Comparative effects of different amendments on saline soils coupled with acidic reaction

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Abstract: The present experiment was carried out to study the changes in properties of soils having two different levels of salinity e.g., soil A (highly saline) and soil B (extremely saline) coupled with acidic reaction as affected different amendments e.g., vermicompost (VC), wood ash (WA) and zeolite (ZL) applied at the rate of 1% and 2% both singly and in combination. The ANOVA test revealed that the application of amendments caused significant ($p<0.01$) variation in pH and electrical conductivity (EC). While the concentrations of both available and total nitrogen (N) in soils were found to be highest when VC was applied either alone or in combination, the incorporation of WA either alone or in combination resulted in higher pH, EC, concentrations of available and total potassium (K), sulfur (S), calcium (Ca) and magnesium (Mg) in soils. The present findings suggested the application of VC alone with WA at the rate of 1% of each in saline soils coupled with acidic reaction in order to maintain proper nutritional balance and to bring the soil pH at the level suitable for nutrient availability.

1. Introduction

Saline soils contain salts high enough to inhibit normal growth of plants by a number of mechanisms e.g., osmotic stress, imbalance absorption of essential elements as well as toxicities of several elements (Brady and Weil, 2005; El Hasini *et al*., 2019; Roy and Chowdhury, 2021) affecting production of crops throughout the world (Etesami and Noori, 2019; Gull *et al*., 2019; Atemni *et al*., 2022). Salt-affected soils occupy approximately 20% of the agricultural lands (Etesami and Noori, 2019; Khan and Duke, 2001) covering more than 1100 million hectares area worldwide (Wicke *et al*., 2011). Soil salinity was found to strongly inhibit the biomass and yield of cabbage (Sahin *et al*., 2018), spinach (Xu, and Mou, 2016), tomato (Zhang *et al*., 2016). About 10–25% decline in the crop yield may be due to soil salinity (Shahid *et al*., 2018). The interaction of sodium (Na) and chlorine (Cl) with that of nitrogen (N), phosphorus (P), sulfur (S), potassium (K), calcium (Ca) and magnesium (Mg) in saline soils can retard plant growth due to limited availability, transport and partitioning of nutrients (Cramer, 2002; Sahin *et al*., 2018; Tester and Davenport, 2003).

Several approaches including leaching practices, incorporation of organic and inorganic amendments have recently been practiced to ameliorate the physical, chemical and microbial

complications of saline soils. Vermicompost (VC) is a stabilized, finely divided peat-like microbiologically-active organic fertilizer that can be prepared from such organic substances as animal dung, municipal sewage sludge and domestic waste (Pirsaheb *et al.*, 2013) by the activity of epigeic earthworms (Suthar and Singh, 2008). The application of VC has recently been practiced to enhance soil fertility and plant growth (Domínguez, 2004; Wang *et al.*, 2014). The addition of VC was found to enhance the growth, yield and uptake of nutrients in beans (Manivannan *et al.*, 2009), spinach (Roy and Chowdhury, 2022). Wood ash (WA), by-product of wood incineration, is well-known as an acid neutralizing substance and can be used to improve the availability of nutrients in soil (Bang-Andreasen *et al.*, 2017; Bougnom *et al.*, 2011; Gómez-Rey *et al.*, 2012). Zeolite (CaAl$_2$Si$_4$O$_{12}$. nH$_2$O), an aluminosilicate, is recently used as an inorganic amendment with the aim to reclaim salt-affected soils and enhance plant growth (Al-Busaidi *et al.*, 2008).

Though the effects of VC, WA and ZL applications in soils have been examined in separate studies, their effects as single and/ or combined applications on the physico-chemical properties of acidic saline soils have not yet been studied. Therefore, the present study was conducted to observe the effects of single and combined applications of VA, WA and ZL on the physico-chemical properties of two different levels of saline soils coupled with acidic reaction.

