J. Asiat. Soc. Bangladesh, Sci. **51**(1): 73-86, June 2025
DOI: http://doi.org/10:3329/jasbs.v51i1.82792

COMPARATIVE EFFECTS OF SOME ORGANIC AMENDMENTS ON ACIDIC SANDY LOAM SOIL: *IN VITRO* STUDY

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Abstract

An incubation study was conducted to investigate the effects of four organic amendments (e.g., banana peel, BP; eggshell, ES; tea waste, TW; and vermicompost, VC) on chemical properties of an acidic sandy loam soil. Three incubation periods *viz.* 38, 120, and 240 days (d) and two rates, e.g., 4% and 8% (w/w) of amendments with three replicates were considered. Amendments and incubation time had significant impacts on soil chemical properties. It was revealed that soil pH, EC, OC, TN, extractable P, K, Ca, Mg, Fe, Cu, Mn, and Zn were increased in most of the amended soils. However, ES had no impact on TN and K. Moreover, it decreased micro-nutrients concentrations. BP and TW had no impact on Ca and Cu, respectively. Soil pH raised (> 8.0) in ES and BP amended soils. Highest OC was recorded in VC and TW amended soils. Highest EC, P, Mg, and micronutrients, except Fe, was recorded in VC amended soils. Both K and Fe was highest in BP; and Ca was highest in ES amended soils. Overall, soil pH, OC, TN, extractable K, Mg, Cu, and Mn significantly reduced with incubation time. In contrast, soil EC, extractable P, Fe, and Zn increased.

Key words: Sandy loam soil, Incubation, Organic amendments, Cost-effective, Extractable nutrients, Bangladesh.

Introduction

Sandy loam soils are poorly fertile soils because of low moisture, low organic matter and poor nutrients content. These soils occupy mostly the southeastern parts of Bangladesh (Huq and Shoaib, 2013). Not only in Bangladesh, in many regions of the world, the marginal and nutrient-deteriorated soils are often used for crop production only after large quantities of chemical fertilizers are applied (Manyanga *et al.*, 2024). Suitability of sandy loam soils for crop cultivation become even worse when they are acidic. In Bangladesh, satisfying food demand for a large population is challenging while land resources are very limited. Soil fertility is declining day by day due to extreme utilization

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of artificial fertilizers without paying much attention to soil health. Therefore, it is urgent to nourish the poorly fertile soils in a way that will protect them from any sorts of degradation. Use of eco-friendly organic amendments (OAs) could be the solution in this regard. Application of OAs to infertile soils could bring suitable physical, chemical, and biological conditions for crop production if are provided in a rational way. In this *in vitro* study, four cost-effective, easily available, and environment-friendly organic amendments e.g., banana peel (BP), eggshell (ES), tea waste (TW), and vermicompost (VC), were selected for organically modification of an acidic sandy loam soil, collected from Chittagong University campus.

Previously, many studies showed that OAs, often with chemical fertilizers, were efficient in improving soil reaction (Candemir and Gülser 2011); and other chemical properties (Ch'Ng *et al.,* 2014; Chen *et al.,* 2018; Anwar *et al.,* 2018). The BP, ES, and TW are relatively new soil modifiers that have been used recently, while VC has been widely used over few decades. Literatures on the effects of BP, ES, and TW on soil properties seemed to be very limited. However, research showed that BP wastes and its biochar was effective in improving soil bio-chemical properties (Sial *et al.,* 2019a). Banana wastes could also reduce heavy metals like Cd, Pb, and Cu in contaminated soil (Wedayani *et al.,* 2024). The ES powder was effective in treating acid mine drainage effluents and increased soil pH and basic cations (Luo *et al.,* 2018; Muliwa *et al.,* 2018; Mahajabin *et al.,* 2019). It also effectively reduced heavy metals in soils (Ok *et al.,* 2011a; Almaroai *et al.,* 2014). Toxic metals uptake was reduced by TW-biochar application (Peiris *et al.,* 2022). The VC amended soils showed increases in OM, TN, pH, EC, available P, K, Ca and Mg but decreases in DTPA-extractable metals (Angelova *et al.,* 2013). Again, soil pH, OC, N, available P, and micronutrients increased with VC application rate in drylands of Ethiopia (Teka *et al.,* 2024; Terefe *et al.,* 2024). Overall, crops grown under organic farming system contained more nutritional values than crops grown in artificially fertilized soils (Mi *et al.,* 2018; Hernandez *et al.,* 2021).

