Scientific Research Publishing

Mitigation Rice Yield Scaled Methane Emission and Soil Salinity Stress with Feasible Soil Amendments

Laila Khatun[1], Muhammad Aslam Ali[1*], Mahmud Hossain Sumon[2], Md. Bazlul Islam[3], Fahima Khatun[4]

[1]Department of Environmental Science, Bangladesh Agricultural University, Mymensingh, Bangladesh
[2]Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh
[3]Department of Seed Science and Technology, Bangladesh Agricultural University, Mymensingh, Bangladesh
[4]Department of Pathobiology, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh
Email: *aslam.envs@bau.edu.bd, *litonaslam@yahoo.com

Abstract

Sea level rise and saline water intrusion have been affecting land use and crop production especially rice in the coastal areas of major rice growing countries including Bangladesh. The upward trend in salinity intrusion has been hampering crop production, particularly rice cultivation in the coastal areas of Bangladesh. Therefore, an experiment was conducted on rice planted saline soils under the Nethouse at Bangladesh Agricultural University, Mymensingh to improve the properties of salt affected soils for rice cultivation as well as controlling methane (CH_4) emissions with feasible soil organic amendments and recommended inorganic fertilizers. The experimental treatments were arranged under 25 mM NaCl, 50 mM NaCl and 75 mM NaCl salinity levels with different combinations of NPKSZn, biochar, phosphogypsum and Trichocompost. It was found that CH_4 emission rates were suppressed with phospho-gypsum and biochar amendments within the salinity level 25 mM to 50 mM, beyond this salinity level (at 75 mM), soil amendments were not effective to control CH_4 emissions. From panicle initiation to grain ripening stages treatment T_4 (100% NPKSZn + 75 mM NaCl stress) showed the highest CH_4 emission rate, while lower CH_4 emission rate was recorded in T_5 (100% NPKSZn + 25 mM NaCl stress + Phospho-gypsum) and T_8 treatment (100% NPKSZn + 50 mM NaCl + Phospho-gypsum). In case of seasonal total CH_4 emission, Phospho-gypsum was found most effective to mitigate total CH_4 emissions followed by biochar and trichocompost amendments in all salinity levels, probably due to the improved soil redox potential status (Eh), decreased

*Corresponding author.

electrical conductivity (EC), increased SO_4^{2-}, NO_3^-, Mn^{4+} etc. in the rice rhizosphere. Rice growth and yield components were badly affected by increasing salinity levels. Phospho-gypsum, biochar and trichocompost amendments increased plant height, panicles number/hill, shoot biomass and grain yield/hill at 25 mM NaCl stress condition. However, salinity stress 50 mM to 75 mM severely affected rice growth and yield components, eventhough phospho-gypsum, biochar and trichocompost were applied. Among the amendments, phosphogypsum and biochar significantly decreased yield scaled CH_4 emission (GHGI) in salinity levels 25 mM to 75 mM. After harvesting rice, the overall soil properties such as organic matter content, available P, available S, exchangeable K^+ and Ca^{2+}, K^+/Na^+, Ca^{2+}/Na^+ ratios etc. were increased with the biochar, phospho-gypsum and trichocompost amendments. The highest ratios of K^+/Na^+ and Ca^+/Na^+ were found in the extract of saline soil at 25 mM with phospho-gypsum amendments followed by biochar and trichocompost amendments. Furthermore, soil SO_4^{2-}, NO_3^-, Mn^{4+} and Fe^{3+} contents in rice root rhizosphere were increased in the amended saline soils, which caused significant reduction in seasonal methane emissions. Therefore, it could be concluded that the combined application of phospho-gypsum and biochar with the recommended NPKSZn fertilizers in saline soils may be a good practice for increasing tolerance to salinity in rice by increasing K^+/Na^+, Ca^{2+}/Na^+ ratios, while decreasing yield scaled CH_4 emission (GHGI) in salinity levels 25 mM to 75 mM.

Keywords

CH_4, Rice, Saline Soils, Phosphogypsum, Biochar, Trichocompost

1. Introduction

Soil salinity problem is a global issue which has been affecting agricultural production in developing as well as developed countries. Soil is called saline when electrical conductivity (EC) of its saturation extract exceeds 4 dS/m, which is equivalent to approximately 40 mM NaCl. In most saline soils, the dominant cations are Na^+, Ca^{2+}, Mg^{2+} and to a lesser extent K^+, while the abundant anions are Cl^-, SO_4^{2-}, HCO_3^-/CO_3^{2-} and NO_3^- [1]. In addition to the ion composition of the soil solution, the EC is an important determinant for the suitability of a saline soil for crop production. Saline soils are characterized by high concentrations of soluble salts in the solution phase (saline soils), and/or a considerable fraction of the cation exchange sites being occupied by Na^+ (sodic soils). The sodium absorption ratio (SAR) provides information on the concentration of Na^+ in relation to Ca^{2+} and Mg^{2+} in the soil solution. Plant growth can be negatively affected by a high SAR even though the EC is below 4. A high SAR causes clay minerals and organic matter to disperse, therefore a poor soil structure is developed which may result in high soil density, clogging of pores and surface crusts, making the soils impermea-