2. Methodology
2.1 Collection and processing of soils and amendments

Bulk top soil samples (0–15 cm) were collected from two different sites [hereinafter referred to as soil A (22°10'24.2"N 91°49'59.1"E) and soil B (22°09'08.4"N 91°50'29.6"E)] of Anowara Upazila (*a sub-unit of District*) which is located in the south-eastern part of Chattogram District (**Figure 1**). Soil A belongs to cultivated land with two cropping season a year, whereas soil B has a history of no crop cultivation for the last 15 years due to extreme soil salinity. The ECe of soil A was in the range of 8-16 mS cm^{-1} and classed as highly saline soil, whereas the ECe of that of soil B was greater than 32 mS cm^{-1} and classed as extremely saline soil (Hardie and Doyle, 2012). Before collecting the soil samples, the upper plant residues were removed with the help of a spade. After collection, soil samples were brought to the laboratory of the Department of Soil Science, University of Chittagong, Bangladesh for processing. Soil samples were dried at room temperature for few days. Visible dried grassroots were manually removed. After drying for few days and breaking down the bulk soil samples with a wooden hammer, soil samples were sieved through 4 mm stainless steel mesh. An amount of 2 kg sieved soil samples were well mixed with VC, WA and ZL at the rate of 1% and 2% both singly and in combination for the pot experiment with spinach (results have not been presented here). Amendments were homogeneously well mixed with soils 2 weeks before sowing of spinach seeds. The incorporation of amendments at different combinations and rates resulted 14 different treatments (**Table 1**). Fourteen different treatments with 3 replications were arranged at completely randomized ways in the net house at the Department of Soil Science, University of Chittagong. During growing period, pot soils were irrigated to maintain water at roughly 70% field capacity by weighting the pots 2-3 days intervals. After harvesting of spinach at the age of 35 days, the soil samples in each pot hereinafter referred to as after harvest soils (AHS) were well mixed and sub-samples were collected by the quartering method as described in Hesse (2002). The AHS were dried at room temperature for several days and then passed through a 2 mm stainless sieve. The sieved soil samples were analyzed to examine different physico-chemical properties as affected by different amendment application.
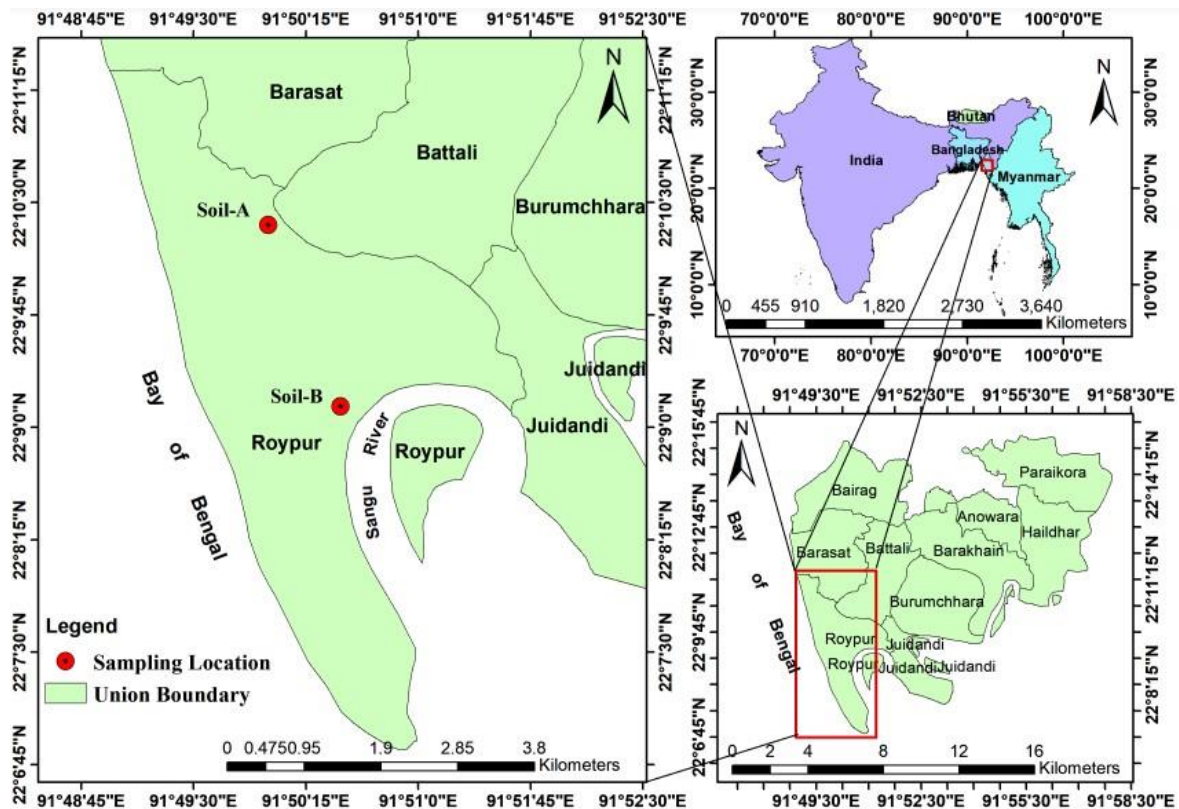
Figure 1. Location of the sampling sites (soil A and soil B) in the study area

Table 1. Treatment legends and their description

Treatment legend	Treatment description
T1	Non-amended soil (control)
T2	Soil + N-P-K
T3	Soil + N-P-K + VC (1%)
T4	Soil + N-P-K + WA (1%)
T5	Soil + N-P-K + ZL (1%)
T6	Soil + N-P-K + VC (1%) + WA (1%)
T7	Soil + N-P-K + VC (1%) + ZL (1%)
T8	Soil + N-P-K + WA (1%) + ZL (1%)
T9	Soil + N-P-K + VC (2%)
T10	Soil+ N-P-K + WA (2%)
T11	Soil + N-P-K + ZL (2%)
T12	Soil+ N-P-K + VC (2%) + WA (2%)
T13	Soil+ N-P-K + VC (2%) + ZL (2%)
T14	Soil + N-P-K + WA (2%) + ZL (2%)

Vermicompost of cow manure (hereinafter referred to as VC), prepared by composting cow manure and banana plants (80:20, w/w) using earthworm *Eisenia fetida*, was collected from an organic farm. Wood ash was prepared by burning of woods in mud stoves and calcium-type ZL ($CaAl_2Si_4O_{12}\cdot nH_2O$), distributed by National Agricare of Indonesia, was collected from local market. All the amendments were passed through a 2 mm stainless sieve. The characteristics of initial bulk soils *i.e.*, soil A and soil B as well as amendments are given in **Table 2**. Both soil A and soil B were acidic in reaction and clay loam in texture. Among the amendments, WA had highest pH and EC values.

Table 2. Initial characteristics of soils and amendments

Parameter	Soil A	Soil B	VC	WA	ZL
pH	5.01	5.22	7.89	11.77	7.47
EC (mS cm^{-1})	9.25	37.64	1.92	11.27	3.09
OC (%)	1.20	1.11	18.06	0.17	0.17
Sand (%)	34.0	31.0	-	-	-
Silt (%)	39.0	42.0	-	-	-
Clay (%)	27.0	27.0	-	-	-
Textural class	Clay loam	Clay loam	-	-	-
Total N (%)	0.23	0.17	2.01	0.1	0.1
Total P (%)	0.25	0.19	0.49	1.16	0.12
Total K (%)	1.67	2.17	2.34	4.13	1.81
Total Ca (%)	0.27	0.31	2.56	10.4	3.04
Total Mg (%)	0.34	0.63	0.42	1.28	0.88
Total Na (%)	0.38	0.67	-	0.11	0.47