Amendment's effects on soil depends on amendment type, its application dose, characteristics of soil treated, and incubation time. Due to chemical compositional variability in OAs, it is unrealistic that amendments used in the present study would have similar impact on soil chemical properties. Hence, to obtain desired soil characteristics for crop production, proper selection of OAs is important. In this study, we used different organic materials for soil amendment to compare their impacts on a locally present sandy loam soil. We hypothesized that application of OAs to such soil could have positive impacts on chemical soil properties. Therefore, the objectives of this study were: i) to assess the characteristics of OAs, ii) to compare the effects of OAs on soil pH, EC, OC, TN, and extractable macro- and micro-nutrients, and iii) to observe the effects of incubation time on selected soil properties.

Materials and Methods

Materials description: Dried pieces of ripen banana peel (BP), poultry eggshell (ES), and tea waste (TW) was ground by a grinder machine to get powder form; however, cow-dung derived vermicompost (VC) was used in its original but air-dried condition. OAs were passed via a 2 mm sieve before storage. Sandy loam soil was collected from mineral horizon (0-15 cm) of a field at Chittagong University campus (22°46′N; 91°78′E), Bangladesh. Soil was developed under tropical climatic conditions with 1551 mm mean annual precipitation and 26°C mean annual temperature. This soil belongs to 'Brown Hill soils' (FAO/UNDP, 1988). World Reference Base (WRB) classified these type of soils as Dystric Cambisols, Haplic and Ferric Alisols. Soil was disintegrated, air-dried, and passed via a 2 mm sieve. The OAs and initial sandy loam soil were investigated for several parameters (Table 1).

Experimental design: A 240 d incubation study was conducted on sandy loam soil under controlled condition at ~25°C. Experimental design was randomized complete block (RCB) with 9 treatments, 3 replications, and 3 incubation time. Treatments were control (unamended soil), BP4% (banana peel 4%), BP8% (banana peel 8%), ES4% (eggshell 4%), ES8% (eggshell 8%), TW4% (tea waste 4%), TW8% (tea waste 8%), VC4% (vermicompost 4%), and VC8% (vermicompost 8%). Exactly, 315 g soil (dry weight) was mixed with each treatment on a clean tray before transferring to 500 mL plastic jars with perforated lids. Field capacity of soil was maintained with distilled water throughout the study. At 38, 120, and 240 d soil samples were taken out from jars (27 ×3 = 81 jars) for air-drying. Soils that were not analyzed immediately, were kept in refrigerator.

Laboratory analyses: OAs were scanned via wavelength dispersive X-ray fluorescence (XRF) spectrometer (Rigaku ZSX Primus IV) for rapid investigation of elements (Musa *et al.*, 2021). XRF showed high efficiency in nutrients analyses in many OAs and composts (López-Núñez 2022). Particle size distribution was analyzed following hydrometer method. Soils were investigated for pH, EC, OC, TN, extractable P, Ca, Mg, K, Fe, Cu, Mn, and Zn. pH of soil:water suspension (1:2.5, w/v) and of amendment:water suspension (1:10, w/v) was measured by digital pH meter (Adwa, AD1020). EC (using suspension of 1:5 soil:water (w/v), and 1:10 amendment:water (w/v)) was measured by portable EC meter (Adwa, AD330). The OC was determined followed by wet-oxidation method (Walkley and Black 1934). The TN was determined followed by micro-Kjeldahl digestion and distillation. Extractable P determination followed Bray & Kurtz extraction (Bray and Kurtz 1945), and ascorbic acid blue color method (Murphy and Riley, 1962). Samples were extracted with 1 N NH_4OAC at pH 7.0 for Ca, Mg, and K; and with DTPA for Fe, Cu, Mn and Zn measurement. Concentrations of elements in extracts were determined by Shimadzu AA-7000® atomic absorption spectrophotometer (AAS).