ble to air and water. Saline soils are widely distributed in arid, semi-arid and in coastal areas. Salinity is most widespread in coastal areas, while saline-sodic soils are more spread in inlands but also occur in coastal areas. It has been estimated that the saline or sodic soils in India cover about 9 - 12 Mha [2]; while in Bangladesh covers 1 Mha. In Asia, 21.5 million hectares of land areas are affected by salinity, which may cause about 50% fertile land loss by the 21st midcentury [3]. In Bangladesh, out of 2.68 million haof coastal and off shore lands, about 1.065 million ha of arable lands are affected by various degrees of salinity [4]. The upward trend in salinity intrusion has been hampering crop production, particularly boro rice in the dry season of Bangladesh, which may fall rice production significantly by 2051 due to salinity [5]. The coastal areas of Bangladesh cover about 30% of the cultivable land of the country and more than 53% of the coastal areas are affected by salinity [6]. The majority of the saline land (0.65 million ha) exist in the districts of Satkhira, Khulna, Bagerhat, Barguna, Patuakhali, Pirojpur and Bholaon the western coast and a smaller portion (0.18 million ha) in the districts of Chittagong, Cox's bazar, Noakhali, Lakshmipur, Feni and Chandpur, which are affected by different levels of salinity.

Rice is moderately sensitive to salt in the field as almost all other crop species. The extent of damage for salinity depends on the severity of stress, growth condition and plant sensitivity to salinity [7] (Mishra, 2001). Salinity reduces the growth of plant through osmotic effect, reduces the ability of plant to take up water and this causes reduction in growth. Na^+ and Cl^- are the principal ions in majority of salt affected soils, which may affect plants growth. The roots of rice plants readily absorb Na^+ which is distributed in all plant organs to pose on damage, osmotic stress and imbalance nutrition [8]. It has also been reported that soil salinity seriously affected rice growth and grain yield at the reproductive stage [9] [10]. Soil salinity amelioration may be achieved by deep ploughing, sub-soiling, soil profile inversion, incorporation of chemical reagents such as phosphor-gypsum, calcium chloride, limestone and iron sulphate etc. [11]. Although soil salinity amelioration with chemical amendments is an established technology [12], however, the price of chemical agents has become costly for subsistence farmers in developing countries. Therefore, organic amendments with biochar and trichocompost hold the potential option for increasing soil fertility through enhancing soil physical and chemical properties. The biological amelioration of saline soils using living agents or dead organic matters may improve soil structure and permeability, accelerate salt leaching, decrease surface evaporation and inhibit salt accumulation in surface soils.

Soil salinity may also influence CH_4 emission from wetland rice fields [13] (Bachelet and Neue, 1993), which is a great concern in salt affected coastal areas of Bangladesh during boro season. In the past decade although several studies were conducted for improving saline stress of soils, however no effective amendments were developed for controlling methane emission from rice grown in saline soils. Nowadays phospho-gypsum and biochar have received the most

useful amendments for salinity reclamation. In this regard use of various amendments such as phospho-gypsum ($CaSO_4 \cdot 2H_2O$), biochar and trichocompost in salt affected paddy soils have been given emphasis because of the high content of sulphate in phospho-gypsum might prevent CH_4 formation and Ca^{2+} may effectively reduce salinity by replacing sodium (Na^+). Biochar is a C enriched material derived from the pyrolysis of organic materials under oxygen limited condition [14]. Biochar is a slowly decomposable valuable organic input for improving degraded soil through its effect on the physicochemical properties of soils, thereby enhancing crop growth and yield promotions. Moreover, biochar may accelerate exchange of cations on soil solids and leaching of salts from the root zone [15], hence preventing root from salt injuries. Biochar is known to modify soil physico-chemical parameters, optimize rhizospheric environment and eliminate saline-alkali stress, and increase the rice yield [16] [17]. After application in soil biochar slowly decomposes, increases soil CO_2 concentration and releases H^+ ion. The released H^+ enhances $CaCO_3$ dissolution and liberates more calcium (Ca) for sodium (Na) exchange [18]. Phospho-gypsum is another feasible industrial byproduct of phosphate fertilizer manufacturing process which contains over 90% of $CaSO_4 \cdot 2H_2O$. Phospho-gypsum may be used as saline soil amendment because of its low cost and availability. The use of gypsum as a source of Ca^{2+} is an effective soil amendment to remove the exchangeable Na^+, thereby, ameliorate Na saturated soils, sustain crop productivity and crop yields [19]. The high content of sulfate in gypsum will act as an electron acceptor, thereby might suppress methanogenesis due to enhanced activity of sulphate reducing bacteria for the common substrates [20]. Therefore, methane formation as well as methane emissions are expected to be reduced being reported in our previous research findings [21] (Ali *et al*. 2009). Furthermore, gypsum application may influence the antioxidant enzyme activity in rice plant [22].