2.2 Methods of analysis

The suspension for pH and EC of soil samples and ZL were prepared at 1:5 soil to water ratio (w/v), whereas that of VC and WA were prepared at 1:10 ratio (w/v) (Yue *et al*., 2016) and measured by pH meter (Seven CompactTM pH/Ion S220) and EC meter (Adwa AD 330) meter. The EC$_{1:5}$ of soil samples was converted to ECe by multiplying a conversion factor of 8.6 (Hazelton and Murphy, 2007). The amounts of soil separates were measured by the hydrometer method as described in Huq and Alam (2005). Organic carbon was determined by Walkley and Black wet oxidation method. Available N was extracted with 1N KCl at 1:10 (w/v) (Keeney and Nelson, 1982) and available S with KH$_2$PO$_4$ at 1:10 (w/v) ratio (Gupta, 2001). The concentrations of available Na, K, Ca and Mg were extracted with 1N NH$_4$OAc (pH 7.0) at 1:5 ratio (w/v) by shaking for 30 minutes followed by filtration (Thomas, 1982). For the analysis of total concentrations of elements (except S), the soil samples and amendments, were digested by a digestion mixture solution as mentioned in Parkinson and Allen (1975), while for total analysis of S, the samples were digested using HNO$_3$-HClO$_4$ acid mixture (Hazelton and Murphy, 2007). Available and total N concentrations in the extract and digest were determined by alkali distillation (Bremner and Mulnaney, 1982). The concentration of S was determined by turbidimetric method using spectrophotometer (SP- 3000 nano Optima, Japan) at a wavelength of 420 nm (Huq and Alam, 2005). The concentrations of Na and K were determined by atomic absorption spectrometer (Agilent Technologies 200 Series AA, Australia), whereas Ca and Mg by the ethylene di-amine tetra acetic acid (EDTA) method following the procedures as given in Huq and Alam (2005).

2.3 Statistical analysis

Pearson's correlations between the parameters and standard deviation were determined using Microsoft Excel 2016 and Statistical Packages for Social Sciences (SPSS) programs. In addition, Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT) was performed by using SPSS (version 16) to measure significant differences between pairs of means of the obtained results.

3. Results and Discussion
3.1 pH and ECe

The incorporation of amendments resulted an increasing trend in soil pH and ECe of AHS with significant differences among the treatments (p<0.01) for both soil A and soil B (Table 3). The rises in soil pH were higher when WA was applied either alone or in association with VC and ZL, whereas

VC either alone or in combination with ZL resulted in minimum rise in soil pH in both soil A and soil B. The pH increased by 47.60% and 34.62% in T12 and T14 compared to T1 for soil A and soil B, respectively. The incorporation of WA either alone or in combination with VC and ZL also resulted maximum response in ECe. The ECe of AHS in T14 increased by 66.72% over T1 in soil A. On the other hand, the increase of ECe was 50.00% higher in both T6 and T12 compared to T1 for soil B.

Table 3. pH and ECe (mS cm^{-1}) values (mean±SD) of soil A and soil B

Treatment	Soil A		Soil B	
	pH	ECe	pH	ECe
T1	5.20±0.05[g]	8.76±0.01[h]	5.85±0.05[i]	17.89±0.09[e]
T2	5.18±0.02[g]	10.90±0.78[fg]	6.05±0.15[h]	18.06±0.34[e]
T3	5.23±0.07[g]	10.23±0.09[g]	6.18±0.02[g]	18.32±1.98[de]
T4	7.00±0.05[c]	13.71±0.54[abc]	7.60±0.05[c]	23.87±2.62[abc]
T5	5.35±0.00[f]	11.46±0.69[f]	6.30±0.05[f]	22.36±2.41[bc]
T6	7.18±0.02[b]	12.58±0.55[de]	7.53±0.02[c]	26.83±0.52[a]
T7	5.37±0.03[f]	12.90±0.22[cd]	6.25±0.05[fg]	26.36±1.25[a]
T8	7.13±0.03[b]	14.54±1.30[ab]	7.58±0.0[c]	24.98±1.59[abc]
T9	5.45±0.10[e]	11.83±0.70[ef]	6.53±0.07[d]	21.93±0.69[bcd]
T10	7.63±0.03[a]	13.58±0.05[bcd]	7.73±0.02[b]	21.46±1.51[cde]
T11	5.83±0.02[d]	13.05±0.56[cd]	6.43±0.02[e]	25.11±2.49[abc]
T12	7.68±0.02[a]	13.51±0.11[cd]	7.75±0.05[b]	26.83±0.86[a]
T13	5.83±0.02[d]	12.72±0.10[cd]e	6.53±0.02[d]	24.17±3.61[abc]
T14	7.63±0.03[a]	14.60±0.28[a]	7.88±0.03[a]	25.50±4.09[ab]
p value	<0.01	<0.01	<0.01	<0.01

Mean (s) followed by the same letter within the column do not differ at 5% level of significance. Treatment legend description is given in **Table 1**.

3.2 Concentration of available elements

The concentrations available N, K, S, Ca, Mg and Na were given in **Table 4** and **Table 5** for soil A and soil B, respectively. The application of amendments caused significant variation in the concentration of available N, K, S, Ca, Mg and Na for soil A ($p<0.01$) and soil B ($p<0.01$). The concentration of available N in both soil A and soil B increased when VC was applied either alone or in combination with other amendments. On the other hand, WA either alone or in combination with VC and ZL resulted in higher concentration of available K, S and Ca in both soil A and soil B. The incorporation of WA and ZL in conjunction at 2% rate showed maximum concentrations of available K, S and Ca in both soil A and soil B. The rate of increment was found higher with increasing the rate of respective amendment. The concentration of available N in T9 increased by 132.91% and 214.06% compared to T1, respectively for soil A and soil B. The concentration of available K and Ca in T14 increased by 552.77% and 428.80% compared to respective T1 of soil A, while 354.11% and 351.14% compared to respective T1 of soil B. Available S concentration also increased by 39.96% and 63.65% in T14 compared to the corresponding lowest values observed in soil A (T3) and soil B (T2) respectively. However, the maximum concentration of available Mg was observed in T14 which was 84.89% higher in comparison to T1 in soil A, while the highest concentration of available Mg in soil B was observed in T13 which was 34.19% greater compared to T1. Besides, the concentration of available Na was found to be highest in T7 and T14, whereas lowest in T6 and T1, respectively in soil A and soil B. The concentrations increased by 22.65% and 74.01% respectively in T7 and T14 compared to their corresponding lowest values of soil A and soil B.