Table 1. Characteristics of the OAs and initial soil used in the present study.

Characteristics	BP	ES	TW	VC	Initial soil
Minerals identified by XRD	-	-	-	-	Quartz, albite, muscovite
Sand (%), Silt (%), Clay (%)	-	-	-	-	69, 15, 16
Moisture (%)	7.4	0.5	4.6	8.25	2.0
$pH_{(in\ water)}$	8.8	8.5	5.3	6.5	4.85
EC (dS m^{-1})	7.38	0.30	1.08	3.79	0.103
OC (%)	24.2	1.28	20.43	9.08	0.39
Total N (%)	1.34	0.12	1.4	0.95	0.02
Total P (g kg^{-1})	11.6	1.86	17.5	17.6	-
Total K (g kg^{-1})	580	1.0	129	83.2	-
Total Ca (g kg^{-1})	88.1	691	265	68.7	-
Total Mg (g kg^{-1})	14.6	4.16	26.8	19.0	-
Total Fe (g kg^{-1})	10.9	0.29	30.7	139	-
Total Cu (g kg^{-1})	ND	ND	3.19	0.44	-
Total Mn (g kg^{-1})	9.14	ND	60.8	12.5	-
Total Zn (g kg^{-1})	2.68	ND	5.74	2.22	-
Extractable P (mg kg^{-1})	-	-	-	-	6
Extractable K (mg kg^{-1})	-	-	-	-	35
Extractable Ca (mg kg^{-1})	-	-	-	-	122
Extractable Mg (mg kg^{-1})	-	-	-	-	65
Extractable Fe (mg kg^{-1})	-	-	-	-	38
Extractable Cu (mg kg^{-1})	-	-	-	-	0.32
Extractable Mn (mg kg^{-1})	-	-	-	-	9.3
Extractable Zn (mg kg^{-1})	-	-	-	-	1.3

Note. Elements that were beyond detection limit by XRF were indicated as ND i.e., Not detected.

Statistical analysis: Data were analyzed using SAS software version 9.4 and Microsoft Excel 2010. A two-way Analysis of Variance (ANOVA) was performed to test effects of treatments and incubation times on soil properties. Treatment and incubation time means was considered statistically significant at $P < 0.05$, according to Tukey's test.

Results and Discussion

Soil pH, EC, OC and TN: Amendments, incubation time, and their interaction had significant influence on soil pH, EC, OC and TN (Table 2). Overall, OAs increased soil pH, EC, OC and TN compared to control, except ES, which had no impact on TN (Table 2). The extent of increment depended on amendment type and application rate. Highest value was obtained with highest rate. Soil parameters increased because OAs were higher in pH, EC, OC, and TN than that of initial soil (Table 1). The BP and ES increased soil pH up to 8.5 similar to previous study (Ashrafi *et al.,* 2015). High pH could be due to high to medium K, Ca, and Mg in BP; and extremely high Ca in ES (Table 1). BP and ES was thus efficient in ameliorating soil acidity (Zhang *et al.,* 2023; Gurmessa 2021; Luo *et al.,* 2018). Despite having a pH 6.5, and considerable quantities of Ca and Mg in VC, it did not increase soil pH to that extent. The presence of high-soluble salts in VC could depress soil pH (Naramabuye and Haynes 2006) but remarkably increased soil EC (Demir 2019). EC in amended soils (except BP8%) didn’t surpass critical limit of 4 dS m^{-1}, which is in agreement with others (Angelova *et al.,* 2013; González *et al.,* 2010; Demir 2019). High EC in BP amended soils could be due to presence of high total K in BP. Overall, OC content was almost similar among the amended soils, except ES treated soil (Table 2). However, at least 2% OC (a major threshold for soil OC) was maintained in TW and VC amended soils at higher application rate (Ouda and Mahadeen 2008; Teka *et al.,* 2024). As expected, highest TN in TW amended soils was due to highest TN in TW (Candemir and Gülser 2011). Increased OC resulted in increased TN content (Angelova *et al.,* 2013; Demir 2019).