Recently a new innovative technique has developed to use plant-growth promoting fungi (*Trichoderma* spp) to induce plant resistance to biotic and abiotic stresses [23] [24]. It is an effective way for enhancing plant tolerance to salt stress, which may play a role in the development of sustainable agricultural systems. It has been reported that Trichocompost, a Trichoderma based compost manure was developed by mixing a definite concentration of spore suspension of a *Trichoderma harzianum* strain with measured amounts of processed raw materials, such as cowdung, poultry refuse, water hyacinth, vegetable wastes, sawdust, maize bran and molasses have been using for different crops production [25] and to rejuvenate soils.

In regards to ameliorate the soil salinity and other properties of saline soil, sustaining rice production and reducing methane emissions, there is no alternative but to add organic fertilizer and biological amendments in the coastal saline soils of Bangladesh.

Therefore, this study was undertaken with the following objectives:

1) To find out the suitable soil amendments for mitigating yield scaled me-

thane emission under different salinity stresses.

2) To ameliorate soil salinity stress and overall soil properties with suitable combination of organic materials and inorganic fertilizer.

3) To determine the rice growth and yield components under different salinity levels and organic amendments.

2. Materials and Methods

A pot experiment was conducted in the Net house, Department of Environmental Science, Bangladesh Agricultural University, with BINA dhan-10 during the period January 2017 to June 2017. The experiment was conducted on the roof of Department of Environmental Science, BAU, Mymensingh. Experimental site is located at 24°N latitude and 94°E longitude (AEZ 9). The experimental soils were collected from (0 - 15) cm depth of the top soil of ideal paddy field of Rampal, Bagerhat which is saline soil. The experimental soil collected from Rampal Bagerhat was silty clay loam (Sand 3.0%, Silt 60%, Clay 37%) in nature, pH value of soil was 7.8, EC 5.6 dS/m, OC 1.48%, T-N 0.12%, Av. P 15.8 ppm, Av. K 0.56 (meq/100 g).

Experimental design, layout and Pot preparation

The experimental pots were made of concrete which have small outlets at the lower part to collect leachate water. The radius of each pot was 29.5 cm and its area was 2501 cm^2. Rice cultivar BINA dhan-10 was used in the experiment. The experimental soil was collected from Rampal paddy field (moderate saline soil), Bagerhat. The experiment was carried out in completely randomized design (CRD) with three replications. Each pot contained two seedlings. The total number of pot was 39 (13 × 3). To facilitate cultural operations proper spacings were kept among the pots and pots were rearranged weekly to avoid the position effects. There were thirteen (13) treatments in this experiment such as T_1: 100% NPK (moderate saline soil), T_2: 100% NPK + 25 mM NaCl stress, T_3: 100% NPK + 50 mM NaCl stress, T_4: 100% NPK + 75 mM NaCl stress, T_5: 100% NPK + 25 mM NaCl stress + Phospho-Gypsum (100 g/pot), T_6: 100% NPK + 25 mM NaCl stress + Biochar (100 g/pot), T_7: 100% NPK + 25 mM NaCl stress + Trichocompost (100 g/pot), T_8: 100% NPK + 50 mM NaCl stress + Phospho-Gypsum (100 g/pot), T_9: 100% NPK + 50 mM NaCl stress + Biochar (100 g/pot), T_{10}: 100% NPK + 50 mM NaCl stress + Trichocompost (100 g/pot), T_{11}: 100% NPK + 75 mM NaCl stress + Phospho-Gypsum (100 g/pot), T_{12}: 100% NPK + 75 mM NaCl stress + Biochar (100 g/pot) and T_{13}: 100% NPK + 75 mM NaCl stress + Trichocompost (100 g/pot). Trichocompost was collected from IPM Laboratory, Department of Plant Pathology, Bangladesh Agricultural University, Mymensingh. Phosphogypsum was collected from ACI Ltd. Bangladesh and biochar from Japan. Salt tolerant rice cultivar BINA dhan-l0 was used in this experiment. The duration of this crop is 125 - 130 days. The experimental pots were filled with equal weights of soil (about 8.0 kg). Recommended doses of chemical fertilizers viz. TSP (3 g·pot^{-1}), MOP (3 g·pot^{-1}), Urea (6 g·pot^{-1}) were added to soils. Then