Table 4. Concentration (mg kg^{-1}) of available elements in soil A

Treatment	N	S	Na	K	Ca	Mg
T1	51.43^i	230.14^e	410.91^{cd}	126.81^{fg}	472.802^j	448.96^g
T2	59.89^{gh}	237.58^{de}	392.76^{def}	131.25^{fg}	492.67^j	470.64^g
T3	98.95^c	226.13^e	390.83^{def}	121.80^g	867.36^i	568.80^f
T4	54.03^{hi}	253.40^{cde}	401.78^{cde}	463.05^d	2008.00^d	648.00^{de}
T5	67.70^f	255.49^{cde}	441.27^{ab}	184.74^{ef}	968.096^h	621.76^{ef}
T6	108.07^b	247.06^{cde}	370.54^f	524.09^c	2049.33^d	686.72^{bcd}
T7	88.54^d	275.80^{bc}	454.47^a	215.54^e	1048.27^g	669.60^{cde}
T8	53.38^{hi}	309.48^{ab}	425.81^{bc}	513.33^{cd}	2184.05^c	637.20^{de}
T9	119.78^a	247.56^{cde}	394.30^{def}	216.13^e	920.00^{hi}	612.16^{ef}
T10	62.50^{fg}	281.46^{bc}	378.02^{ef}	766.50^b	2296.13^b	741.92^b
T11	78.12^e	274.01^{bcd}	449.52^{ab}	226.93^e	1276.00^f	645.62^{de}
T12	118.48^a	274.18^{bcd}	372.08^f	800.83^{ab}	2358.40^b	820.88^a
T13	113.27^{ab}	297.67^{ab}	449.13^{ab}	218.99^e	1464.03^e	723.20^{bc}
T14	67.05^f	316.49^a	451.55^{ab}	827.78^a	2500.16^a	830.08^a
p value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Mean (s) followed by the same letter within the column do not differ at 5% level of significance. Treatment legend description is given in **Table 1**.

Table 5. Concentration (mg kg^{-1}) of available elements in soil B

Treatment	N	S	Na	K	Ca	Mg
T1	41.66^f	322.55^d	726.61^f	217.91^g	524.03^j	1032.02^e
T2	58.59^{ef}	319.92^d	926.26^{de}	202.07^g	588.05^j	1070.40^e
T3	95.48^{bc}	373.90^{cd}	874.01^{ef}	257.59^{fg}	761.33^i	1260.32^{bc}
T4	52.08^{ef}	417.25^{bc}	1096.26^{abcd}	571.66^d	1908.09^d	1197.60^{cd}
T5	67.05^{de}	403.53^{bc}	1072.45^{cd}	253.29^{fg}	941.39^h	1183.20^{cd}
T6	95.05^{bc}	397.64^{bc}	1204.72^{abc}	652.21^{cd}	2036.00^c	1324.80^{ab}
T7	103.51^b	445.76^b	1259.78^{ab}	255.93^{fg}	1116.11^g	1356.64^a
T8	65.75^{de}	439.52^b	1189.21^{abc}	722.68^c	2161.07^b	1152.64^d
T9	130.85^a	392.16^{bc}	1077.34^{bcd}	281.58^{efg}	961.36^h	1250.42^{bc}
T10	60.54^{de}	366.08^{cd}	941.93^{de}	868.39^b	2082.80^c	1176.02^{cd}
T11	70.31^{de}	442.03^b	1156.76^{abc}	342.07^{ef}	1212.12^f	1324.80^{ab}
T12	98.95^b	451.70^b	1220.62^{abc}	881.35^b	2188.11^b	1260.00^{bc}
T13	105.46^b	448.91^b	1078.77^{bcd}	380.46^e	1433.60^e	1384.84^a
T14	78.12^{cd}	523.19^a	1264.34^a	989.55^a	2364.08^a	1250.40^{bc}
p value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Mean (s) followed by the same letter within the column do not differ at 5% level of significance. Treatment legend description is given in **Table 1**.

The concentration of available N in soil A was found higher compared to soil B with the range of 0.97–23.44% for all treatments excluding T7, T8, T9 and T14. On the other hand, available S concentration in soil B was found 30.06–65.35% higher compared to soil A regardless of the treatments. Irrespective of the treatments, soil A was characterized by 43.45–69.52% and 9.14–52.72% lower in available Na and K, respectively. Compared to soil A, the concentration of available Ca in soil B were found 0.65–12.22% lower excluding T1, T2, T7 and T9, whereas available Mg in soil A was found 33.61–56.50% lower compared to soil B regardless of the treatments.

3.3 Concentration of total elements

Table 6 and **Table 7** show the concentrations total N, K, S, Ca, Mg and Na in soil A and soil B, respectively. The application of amendments resulted in significant variation in the concentration of total N, K, S and Ca among the treatments both in soil A ($p<0.01$) and soil B ($p<0.01$). Similar to available elements, the total concentration of N was observed higher in VC incorporated soils, while K, S and Ca concentrations were found higher when WA was incorporated alone or in combination with ZL. The maximum concentration of total N in T9 was 29.05% and 32.44% higher compared to T1 for soil A and soil B, respectively. On the contrary, the concentrations of total K, S and Ca in T4 increased by 17.55%, 88.38% and 246.99% compared to corresponding lowest values observed in soil A, whereas 9.77%, 71.20% and 225.53% compared to corresponding lowest values observed in soil B. The concentrations of total Mg and Na among the treatments were not found in any definite trend. While the concentration of total Mg among the treatments differed significantly in soil A ($p<0.05$), no significant difference was observed in soil B ($p>0.05$). The maximum concentrations of total Mg respectively in T12 and T10 were 39.31% and 31.76% higher compared to respective T1 for soil A and soil B. However, the concentration of total Na differed at 1% level of significance among the treatments in case of soil A, while at 5% level of significance in case of soil B. The concentrations of total Na were 25.84% and 22.85% higher in T13 and T4 compared to corresponding lowest values for soil A and soil B, respectively.