Overall, soil pH, OC, and TN was significantly decreased but EC increased during incubation period (Table 2). More specifically, soil pH, EC, OC and TN showed variable trends during incubation depending on amendments type (Fig. 1). Soil pH slightly decreased over incubation period in control and in VC but remarkably decreased in TW amended soils at 120 d (Fig. 1a). A decline of pH might be attributed to NH^{4+}, CO_2, H^+ production and release of various organic acids from organic matter mineralization (Thite *et al.,* 2022). Soil pH seemed stable in BP and ES amended soils (Fig. 1a). This could be due to excellent buffering capacity of BP and ES. Gradual EC increment in all soils (Fig. 1b) could be attributed to release of bases and soluble salts from decomposing amendments (Thite *et al.,* 2022). Overall, soil OC and TN showed a decreasing trend over incubation period for all treatments (Fig. 1c and Fig. 1d). Decrease of OC and TN reflected the mineralization of the amendments with time. Soil OC in organically amended Inceptisols started to decrease at 30 d of incubation (Thite *et al.,* 2022).

Table 2. Effects of amendments and incubation time on soil pH, EC, OC, and TN.

	pH	EC	OC	TN
		dS m^{-1}	%	
Amendment				
Control	4.05 ± 0.52 g	0.17 ± 0.03 g	0.33 ± 0.06 g	0.05 ± 0.02 e
BP4%	7.37 ± 0.15 b	1.44 ± 0.28 e	1.27 ± 0.33 e	0.11 ± 0.04 d
BP8%	8.50 ± 0.36 a	3.11 ± 0.90 b	1.77 ± 0.42 c	0.16 ± 0.05 b
ES4%	7.93 ± 0.15 b	0.37 ± 0.13 f	0.54 ± 0.11 f	0.04 ± 0.02 e
ES8%	8.17 ± 0.35 b	0.47 ± 0.29 f	0.61 ± 0.12 f	0.05 ± 0.02 e
TW4%	4.57 ± 1.86 f	1.36 ± 0.39 e	1.54 ± 0.36 d	0.14 ± 0.03 c
TW8%	5.37 ± 1.10 d	1.71 ± 0.68 d	2.25 ± 0.66 a	0.20 ± 0.07 a
VC4%	5.03 ± 0.51 e	2.29 ± 0.24 c	1.79 ± 0.52 d	0.16 ± 0.03 c
VC8%	5.27 ± 0.42 e	3.68 ± 0.37 a	2.05 ± 0.06 b	0.18 ± 0.01 a
Incubation time (T, days)				
38	6.80 ± 1.33 a	1.33 ± 1.07 c	1.65 ± 0.86 a	0.15 ± 0.05 a
120	6.19 ± 1.89 b	1.51 ± 1.11 b	1.23 ± 0.63 b	0.11 ± 0.06 b
240	5.87 ± 2.04 c	2.04 ± 1.37 a	1.18 ± 0.65 b	0.11 ± 0.05 b
Source of variation				
Amendment (A)	***	***	***	***
Incubation time (T)	***	***	***	***
A × T	***	***	***	***

Note: Values are mean ± standard deviation of three replications. Means followed by different lowercase letters are significantly different (within amendment or incubation time) at $P < 0.05$ (Tukey's test). ***, significant at the 0.001 probability level.