Phospho-gypsum, biochar and trichocompost were added (5 t/ha) in selective pots 125 g·pot⁻¹, 125 g·pot⁻¹ and 125 g·pot⁻¹ according to treatments. Urea was applied in three split doses; first dose (6 gm·pot⁻¹) after 10 days (26ᵗʰ January, 2017) of transplanting, second dose (6 gm·pot⁻¹) was applied on (25ᵗʰ February, 2017) and third dose (6 g·pot⁻¹) was applied on 29ᵗʰ March, 2017. The seedlings of BINA dhan-10 were collected from Environmental Science Field, BAU, at 28 days old and then two seedlings were transplanted in each pot on 16ᵗʰ January, 2017. Irrigation was given as per experimental specification i.e. measured water (normal water)was added to keep water level 5 cm on the soil surface of the pot and required NaCl was added to maintain proper salinity level in respective treatments. Soil redox status (Eh), pH, EC and rice leaf chlorophyll contents were recorded at active tillering stage, panicle initiation stage, flowering stage and rice grains ripening stages. Irrigation water was stopped two weeks before rice harvesting. Rice plants were harvested at maturity when about 90% grains became yellow. Harvesting was done on 15ᵗʰ May, 2017. The harvested rice hills of each pot were separately collected and properly tagged. Threshing was done carefully by hand. The grains were sun dried to a moisture content of 14%. Straws were also sun dried properly. Finally grain and straw yields were recorded as g·plant⁻¹.

Harvest index (%) was determined with the following formula

$$\text{Harvest index}\ (\%) = \frac{\text{Grain yield}}{\text{Grain yield} + \text{Straw yield}} \times 100$$

Gas sampling collection

A closed-chamber method was used to measure CH₄ emissions from rice planted pots during rice cultivation [26]. The gas collection chambers having a diameter of 55 cm and height of 100 cm. Gas samples were collected at different growth stages (tillering, flowering, and heading) to get the average CH₄ emissions during the cropping season. At first, gas chamber was placed in a water filled tray. The air gas samples were collected from chambers using 50 ml air-tight syringes at 0, 15 and 30 min intervals after chamber placement over the rice planted pot. CH₄ concentrations in the collected air samples were measured by gas chromatography (Shimadzu, GC-2015, Japan) packed with a Porapak NQ column (Q 80 - 100 mesh) and equipped with a flame ionization detector (FID). The temperatures of column, injector and detector were adjusted at 100˚C, 200˚C, and 200˚C respectively. The methane emission rate from a chamber is calculated with linear regression from the temporal increase of the CH₄ concentration in the chamber. Each emission rate is based on 3 samples, r-squared of the linear regression of the CH₄ concentration against time is typically > 0.95. The samples were analyzed at Professor Muhammad Hussain Central Laboratory of Bangladesh Agricultural Uniyersity Mymensingh.

CH₄ Emission Rate

CH₄ emission rate was estimated by following equation [26]

$$F = \rho \cdot V / A \cdot \Delta c / \Delta t \cdot 273 / T$$

where,

F = methane emission rate (mg CH$_4$ m^{-2} hr^{-1});

ρ = gas density (0.714 mg cm^{-3});

V = volume of chamber (m^3);

A = surface area of chamber (m^2);

$\Delta c / \Delta t$ = rate of increase of gas concentration in the chamber (mg m^{-3} hr^{-1});

T = (absolute temperature) = 273 + mean temperature in chamber (˚C).

Determination of SOC, pH, Eh, EC, exchangeable cations and other soil properties

Soil samples were collected at a depth of (0 - 15 cm) from the experimental pots. Collected soil samples were spread on brown paper and then plant roots, leaves, dried grass, etc. were picked up and removed through a 2 mm mesh sieve and stored in clean plastic containers for physical and chemical analysis. Soil redox potential (Eh) was measured by Eh meter (Model NU HACH, USA). Soil pH was also measured with the help of glass electrode p^H meter, using soil water suspension of 1:5. Organic carbon was determined volumetrically by wet oxidation method and the organic matter content was calculated by multiplying the percent organic carbon with the Van Bemmelen factor of 1.73. Total nitrogen content in soil was determined by Micro-Kjeldahl method. Digestion was made with conc. H$_2$SO$_4$ and catalyst mixture (K$_2$SO$_4$:CuSO$_4$·5H$_2$O: soil in the ratio of 100:10:1). Total-Nitrogen in the digest was estimated by distillation with 40% NaOH followed by titration of distillate trapped in H$_3$BO$_3$ with 0.01 N H$_2$SO$_4$. The exchangeable K, Ca and Na were determined from the extract by using flame photometer (FP 902-5, PG Instrument).