Table 6. Concentration (%) of total elements in soil A

Treatment	N	S	Na	K	Ca	Mg
T1	0.20[ef]	0.05[cd]	0.25[bc]	1.29[f]	0.17[g]	0.29[d]
T2	0.19[f]	0.04[d]	0.26[bc]	1.37[e]	0.18[fg]	0.28[d]
T3	0.23[bc]	0.04[d]	0.25[bc]	1.37[e]	0.21[f]	0.34[abcd]
T4	0.19[f]	0.05[cd]	0.26[bc]	1.49[ab]	0.38[c]	0.32[bcd]
T5	0.20[ef]	0.04[d]	0.25[bc]	1.36[e]	0.22[f]	0.31[cd]
T6	0.21[def]	0.04[d]	0.25[bc]	1.40[de]	0.35[c]	0.36[abcd]
T7	0.24[ab]	0.05[cd]	0.26[bc]	1.24[g]	0.20[fg]	0.35[abcd]
T8	0.22[bcd]	0.05[cd]	0.27[bc]	1.43[cd]	0.30[d]	0.36[abcd]
T9	0.26[a]	0.04[d]	0.24[c]	1.31[f]	0.20[fg]	0.32[bcd]
T10	0.22[bcd]	0.05[cd]	0.26[bc]	1.45[bc]	0.50[b]	0.40[ab]
T11	0.22[bcd]	0.05[cd]	0.27[bc]	1.37[e]	0.22[f]	0.31[cd]
T12	0.24[ab]	0.06[b]	0.25[bc]	1.43[cd]	0.52[b]	0.41[a]
T13	0.24[ab]	0.07[a]	0.31[a]	1.37[e]	0.26[e]	0.33[abcd]
T14	0.20[ef]	0.07[a]	0.28[ab]	1.52[a]	0.58[a]	0.38[abc]
p value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05

Mean (s) followed by the same letter within the column do not differ at 5% level of significance. Treatment legend description is given in **Table 1**.

The concentration of total N was found 23.74–58.00% higher in soil A compared to soil B irrespective of the treatments. On the contrary, the concentrations of total K, S, Na were found lower in soil A in their respective treatment compared to soil B. Regardless of the treatments, the concentrations of total K, S and Na were found 11.99–24.61%, 34.83–61.71% and 30.88–51.21% lower in soil A in comparison to soil B. Similarly, the concentration of total Ca concentration was found 2.51–23.88% lower in soil A than soil B except for T4, T5 and T10.

Table 7. Concentration (%) of total elements in soil B

Treatment	N	S	Na	K	Ca	Mg
T1	0.15^{ef}	0.07^{e}	0.44^{c}	1.66^{bcd}	0.19^{i}	0.45^{c}
T2	0.15^{ef}	0.09^{d}	0.53^{ab}	1.77^{a}	0.21^{hi}	0.48^{bc}
T3	0.18^{bc}	0.09^{d}	0.48^{bc}	1.78^{a}	0.22^{ghi}	0.47^{bc}
T4	0.15^{ef}	0.09^{d}	0.54^{a}	1.80^{a}	0.35^{de}	0.52^{abc}
T5	0.15^{ef}	0.10^{c}	0.47^{bc}	1.74^{abc}	0.21^{hi}	0.51^{abc}
T6	0.16^{de}	0.10^{c}	0.49^{abc}	1.59^{d}	0.39^{d}	0.54^{abc}
T7	0.17^{cd}	0.11^{b}	0.49^{abc}	1.63^{d}	0.26^{gh}	0.50^{abc}
T8	0.14^{f}	0.10^{c}	0.50^{abc}	1.79^{a}	0.39^{d}	0.52^{abc}
T9	0.20^{a}	0.10^{c}	0.48^{bc}	1.74^{abc}	0.27^{fg}	0.45^{c}
T10	0.15^{ef}	0.10^{c}	0.45^{c}	1.82^{a}	0.46^{c}	0.59^{a}
T11	0.15^{ef}	0.11^{b}	0.48^{bc}	1.65^{bcd}	0.25^{gh}	0.54^{abc}
T12	0.18^{bc}	0.11^{b}	0.46^{c}	1.65^{bcd}	0.53^{b}	0.55^{abc}
T13	0.19^{ab}	0.12^{a}	0.44^{c}	1.64^{cd}	0.31^{ef}	0.50^{abc}
T14	0.14^{f}	0.12^{a}	0.47^{bc}	1.82^{a}	0.61^{a}	0.58^{ab}
p value	<0.01	<0.01	<0.05	<0.01	<0.01	>0.05

Mean (s) followed by the same letter within the column do not differ at 5% level of significance. Treatment legend description is given in **Table 1**.

The concentration of total Mg was 34.50–75.16% higher in soil B relative to soil A regardless of the treatments. The concentrations increased by 22.65% and 74.01% respectively in T7 and T14 compared to their corresponding lowest values of soil A and soil B.

3.4 Co-efficient of correlation (r)

Table 8 shows the correlation co-efficient values among different parameters of AHS. In case of soil A and soil B, the relations of ECe with pH and all other available elements were positive and significant either at 1% or 5% level of significance. In soil B, the relations of Na with that of K, Ca and Mg were positive which were highly significant. On the other hand, the relation of Na with that of K and Ca in soil A was negative, while that of Mg was positive, though all relations were not significant. Moreover, the relationships among available K, Ca and Mg were found positive in both soil A and soil B.

Table 8. Correlation co-efficient (r) values among different available elements of soil A and soil B

	pH	ECe	N	S	Na	K	Ca	Mg
pH	-	0.522**	-0.015	0.463**	0.481**	0.945**	0.972**	0.131
ECe	0.745**	-	0.301	0.694**	0.935**	0.478*	0.622**	0.625**
N	-0.041	0.007	-	0.292	0.392*	-0.023	0.019	0.646**
S	0.499**	0.673**	-0.053	-	0.705**	0.479**	0.565**	0.551**
Na	-0.265	0.241	-0.213	0.391*	-	0.444**	0.567**	0.607**
K	0.963**	0.729**	-0.020	0.517**	-0.220	-	0.929**	0.103
Ca	0.974**	0.833**	0.027	0.587**	-0.119	0.932**	-	0.258
Mg	0.738**	0.757**	0.344*	0.648**	0.088	0.780**	0.821**	-

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
† Values below – sign indicate r for soil A and values above – sign indicate r for soil B