Extractable P, K, Ca, and Mg: Amendments, incubation time, and their interaction had significant impact on soil extractable P, K, Ca, and Mg, excepting that incubation time had no impact on Ca variation (Table 3). Compared to control, most of the treatments enhanced soil macro-nutrients to the extent of their respective element content, and their application rate (Table 1 and Table 3). Accordingly, highest P, K, and Ca was observed with VC, BP, and ES applications, respectively. ES had no significant impact on K, and BP had no significant impact on Ca. Enrichment in amended soils suggested the release

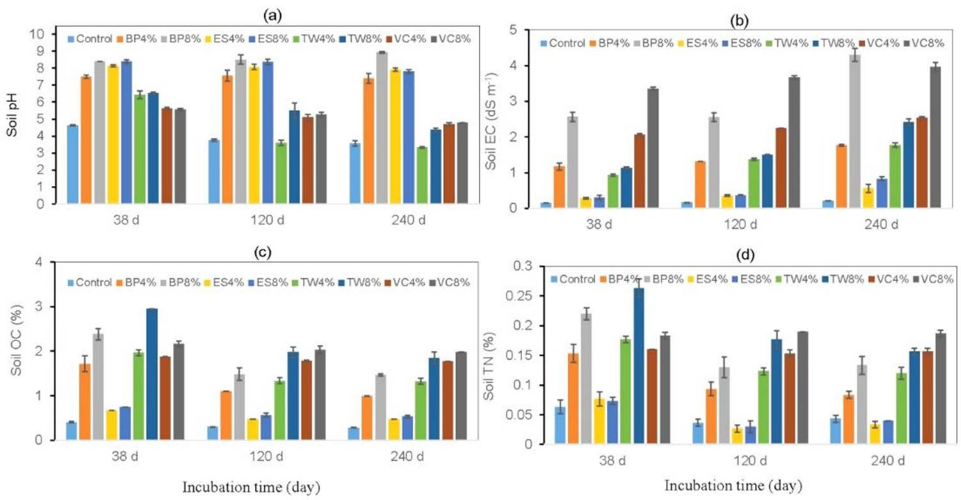

Fig. 1. Variation in Soil pH (a), EC (b), OC (c) and TN (d) during 240 days incubation. Bars represent standard errors of the mean (*n*=3).

of available plant nutrients from the amendments during incubation. ES and TW showed least impact on P, whereas VC8% contributed to ~94% increase in extractable P over control. Large fraction of P in VC could remain in labile form (López *et al.*, 2021). Soil P increment with increased VC rate proved its efficiency as P supplement in Ethopian sandy soil (Teka *et al.*, 2024). In acid soil, P might increase due to OAs application as they raised soil pH, which allowed Al or Fe fixation instead of P (Ch'Ng *et al.*, 2014). BP8% contributed to ~96% increment in K. Research showed BP and its biochar remarkably accelerated soil available K (Panwar 2015; Islam *et al.*, 2019). ES8% contributed to ~90% increase in Ca over control because of its extraordinary Ca level. Surprisingly, though VC contained relatively lower amount of total Ca among amendments, it supplied greater extractable Ca than BP or TW did. This suggested VC contained nutrients mostly in plant available forms (Angelova *et al.*, 2013). Highest extractable Mg in VC amended soils also reflected similar attribute.

Overall, P showed increasing trend until end of incubation. K and Mg decreased slightly. Ca seemed stable as was not impacted by incubation time (Table 3). More specifically, maximum P was observed at 240 d upon VC application followed by BP. P increment stopped at 120 d in TW amended soils, whereas P did not change in ES amended soils with incubation time (Fig. 2a). However, TW was unable to supply much extractable P as VC supplied. The dynamic of P release from VC suggested its high efficiency in correcting soil P deficiency. K was noticeably decreased only in VC amended soils, whereas it seemed stable in others (Fig. 2b). Often, available K can be fixed by soil minerals. Ca slightly increased in VC amended soils until 240 d (Fig. 2c). Gradual increase in Ca suggested slow release of Ca from VC (Dey et al. 2019). Mg seemed stable throughout the incubation study (Fig. 2d).

Table 3. Effects of amendments and incubation time on soil extractable P, K, Ca, and Mg.