Digestion and determination of soil Cd, Fe, Zn and Mn

Determination of total soil Cd, Fe, Zn and Mn involves decomposition of the soil mineral and organic component that are responsible for binding Cd, Fe, Zn and Mn in the soil matrix and then the subsequent analysis of the Cd, Fe, Zn and Mn. The soil sample weighing 0.3 g for was taken into a dry clean digestion vessel. 3 mL trace element grade HNO$_3$ was added to the vessel and allowed to stand for overnight. The following day, 3 mL H$_2$O$_2$ was added and waited to minimize reaction with organic matter for 30 minutes. The digestion vessels were placed on a heating block and heated at a temperature slowly raised to 115˚C. Heating was normally stopped when the dense white fume occurred, after which the volume reduced to 3 - 4 mL. The digest was cooled, diluted to 10 mL with deionized water and filtered through Double Ring filter paper into plastic tube. Total cadmium, iron and zinc concentration were determined from this digest by the Graphite Furnace Atomizer (Model: SHIMADJU AA-7000) of Atomic Absorption Spectrophotometer (AAS) at Soil Science Laboratory of the Bangladesh Rice Research Institute, Gazipur.

Preparation of plant samples

N, P, K, S, and Zn contents in grain were determined. Grain samples were dried in an oven at about 650˚C for 48 hours and then ground in a grinding machine to pass through a 20 mesh sieve. The ground plant materials (grain)

were stored in small paper bags and placed in desiccators.

Digestion of plant samples for N determination

Plant extract was prepared by digesting dried samples first with concentrated sulphuric acid and then hydrogen peroxide for the determination of N. An amount of 0.1 g oven-dry ground samples was taken in 100 ml Kjeldahl flask. Five ml of conc. H_2SO_4 acid was added to the flask and the flask was allowed to stand for overnight. Then 3 ml hydrogen peroxide was added into the flask. After leaving for a while, the flask was heated and the temperature was raised slowly to 300°C. Heating was continued until the digest was clear and color less. After cooling, the content was transferred into a 100 ml volumetric flask, and the volume was made up to the mark with distilled water. A reagent blank was prepared in a similar manner. This digestion was performed particularly for N determination.

Digestion of plant samples for determination of P, K and S concentrations

Plant sample of grain 0.5 g was transferred into 100 ml digestion vessel. Ten ml of di-acid mixture (HNO_3:$HClO_4$ = 2:1) was added into the vessel. After leaving for a while, the flask was heated at a temperature slowly raised to 200°C. Heating was stopped when the dense white fume of $HClO_4$ occurred. After cooling, the contents were taken into a 50 ml volumetric flask and the volume was made with distilled water. The digests were used for the determination of P, K and S.

Determination of N, P, K and S from plant digest

Total-Nitrogen (N) in the digest was estimated by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01N H_2SO_4. Phosphorus was extracted from plant sample with 0.5 M $NaHCO_3$ solution at pH 8.5 following Olsen method. From 50 ml extract; 1 ml digest for grain sample was used. The phosphorus was determined by developing blue color by $SnCl_2$ reduction of phospho-molybdate complex and the color intensity was measured Colorimetrically at 660 nm. The K was determined from the extract by using Flame photometer. Sulphur was determined by using 5 ml digest samples (grain). Sulphur was determined by developing turbidity by adding 1 ml acid solution (20 ppm S as K_2SO_4 in 6N HCl) and 0.5 g $BaCl_2$ crystal. The intensity of turbidity was measured by Spectrophotometer at 420 nm wave length.