3.5 Discussion

Both soil A and soil B were saline in nature having acidic reaction initially. Soil salinity coupled with low soil reaction is very exceptional in nature. Soils are called saline when the EC of saturation extract is greater than 4 mS cm^{-1} (Brady and Weil, 2005; Hardie and Doyle, 2012). The acidic character of saline soils from different parts of the world has been stated by several studies (Jamil *et al.*, 2020; LRUG, 1997; Gunarathne *et al.*, 2020; Roy *et al.*, 2021). The dryness of soil could be one of the reasons for low soil pH. This result agreed with the findings of Zárate-Valdez *et al.* (2006). The bulk soil samples were collected in the month of March when the soils contain very little moisture in the studied area. Decrease in soil pH in relation to moisture content could be ascribed to proton generation associated with NO_3^- and SO_4^{2-} formation in dry condition (Gunarathne *et al.*, 2020), whereas increase in soil pH results from their concomitant removal from the soil solution with percolating water (Roy and Chowdhury, 2020). The incorporation of amendments either from organic or inorganic origin resulted increase in pH and EC of AHS samples which is in consistent with the results of other authors (Gunarathne *et al.* 2020; Roy and Kashem, 2014). The increase in pH of amended soils could be due to the relatively higher pH value of the VC (pH 7.89), WA (pH 11.77) and ZL (pH 7.47) in relation to soil A (pH 5.01) and soil B (pH 5.22). Similar results was found by Angelova *et al.* (2013) where addition of organic amendments increased soil pH. The application of VC, WA and ZL also led to increase in EC values compared to un-amended soils which could be due to the release of different ions from the amendments applied to soils. In contrast to the present findings, several authors found that the addition of organic amendments decreased soil pH and EC (Ding *et al.*, 2020; Oo *et al.*, 2015; Wang *et al.*, 2014). The decrease in pH of amended soils could be due to the formation of different types of organic acids during the mineralization of organic amendments (Angelova *et al.*, 2013).

The incorporation of amendments increased nutrient concentrations of AHS in general. The results of the present study is in agreement with the findings of other authors where VC was found to improve soil fertility (Angelova *et al.*, 2013; Garg *et al.*, 2012; Nada *et al.*, 2011). This could be due to the presence of humic compounds, macro and micronutrient elements, amino acids and beneficial soil microorganisms in VC. Several authors also reported that the incorporation of organic amendments in saline soils enhanced the concentrations of available and total nutrients (Ding *et al.*, 2020; Wu *et al.*, 2018). The higher concentration of available Na in ZL incorporated soils (especially T7 and T14) could be due to inherent high concentration of Na in ZL among the treatments (**Table 2**). Similar result was observed by Al-Busaidi *et al.* (2008). Similarly, though treatments did not affect total Mg in the soil B, the availability or mobility was significantly varied which could be ascribed to the portion of active pool which influences the availability of nutrients in soil. The differences in the availability of elements in soil are influenced by a number of such soil factors as pH, clay content, level of moisture, organic matter content, etc (Jackson, 2014; Wei *et al.*, 2006).

The high concentration of N in soils amended with VC may be due to high N contents in VC in relation to WA and ZL. The present result is in agreement with the findings of Gunarathne *et al.* (2020) who observed the improvement in pH as well as increase in the concentration of N in acidic saline soils due to usage of different organic amendments. Treatments with WA either alone or in association with VC and ZL had maximum concentrations of K, Ca and Mg which could be due to inherent high concentrations of Ca (10.40%), K (4.13%) and Mg (1.28%) in WA. In previous experiment, the application of WA was also found to increase the concentrations of P, K, Ca and Mg in soils (Augusto *et al.*, 2008; Deighton and Watmough, 2020). Similar result was also observed by An and Park (2021), where introduction of WA in soils increased soil pH, EC and exchangeable cations

(K, Ca and Mg). However, treatments receiving WA and ZL either alone or in combination had low N content in comparison to treatments receiving VC which could be ascribed to the trace amount of N in WA and ZL. This result is in consistent with the findings of Augusto *et al.* (2008) who stated lack of N in WA. Symanowicz *et al.* (2018) also observed the concentration of macronutrients in WA in the sequence of Ca > K > Mg > S > N.

Conclusion

Salinity of soils is one of the most severe abiotic constraints limiting the production of crops worldwide. However, proper maintenance of nutrients is a feasible and cost effective approach for better management of saline soils in respect to the performance of plants and microorganisms. The present study provided important findings toward sustainable management of salt affected areas coupled with acidic reaction through the application of different organic and inorganic amendments. The application of VC substantially increased the amount of N, while WA improved the status of K, Ca and Mg in soils. Besides, WA provided an interesting alternative with acid-neutralizing capacity for improvement of soil health. From the present findings it can be concluded that the application of VC in association with WA can successfully be adopted as an effective management practice in saline soils coupled with acidic reaction for the betterment of soil health.

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References

Al-Busaidi A., Yamamoto T., Inoue M., Eneji A.E., Mori Y., Irshad M. (2008). Effects of zeolite on soil nutrients and growth of barley following irrigation with saline water. *J. Plant Nutr.,* 31(7*)*, 1159-1173. https://doi.org/10.1080/01904160802134434

An J.Y., Park B.B. (2021). Effects of wood ash and N fertilization on soil chemical properties and growth of *Zelkova serrate* across soil types. *Sci. Rep.,* 11, 14489. https://doi.org/10.1038/s41598-021-93805-5

Angelova V.R., Akova V.I., Artinova N.S., Ivanov K.I. (2013). The effect of organic amendments on soil chemical characteristics. *Bulg. J. Agric. Sci.,* 19(5), 958-971.

Atemni I., Mehdaoui I., Ainane A., Gaga Y., Chetouani A., Hammouti B., Taleb M., Rais Z. (2022), Impact of composts prepared from olive waste on the growth and production parameters of some fruit trees, *Mor. J. Chem.* 10(2), 258-268

Augusto L., Bakker M.R., Meredieu C. (2008). Wood ash applications to temperate forest ecosystems-potential benefits and drawbacks. *Plant Soil.,* 306, 181-198. https://doi.org/10.10007/s11104-008-9570-z

Bang-Andreasen T., Nielsen J.T., Voriskova J., Heise J., Rønn R., Kjøller R., Hansen H.C.B., Jacobsen C.S. (2017). Wood ash induced pH changes strongly affect soil bacterial numbers and community composition. *Front Microbiol.,* 8, 1-14.