	P	K	Ca	Mg
		mg kg^{-1}		
Amendment				
Control	12.23 ± 5.94 h	51 ± 7.80 g	101 ± 18.15 g	82 ± 13.84 g
BP4%	37.55 ± 2.42 d	961 ± 9.01 b	111 ± 6.11 g	188 ± 8.40 d
BP8%	75.97 ± 10.35 c	1344 ± 19.24 a	114 ± 15.10 g	212 ± 5.92 bc
ES4%	15.82 ± 2.46 g	61 ± 2.25 g	900 ± 27.50 b	86 ± 6.62 g
ES8%	16.43 ± 2.10 fg	61 ± 4.50 g	1028 ± 55.43 a	100 ± 5.23 f
TW4%	17.26 ± 3.21 f	173 ± 9.81 f	288 ± 10.58 f	182 ± 8.68 e
TW8%	27.67 ± 7.98 e	242 ± 14.06 e	397 ± 24.03 e	206 ± 9.70 c
VC4%	182.51 ± 9.23 b	345 ± 120.86 d	479 ± 111.18 d	214 ± 7.81 ab
VC8%	230.42 ± 21.00 a	480 ± 169.59 c	681 ± 111.88 c	218 ± 3.17 a
Incubation time (T, days)				
38	60.93 ± 75.11 c	459 ± 445 a	450 ± 340.86 a	167 ± 58.58 a
120	68.37 ± 75.57 b	397 ± 449 b	462 ± 331.74 a	166 ± 55.81 a
240	75.64 ± 84.28 a	393 ± 437 b	460 ± 339.46 a	163 ± 55.00 b
Source of variation				
Amendment (A)	***	***	***	***
Incubation time (T)	***	***	**NS**	***
A × T	***	***	***	***

Note: Values are mean ± standard deviation of three replications. Means followed by different lowercase letters are significantly different (within amendment or incubation time) at $P < 0.05$ (Tukey's test). ***, significant at the 0.001 probability level.

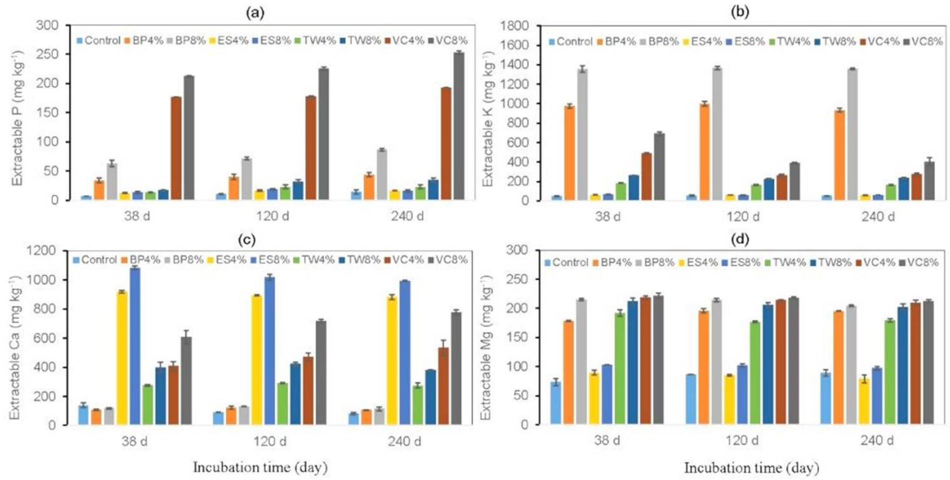

Fig. 2. Variation in soil extractable P (a), K (b), Ca (c) and Mg (d) during 240 days incubation. Bars represent standard errors of the mean (*n*=3).

