility and productivity (Yunan *et al.* 2018). In this study, organic fertilizer application significantly ($p \leq 0.05$) increased soil CEC across all soil types compared to the control.

The initial CEC was 3.60 cmol kg^{-1} in acid soil (Table II), which increased steadily throughout the 90-day incubation under alternate wetting and drying. The highest CEC was recorded under treatment S_1T_4 (TC_{10}), where tricho-compost outperformed other amendments. This enhancement is attributed to tricho-compost's inherently higher CEC and its capacity to improve nutrient retention through the addition of organic colloids (Table V).

In calcareous soil, initial CEC was 20.05 cmol kg^{-1}.It went up slowly from 20.13-24.16 cmol kg^{-1} at 15 days to 21.22-25.01 cmol kg^{-1} at 90 days. The greatest increase occurred under treatment S_2T_4 (TC_{10}) (Table V) which reflected substantial improvement toward the optimum range for Bangladeshi agricultural soils (~25 cmol kg^{-1}). These findings are consistent with Schjønning *et al.* (1994), who reported similar CEC enhancement following organic fertilization.

In the mixed soil (1:1 acid:calcareous), initial CEC (13.05 cmol kg^{-1}) rose significantly ($p \leq 0.05$) over time. The CEC value was 16.75 cmol kg^{-1} after 90 days, with S_3T_4 (TC_{10}) showing the highest increase. The improvement likely resulted from enhanced retention of exchangeable cations on organic colloids (Radulov *et al.* 2011) and increased soil organic carbon, which is a primary contributor to CEC (Rashidi and Seilsepour, 2008). The superior performance of tricho-compost across soils is mechanistically linked to its abundance of functional groups (-COOH, -OH) and biologically active components. These provide additional negative

Table V. Changes in CEC values in different soils at different time intervals as influenced by the application of different organic fertilizers in the incubation study (cmol kg^{-1})

Treatment	Incubation days					
Denotation						
S_1T_0=Control	3.81 g	3.84 g	3.86 f	3.87 g	3.95 g	4.02 g
S_1T_1=V_5	4.23 g	4.24 e	4.25 e	4.52 e	4.59 e	4.66 e
S_1T_2=V_{10}	5.51 b	5.51 b	5.53 b	5.98 b	6.28 b	6.57 b
S_1T_3=TC_5	4.45 d	4.46 d	4.51 d	4.72 d	4.81 d	4.87 d
S_1T_4=TC_{10}	6.57 a	6.58 a	6.66 a	6.85 a	6.91 a	6.99 a
S_1T_5=BPL_5	4.19 f	4.23 f	4.25 e	4.39 f	4.41 f	4.45 f
S_1T_6=BPL_{10}	4.87 c	4.88 c	4.98 c	5.56 c	5.79 c	6.02 c
S_2T_0=Control	20.13 g	20.14 g	20.14 g	20.69 g	20.77 g	21.22 g
S_2T_1=V_5	21.10 e	21.11 e	21.24 e	21.50 e	21.61 e	21.62 e
S_2T_2=V_{10}	23.53 b	23.56 b	23.59 b	23.78 b	23.85 b	23.87 b
S_2T_3=TC_5	21.40 d	21.41 d	21.50 d	21.80 d	21.81 d	21.83 d
S_2T_4=TC_{10}	24.16 a	24.17 a	24.22 a	24.68 a	24.96 a	25.01 a
S_2T_5=BPL_5	20.56 f	20.57 f	20.64 f	21.09 f	21.22 f	21.44 f
S_2T_6=BPL_{10}	22.88 c	22.89 c	22.72 c	22.87 c	22.96 c	23.11 c
S_3T_0=Control	13.56 f	13.5 f	13.66 f	13.99 g	14.23 f	14.62 f
S_3T_1=V_5	13.78 e	13.88 e	13.93 e	14.73 e	15.37 c	15.6 c
S_3T_2=V_{10}	14.83 b	14.85 b	14.99 b	15.38 b	15.66 b	15.89 b
S_3T_3=TC_5	14.09 d	14.11 d	14.12 d	15.23 d	15.33 d	15.47 d
S_3T_4=TC_{10}	15.26 a	15.19 a	15.2 a	16.36 a	16.57 a	16.75 a
S_3T_5=$S1BPL_5$	13.35 g	13.36 g	13.45 g	14.33 f	14.58 e	14.84 e
S_3T_6=BPL_{10}	14.20 c	14.24 c	14.33 c	15.26 c	15.38 c	15.47 d

Different letters in the same column indicate significant ($p \leq 0.05$) statistically differences by Tukey's test charges for cation adsorption and foster the formation of humic substances with high surface reactivity. The Trichoderma inoculum further accelerates organic matter decomposition, promoting humification and creating new exchange sites. In acid soils, this activity aids in neutralizing proton acidity, while in calcareous soils, localized micro-acidification enhances micronutrient solubility (Maffia *et al.* 2024).

Conclusion

Tricho-compost proved to be an effective and sustainable amendment to improve degraded soils, particularly acid, calcareous, and mixed soils. Its application optimized soil pH (6.0-7.0) and several soil fertility indicators, including organic matter, cation exchange capacity, electrical conductivity, and nutrient availability. These enhancements indicate greater buffering capacity and nutrient retention, which may also increase microbial processes, especially under alternate wetting and drying conditions. In comparison to vermicompost and poultry litter, tricho-compost consistently produced more favorable changes in soil properties. It highlights its potential as a sustainable option for rehabilitating degraded soils. Although the current study concentrated on soil chemical dynamics, field trials are still necessary to validate the implications for crop performance. Therefore, to confirm the agronomic benefits of tricho-compost, future work should examine nutrient release dynamics and plant responses under realistic cropping systems.

Acknowledgment

The authors acknowledge the Ministry of Environment, Forest and Climate Change (MoEFCC) of the Government of the People's Republic of Bangladesh for financing the project (2017 to 2020; No cost extension till June 2023, codes: DU 410 & 573) entitled ‘Assessment of Impacts of Climate Change on Soil Health and Food Security and Adaptation of Climate-smart Agriculture in Most Adversely Affected Areas of Bangladesh’ through the Climate Change Trust Fund (CCTF). They also express gratitude to the Ministry of Science and Technology for conferring the NST fellowship to the first author.

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