Statistical Analysis

Data on the plant characteristics and CH_4 emissions were analyzed using the analysis of variance (ANOVA) technique with the help of MSTAT-C computer package program and treatments mean differences were adjusted by Duncan's Multiple Range Test (DMRT).
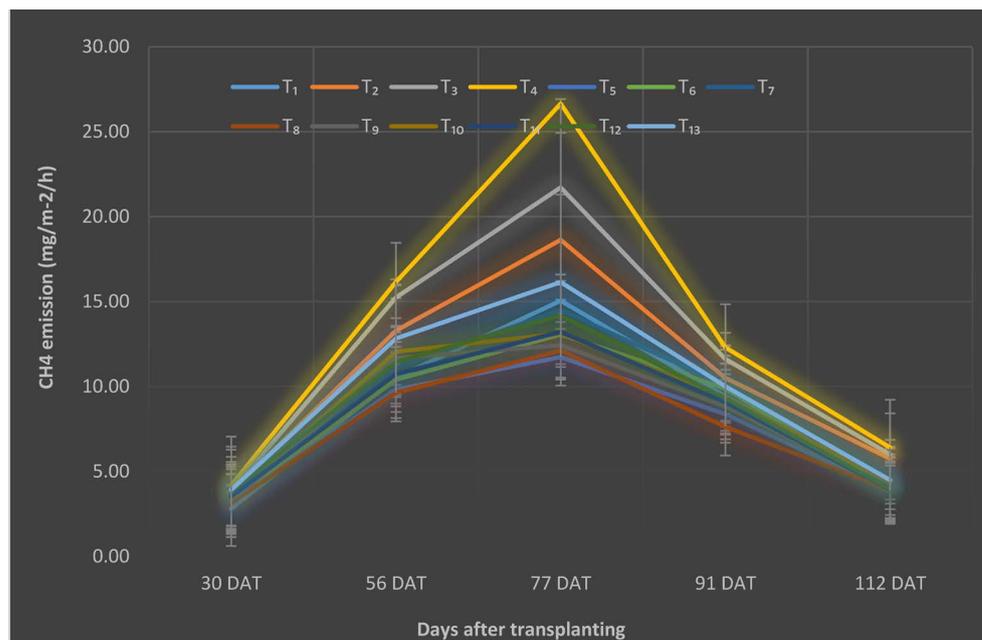
3. Results and Discussion

CH_4 emission and Yield scaled methane emission (GHGI)

CH_4 emission rates were significantly influenced with phospho-gypsum, biochar and trichocompost amendments (Figure 1). At active tillering stage (30 DAT), CH_4 emission ranged from 2.81 to 4.18 mg·m^{-2}·h^{-1} where the highest CH_4

emission was found (4.18 mg CH_4 $m^{-2} \cdot h^{-1}$) in treatment T_4 (100% NPKSZn + 75 mM NaCl) and the lowest CH_4 emission was recorded (2.81 mg CH_4 $m^{-2} \cdot h^{-1}$) in treatment T_1 (Non saline control).

At panicle initiation stage (56 DAT), treatment T_4 showed the highest (16.16 $mg \cdot m^{-2} \cdot h^{-1}$) CH_4 emission, while the lowest CH_4 emission (9.63 $mg \cdot m^{-2} \cdot h^{-1}$) was found in T_8 treatment (100% NPKSZn + 50 mM NaCl + Phospho-Gypsum). At flowering stage (77 DAT), CH_4 emission recorded 11.73 to 26.65 $mg \cdot m^{-2} \cdot h^{-1}$, where T_4 showed the highest CH_4 emission and the lowest CH_4 emission in T_5 (100% NPKSZn + 25 mM NaCl stress + Phospho-gypsum). With increasing rice growth and grain initiation (milking stage 91 DAT), CH_4 emission was found 7.64 to 12.31 $mg \cdot m^{-2} \cdot h^{-1}$, where treatment T_4 showed the highest (12.31 $mg \cdot m^{-2} \cdot h^{-1}$) and T8 (100% NPKSZn + 50 mM NaCl + Phospho-gypsum) revealed the lowest CH_4 emission (7.64 $mg \cdot m^{-2} \cdot h^{-1}$). At ripening stage (112 DAT), CH_4 emission was recorded 3.84 to 6.41 $mg \cdot m^{-2} \cdot h^{-1}$. The highest CH_4 emission was found in treatment T_4 (6.41 mg CH_4 $m^{-2} \cdot h^{-1}$) and the lowest emission (3.84 mg CH_4 $m^{-2} \cdot h^{-1}$) was recorded in T_6 (100% NPKSZn + 25 mM NaCl + Biochar). Therefore, this study revealed that CH_4 emissions were suppressed with phospho-gypsum and biochar amendments within the salinity level 25 mM to 50 mM, beyond this salinity level (at 75 mM) soil amendments were not effective to control CH_4 emissions. The least yield scaled CH_4 (0.167g CH_4/g yield) emission (GHGI) was

Here, T_1 denotes 100% NPK (moderate soil), T_2: 100% NPK + 25 mM NaCl stress, T_3: 100% NPK + 50 mM NaCl stress, T_4: 100% NPK + 75 mM NaCl stress, T_5: 100% NPK + 25 mM NaCl stress + Phospho-gypsum (100 g/pot), T_6: 100% NPK + 25 mM NaCl stress + Biochar (100 g/pot), T_7: 100% NPK + 25 mM NaCl stress + Trichocompost (100 g/pot), T_8: 100% NPK + 50 mM NaCl stress + Phospho-gypsum (100 g/pot), T_9: 100% NPK + 50 mM NaCl stress + Biochar (100 g/pot), T_{10}: 100% NPK + 50 mM NaCl stress + Trichocompost (100 g/pot), T_{11}: 100% NPK + 75 mM NaCl stress + Phosphogypsum (100 g/pot), T_{12}: 100%NPK + 75 mM NaCl stress + Biochar (100 g/pot), T_{13}: 100% NPK + 75 mM NaCl stress + Trichocompost (100 g/pot).