Extractable Fe, Cu, Mn, and Zn: Amendments, incubation time, and their interaction had significant impact on DTPA extractable Fe, Cu, Mn, and Zn (Table 4). Overall, amendments, except ES, increased Fe, Cu, Mn, and Zn content to the extent of their application rate. Study revealed that ES was highly effective in minimizing micro-nutrients (metals) in soil. This was probably due to alkaline condition in ES amended soil, favorable for metal immobilization (Ashrafi *et al.,* 2015; Luo *et al.,* 2018). However, despite high pH in BP amended soil, Fe, Cu, Mn, and Zn was still higher than ES amended soil because BP naturally contained more of these elements than ES (Table 1). Banana stem amendment did not decreased Pb and Zn in sandy soil (pH 7.83) but ES decreased (Ashrafi *et al.,* 2015). Several other factors also control metal immobilization (Ruttens *et al.,* 2010; Zhou *et al.,* 2012; Houben *et al.,* 2012). TW addition increased Fe, Mn, and Zn but had no impact on Cu. At least 60% Fe increment in BP8% and TW8% amended soils suggested that both amendments were potential in releasing bio-available Fe. TW supplied higher extractable Mn as contained highest total Mn among amendments. VC showed highest efficiency in increasing Cu, Mn, and Zn (Table 4). Surprisingly, despite high Fe content in VC (Table 1), extractable Fe did not increased with its application. Moreover, Fe declined with increased addition of VC. This could be due to complex formation of Fe as insoluble $FePO_4$ in VC amended soil.

Table 4. Effects of amendments and incubation time on DTPA soil extractable Fe, Cu, Mn, and Zn.

	Fe	Cu	Mn	Zn
		mg kg^{-1}		
Amendment				
Control	40.98 ± 0.08 d	0.31 ± 0.03 d	12.56 ± 1.99 g	1.61 ± 0.10 f
BP4%	75.74 ± 29.51 b	0.38 ± 0.07 c	13.18 ± 5.12 f	1.70 ± 0.17 e
BP8%	113.33 ± 53.57 a	0.52 ± 0.15 b	23.71 ± 1.62 e	2.63 ± 0.18 c
ES4%	6.81 ± 2.54 f	0.20 ± 0.03 e	0.31 ± 0.12 h	0.47 ± 0.14 g
ES8%	5.71 ± 2.19 f	0.16 ± 0.01 e	0.30 ± 0.17 h	0.47 ± 0.12 g
TW4%	45.15 ± 23.61 c	0.32 ± 0.02 d	42.11 ± 13.89 d	2.27 ± 0.71 d
TW8%	109.18 ± 53.66 a	0.31 ± 0.02 d	57.05 ± 5.59 c	2.24 ± 0.55 d
VC4%	42.11 ± 12.97 d	0.52 ± 0.08 b	67.52 ± 27.05 b	5.69 ± 0.21 b
VC8%	26.05 ± 7.49 e	0.76 ± 0.28 a	123.00 ± 46.94 a	6.11 ± 0.52 a
Incubation time (T, days)				
38	32.82 ± 19.43 c	0.41 ± 0.25 a	45.79 ± 55.98 a	2.55 ± 2.12 b
120	52.61 ± 42.77 b	0.36 ± 0.13 c	35.00 ± 32.69 b	2.55 ± 1.88 b
240	70.16 ± 56.04 a	0.38 ± 0.17 b	33.22 ± 30.97 c	2.66 ± 1.87 a
Source of variation				
Amendment (A)	***	***	***	***
Incubation time (T)	***	***	***	***
A × T	***	***	***	***

Note: Values are mean ± standard deviation of three replications. Means followed by different lowercase letters are significantly different (within amendment or incubation time) at $P < 0.05$ (Tukey's test). ***, significant at the 0.001 probability level.