Benkaddour R., Hammouti B., El-Mrabet M., Dahchour M., Aouniti A., Haouadi B., Ouardi A. (2004) Salinité et pollution par les nitrates des eaux souterraines de la plaine de Triffa, *Actes Inst. Agron. Vet. (Maroc)* 24(3&4), 147-158.

Bougnom B.P., Knapp B.A., Etoa F.X., Insam H. (2011). Possible use of wood ash and compost for improving acid tropical soils. In: Insam H and Knapp BA (eds), Recycling of biomass ashes. Springer-Verlag, Berlin Heidelberg. pp. 87-105.

Brady N.C., Weil, R.R. (2005). The nature and properties of soils. 13th ed. Pearson-Prentice Hall, Delhi, India. 960 p.

Bremner J.M., Mulnaney C.S. (1982). Nitrogen-total. In: Page AL, Miller RH and Keeney DR (eds), Methods of soil analysis: Chemical and microbiological properties (part-2). American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison, Wisconsin, USA. pp. 595-624.

Cramer G.R. (2002). Sodium-calcium interactions under salinity stress. In: Läuchli A and Lüttge U (eds), Salinity: Environment-plants- molecules. Springer, Dordrecht. pp. 205-227. https://doi.org/10.1007/0-306-48155-3

Deighton H.D., Watmough S.A. (2020). Effects of non-industrial wood ash (NIWA) applications on soil chemistry and sugar maple (*Acer saccharum*, Marsh.) seedling growth in an acidic sugar bush in Central Ontario. *Forests,* 11, 693. https://doi.org/10.3390/f11060693

Ding Z., Kheir A.M.S., Ali M.G.M., Ali O.A.M., Abdelaal A.I.N., Lin X., Zhou Z., Wang B., Liu B., He Z. (2020). The integrated effect of salinity, organic amendments, phosphorus fertilizers, and deficit irrigation on soil properties, phosphorus fractionation and wheat productivity. *Sci. Rep.,* 10, 2736. https://doi.org/10.1038/s41598-020-59650-8

Domínguez J. (2004). State of the art and new perspectives on vermicomposting research. In: Edwards CA (ed), Earthworm ecology. CRC Press LLC. pp. 401-424.

El hasini S., Iben Halima O., El. Azzouzi M., Douaik A., Azim K., Zouahri A. (2019), Organic and inorganic remediation of soils affected by salinity in the Sebkha of Sed El Mesjoune – Marrakech (Morocco), *Soil and Tillage Research,* 193, 2019, 153-160, ISSN 0167-1987, https://doi.org/10.1016/j.still.2019.06.003

Etesami H., Noori F. (2019). Soil salinity as a challenge for sustainable agriculture and bacterial-mediated alleviation of salinity stress in crop plants. In: Kumar M, Etesami H and Kumar V (eds), Saline soil-based agriculture by halotolerant microorganisms. Springer Singapore. pp. 1-22. https://doi.org/10.1007/978-981-13-8335-9_1

Garg V., Suthar S., Yadav A. (2012). Management of food industry waste employing vermicomposting technology. *Bioresour. Technol.,* 126, 437-443.

Gómez-Rey, M.X., Madeira, M., & Coutinho, J. (2012). Wood ash effects on nutrient dynamics and soil properties under Mediterranean climate. *Ann. For. Sci.,* 69(5), 569-579. https://doi.org/10.1007%2Fs13595-011-0175-y

Gull A., Lone A.A., Wani N.U.I. (2019). Biotic and abiotic stresses in plants. In: de Oliveira AB (ed). Abiotic and biotic stress in plants. IntechOpen, London, UK. pp. 1-6. https://doi.org/10.5772/intechopen.85832

Gunarathne V., Senadeera A., Gunarathne U., Biswas J.K., Almaroai Y.A., Vithanage M. (2020). Potential of biochar and organic amendments for reclamation of coastal acidic-salt affected soil. *Biochar,* 2, 107-120. https://doi.org/10.1007/s42773-020-00036-4

Gupta P.K. (2001). Methods in environmental analysis: Water, soil and air. Agrobios, India.

Hardie M., Doyle R. (2012). Measuring soil salinity. In: Shabala S and Cuin TA (eds), Plant salt tolerance: Methods and protocols, methods in molecular biology. Humana Press, Totowa, NJ. pp. 415-425. https://doi.org/10.1007/978-1-61779-986-0_28

Hazelton P., Murphy B. (2007). Interpreting soil test results: what do all the numbers mean? CSIRO publishing, Australia.

Hesse P.R. (2002). A textbook of soil chemical analysis. CBC publishers & Distributors. New Delhi, India. 520 p.

Huq S.M.I., Alam M.D. (2005). A handbook on analysis of soil, plant and water. BACER-DU, University of Dhaka, Bangladesh. 246 p.

Jackson R.S. (2014). Wine Science: Principles and Applications. 4th ed. Academic Press 960 p. https://doi.org/10.1016/B978-0-12-381468-5.00013-0

Jamil M.R., Kabir M.H., Chowdhury M.N., Islam M.T., Islam M.S. (2020). Seasonal changes of soil salinity and nutrients in the coastal Bhola Island, Bangladesh. *Bangladesh J. Environ. Sci.,* 39, 5-12.

Keeney D.R., Nelson D.W. (1982). Nitrogen- inorganic forms. In: In: Page AL, Miller RH and Keeney DR (eds), Methods of soil analysis: Chemical and microbiological properties (part-2). American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison, Wisconsin, USA. pp. 643-658.

Khan M.A., Duke N.C. (2001). Halophytes- A resource for the future. *Wetl. Ecol. Manag.,* 6, 455-456. https://doi.org/10.1023/A:1012211726748

LRUG (1997). Land resource utilization guide (Anowara Thana). Soil Resource Development Institute, Ministry of Agriculture, Government of the People's Republic of Bangladesh.

Manivannan S., Balamurugan M., Parthasarathi K., Gunasekaran G., Ranganathan L.S. (2009). Effect of vermicompost on soil fertility and crop productivity- Beans (*Phaseolus vulgaris*). *J. Environ. Biol.,* 30(2), 275-281.