Figure 1. CH_4 emission during rice cultivation.

found in non-saline control (T1) treatment, which significantly increased with salinity levels 25 mM to 75 Mm and highest GHGI (1.19 g CH_4/g yield) was recorded in T4 treatment (100% NPKSZn + 75 mM NaCl). Among the amendments, phosphogypsum and biochar significantly decreased yield scaled CH_4 emission (GHGI) in salinity levels 25 mM to 75 mM.

It has been reported that gypsum amendments effectively reduced methane emission from rice paddy under saline and non-saline conditions [27] [28]. Under saline conditions (25 mM NaCl), CH_4 emissions were decreased by 23%, 27% and 61% with gypsum applications 1 Mg/ha, 2.5 Mg/ha and 5.0 Mg/ha respectively. On the other hand, CH_4 emissions were reduced by 22%, 52% and 73% with gypsum addition of 1 Mg/ha, 2.5 Mg/ha and 5.0 Mg/ha respectively, compared with non-saline control pot. The maximum decrease in cumulative seasonal CH_4 emissions was recorded 32.6% with Azolla-cyanobacteria plus phospho-gypsum amendments in paddy soils of Bangladesh [26]. It has been also reported that the CH_4 emission rate was significantly decreased with increasintg salt accumulation, but total CH_4 flux at EC 5.50 dS·m^{-1} treatment was lower than that of EC 9.48 dS·m^{-1} treatment [29]. It was also observed that organic amendments decreased CH_4 emission rates significantly inside the saline patch (average methane emission 251 - 334 mg m^{-2}·day^{-1}) compared with outside the saline patch (209 - 544 mg CH_4 m^{-2}·day^{-1}) [30]. It is assumed that the higher CH_4 production under saline conditions might be due to the Na$^+$ requirement of methanogens, however the lower CH_4 production over a specific salinity level might be due to Cl$^-$ toxicity under higher additions of NaCl [31]. Furthermore. the extend of CH_4 emission under saline conditions may be influenced by the existence of electron acceptors such as NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-} ions that accumulate in rice growing environments due to the osmotic stress of rice plants. The annual CH_4 flux from coastal salt marshes in the USA showed a strong negative correlation with soil salinity which was mainly attributed to increasing sulfate concentrations along the salinity gradient [32] [33]. It has already been reported that 55% - 72% total seasonal CH_4 emission could be reduced from wetland rice fields amended with gypsum (6.6 t/ha) in Philippines, probably due to sulfate-reducing bacteria outcompete methanogens [34]. This indicates that soil salinity accompanied by high sulfate levels suppress CH_4 emission much stronger than salinity caused by non-sulfate containing salts.

Changes of soil redox potential (Eh) value under different amendments

It was observed that redox potential (Eh) significantly decreased with the advancement of rice growth stages. Eh ranged from −59.04 to −90.13 mV at 30 DAT, −166.33 to −202.33 mV at 56 DAT, −188.67 to −249.67 mV at 77 DAT, −179.03 to −234.00 mV at 91 DAT and −128.68 to −185.83 mV at 112 DAT (Figure 2). At tillering stage (30 DAT), treatment T_5 (100% NPK + 25 mM NaCl + Phospho-gypsum) showed the less reduction of Eh (−59.0 mV), while treatment T_4 (100% NPKSZn + 75 mM NaCl) revealed the intense reduction condition (Eh −90.13 mV). At panicle initiation stage, (56 DAT) slightly reduced con-

NaCl stress, **T₄**: 100% NPK + 75 mM NaCl stress, **T₅**: 100% NPK + 25 mM NaCl stress + Phospho-gypsum (100 g/pot), **T₆**: 100% NPK + 25 mM NaCl stress + Biochar (100 g/pot), **T₇**: 100% NPK + 25 mM NaCl stress + Trichocompost (100 g/pot), **T₈**: 100% NPK + 50 mM NaCl stress + Phospho-gypsum (100 g/pot), **T₉**: 100% NPK + 50 mM NaCl stress + Biochar (100 g/pot), **T₁₀**: 100% NPK + 50 mM NaCl stress + Trichocompost (100 g/pot), **T₁₁**: 100% NPK + 75 mM NaCl stress +Phosphogypsum (100 g/pot), **T₁₂**: 100%NPK + 75 mM NaCl stress + Biochar (100 g/pot), **T₁₃**: 100% NPK + 75 mM NaCl stress + Trichocompost (100 g/pot).