Overall, Fe and Zn significantly increased but Cu and Mn decreased at 240 d of incubation (Table 4). However, these nutrients showed variable patterns with incubation time depending on types of amendments (Fig. 3). Fe was remarkably increased in BP and TW amended soils but slightly increased in VC amended soils. However, it was stable in ES amended soil (Fig. 3a). Though total Fe level was superior in VC among all (Table 1), extractable Fe content could be low in VC. Cu was ultimately decreased in VC and increased very slowly in BP amended soils at higher application rates at 240 d. It remained unchanged in ES and TW amended soils (Fig. 3b). Presence of high content of extractable Cu in VC could led faster Cu release during early stage of incubation (Fig. 3b). Slow increase of Cu in amended soils with time indicated low content as well as minimum release. Mn dramatically decreased with incubation time in VC amended soil but negligibly increased in TW amended soil. It remained stable in ES and BP amended soils (Fig. 3c). Highest extractable Mn in VC amended soils at 38 d indicated maximum content of readily available Mn in VC (Dey *et al.*, 2019). Variations in time-dependent Cu and Mn release could be attributed to formation of stable complexes of Cu and Mn with C fractions present in OAs in amended soils (Stevenson 1991). Mn stability in ES and BP amended soils was due to its poor content (below detection limit) in amendments (Table 1). With incubation period, extractable Zn was remarkably increased in TW treated soil, which was directly related with total Zn as well as higher extractable Zn content in TW (Table 1, Fig. 3d). Zn remained stable in other soils. This might be due to lower Zn content in the amendments.

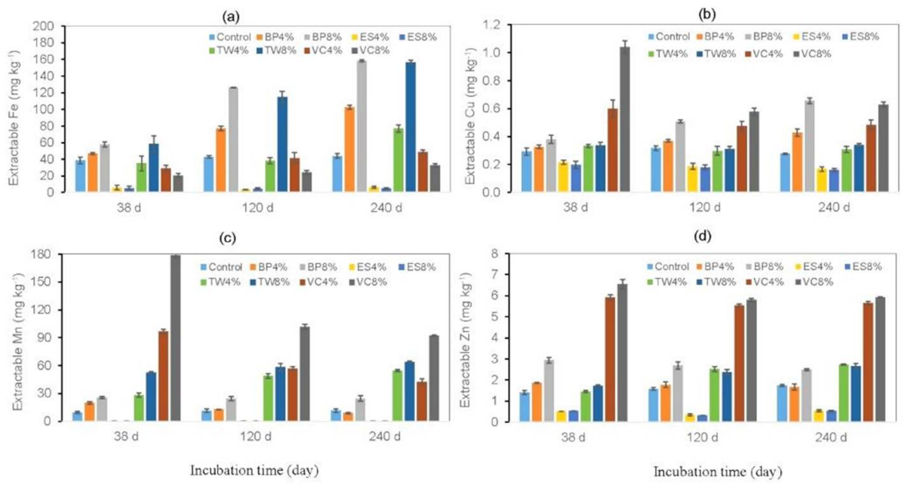

Fig. 3. Variation in soil extractable Fe (a), Cu (b), Mn (c) and Zn (d) during 240 days incubation. Bars represent standard errors of the mean (*n*=3).

Conclusion

In this study, organic amendments proved their significant efficiencies in improving chemical fertility of sandy loam soils. The amendments were cost-effective, eco-friendly, and easily accessible. The extent of impacts of amendments was dependent on amendment characteristics, their application rate, and incubation time. Overall, the amendments improved soil pH, EC, OC and nutrient properties. According to this study, TW and VC are suggested as the best choice for OC increment whereas, ES and BP are recommended for improving soil pH in acid soil. In heavy metals contaminated soils, ES can be highly effective in metal immobilization. Overall, VC is highly recommended for improving EC, soil P, and micronutrients. In future, field application of BP, ES, TW and VC is suggested to assess their potentiality for crop production. In conclusion, organic amendment selectivity is important considering the characteristics of soil to be treated.

Acknowledgement

This research was conducted in the laboratory of the Department of Soil Science, University of Chittagong, Bangladesh. A part of analyses was carried out in Soil Resources Development Institute (SRDI), Sylhet division. The first author acknowledges Professor Dr. Coskun Gülser, Ondokuz Mayıs University, Turkey for his valuable suggestions during manuscript writing.

Funding

This research received no specific funding from any institution or agency.

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(Revised copy received on 18/05/2025)