Nada W.M., Rensburg L.V., Claassens S., Blumenstein O. (2011). Effect of vermicompost on soil and plant properties of coal spoil in the Lusatian region (Eastern Germany). *Commun. Soil Sci. Plant Anal.,* 42, 1945-1957.

Oo A.N., Iwai C.B., Saenjan P. (2015). Soil properties and maize growth in saline and nonsaline soils using cassava-industrial waste compost and vermicompost with or without earthworms. *Land Degrad. Dev.,* 26(3), 300-310. https://doi.org/10.1002/ldr.2208

Parkinson J.A., Allen S.E. (1975). A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. *Commun. Soil Sci. Plant Anal.,* 6(1), 1-11. https://doi.org/10.1080/00103627509366539

Pirsaheb M., Khosravi T., Sharafi K. (2013). Domestic scale vermicomposting for solid waste management. *Int. J. Recycl. Org. Waste Agric.,* 2, 4. https://doi.org/10.1186/2251-7715-2-4

Roy S., Chowdhury N. (2020). Effects of leaching on the reclamation of saline soils as affected by different organic and inorganic amendments. *J. Environ. Sci. Sustain. Dev.,* 3(2), 329-354. https://doi.org/10.7454/jessd.v3i2.1075

Roy S., Chowdhury N. (2021). Salt stress in plants and amelioration strategies: A critical review. In: Fahad S, Saud S, Chen Y, Wu C and Wang D (Eds.), Abiotic Stress in Plants. IntechOpen, UK, London. pp. 391-422. https://doi.org/10.5772/intechopen.93552

Roy S., Chowdhury N. (2022). Responses of spinach (*Spinacia oleracea* L.) to acidic saline soils as affected by different amendments. IntechOpen, UK, London. https://doi.org/ 10.5772/intechopen.101633

Roy S., Kashem M.A. (2014). Effects of organic manures in changes of some soil properties at different incubation periods. *Open J. Soil Sci.,* 4(3), 81-86. https://doi.org/10.4236/ojss.2014.43011

Roy S., Nath B., Chowdhury N. (2021). Study of spatio-temporal variations of soil salinity in the south-eastern coastal part of Bangladesh. *Soil Sci. Ann.,* 72(3), 144725. https://doi.org/10.37501/soilsa/144725

Sahin U., Ekincib M., Orsa S., Turanc M., Yildizb S., Yildirimb E. (2018). Effects of individual and combined effects of salinity and drought on physiological, nutritional and biochemical properties of cabbage (*Brassica oleracea* var. capitata). *Sci. Hortic.,* 240, 196-204. https://doi.org/10.1016/j.scienta.2018.06.016

Shahid S.A., Zaman M., Heng L. (2018). Introduction to soil salinity, sodicity and diagnostics techniques. In: Zaman M, Shahid SA and Heng L (eds), Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques. Springer, Cham. pp. 1-42. https://doi.org/10.1007/978-3-319-96190-3_1

Suthar S., Singh S. (2008). Vermicomposting of domestic waste by using two epigeic earthworms (*Perionyx excavatus* and *Perionyx sansibaricus*). *Int. J. Environ. Sci. Technol.,* 5(1), 99-106. https://doi.org/10.1007/BF03326002

Symanowicz B., Becher M., Jaremko D., Skwarek K. (2018). Possibilities for the use of wood ashes in agriculture. *J. Ecol. Eng.,* 19(3), 191-196. https://doi.org/10.12911/22998993/86156

Tester M., Davenport R. (2003). Na+ tolerant and Na+ transport in higher plants. *Annals of Botany.* 91, 503-527.

Thomas G.W. (1982). Exchangeable cations. In: Page AL, Miller RH and Keeney DR (eds), Methods of soil analysis: Chemical and microbiological properties (part-2). American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison, Wisconsin, USA. pp. 159-161.

Wang L., Sun X., Li S., Zhang T., Zhang W., Zhai P. (2014). Application of organic amendments to a coastal saline soil in North China: Effects on soil physical and chemical properties and tree growth. *PLoS ONE,* 9(2), e89185. https://doi.org/10.1371/ journal.pone.0089185

Wei X., Mingde Hao, Mingan Shao, Gale W. J. (2006), Changes in soil properties and the availability of soil micronutrients after 18 years of cropping and fertilization, *Soil and Tillage Research*, 91, Issues 1–2, 120-130, ISSN 0167-1987, https://doi.org/10.1016/j.still.2005.11.009

Wicke B., Smeets E., Dornburg V., Vashev B., Gaiser T., Turkenburg W., Faaij A. (2011). The global technical and economic potential of bioenergy from salt-affected soils. *Energy Environ. Sci.,* 4, 2669-2681. https://doi.org/10.1039/C1EE01029H

Wu Y., Li Y., Zhang Y., Bi Y., Sun Z. (2018). Response of saline soil properties and cotton growth to different organic amendments. *Pedosphere,* 28(3), 521-529. https://doi.org/10.1016/S1002-0160(17)60464-8

Xu C., Mou B. (2016). Responses of spinach to salinity and nutrient deficiency in growth, physiology, and nutritional value. *J. Am. Soc. Hortic. Sci.,* 141(1), 12-21. https://doi.org/10.21273/JASHS.141.1.12

Yue Y., Guo W.N., Lin Q.M., Li G.T., Zhao X.R. (2016). Improving salt leaching in a simulated saline soil column by three biochars derived from rice straw (*Oryza sativa* L.), sunflower straw (*Helianthus annuus*), and cow manure. *J. Soil Water Conserv.,* 71(6), 467-475. https://doi.org/10.2489/jswc.71.6.467

Zhang P., Senge M., Dai Y. (2016). Effects of salinity stress on growth, yield, fruit quality and water use efficiency of tomato under hydroponics system. *Rev Agric. Sci.,* 4, 46- 55. https://doi.org/10.7831/ras.4.46.

Zárate-Valdez J.L., Zasoski R.J., Läuchli A.E. (2006). Short-term effects of moisture content on soil solution pH and soil Eh. *Soil Sci.,* 171(5), 423-431. https://doi.org/10.1097/01.ss. 0000222887.13383.08

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