Figure 2. Changes in soil Eh during rice cultivation.

dition was observed in phospho-gypsum treated (T₅) potted soil, while highly reduced condition (−202.33 mV) was found in treatment T₄ (100% NPKSZn + 75 mM NaCl). Similar trends of soil reduction were observed at flowering stage (77 DAT).

At 91 DAT, the lowest reduction of soil Eh was recorded (−179.03 mV) in the non-saline treatment T₁ pot (100% NPKSZn), while the highly reduced condition of soil Eh (−245 mV) was recorded in saline treatment T₄ (100% NPK + 75 mM NaCl) pot. At ripening stage (112 DAT), the lowest reduction was found in treatment T₅ (−128.68 mV), while maximum reduced condition was recorded in treatment T₄ (−185.83 mV). It has revealed that soil reductive condition developed with the rice growth stages and the decomposition of soil organic matter. However, exogenous application of phospho-gypsum, biochar and trichocompost in saline soil controlled the reduction of Eh compared to only salinity stress conditions. Among the amendments phospho-gypsum improved the soil redox potential by releasing SO_4^{2-} which acted as electron acceptor thereby reduced CH_4 emission. From our previous study it was) reported that the application of phospho-gypsum amendments with *Azolla*-cyanobacteria inoculated paddy soils improved the soil redox potential status [26].

Growth and yield attributes of BINA Dhan-10 under different amendments and salinity status

A significant decrease in plant height, number of panicles per hill, panicle length, number of filled grains per hill, grain yield and straw yield per hill of BINA dhan-10 were recorded with the increasing levels of salinity from 25 mM to 75 Mm (Table 1). On the other hand, phospho-gypsum, biochar and trichocompost

Table 1. Effect of soil amendments on rice growth, yield attributes and yield scaled methane emission from rice grown in Saline soil.

Treatments	Plant height (cm)	No. of panicles/ hill	Chlorophyll content	Panicle length (cm)	No. of filled grains/plant	Grain yield g/Pot	Shoot dry weight g/Pot	Root dry weight g/Pot	HI %	Total CH$_4$ emission g/Pot/season	GHGI CH$_4$ (g) evolved/grain yield (g)
T$_1$	96.17^a	24.6^a	46.6^a	19.81^a	3225.67^a	39.5^a	48.6^a	15.3^a	38.9^a	6.6	0.167
T$_2$	91.15^{abcd}	17.0^b	36.5^{ab}	16.86^{bcd}	2013.3^c	28.7^c	36.9^b	10.6^b	36.94^a	6.1	0.212
T$_3$	88.73^{abcd}	8.6^e	27.6^{cde}	15.74^{bcd}	855.67^{ef}	15.9^e	27.5^d	6.7^d	37.15^a	5.6	0.352
T$_4$	85.94^{cd}	3.6^g	19.6^e	14.56^b	353.33^g	4.5^f	7.5^f	3.5^e	24.90^c	4.9	1.19
T$_5$	94.74^{ab}	19.0^{ab}	39.8^{ab}	18.33^{ab}	2695.3^b	31.6^b	39.7^{ab}	11.5^{ab}	37.63^a	5.1	0.167
T$_6$	93.5^{abc}	18.0^{ab}	40.5^{abc}	17.70^{abc}	1933^c	33.5^{ab}	41.5^{ab}	12.6^{ab}	37.27^a	5.7	0.181
T$_7$	92.08^{abcd}	17.3^b	38.6^{abcd}	17.40^{abcd}	2126.67^c	29.8^{bc}	35.5^{ab}	10.6^b	37.41^a	5.8	0.196
T$_8$	91.4^{abcd}	10.3^c	33.46^{abcde}	17.28^{abcd}	1324.3^d	19.7^{cd}	30.8^{ab}	7.5^c	34.03^{ab}	4.5	0.228
T$_9$	90.72^{abcd}	10.7^c	35.27^{bcde}	16.59^{bcd}	1276.7^d	21.6^c	32.5^{bc}	8.0^{bc}	33.45^{ab}	4.8	0.233
T$_{10}$	89.48^{abcd}	9.5^d	30.76^{abcde}	16.35^{bcd}	1126.33^{de}	17.50^d	29.6^c	7.5^{cd}	25.03^c	5.0	0.285
T$_{11}$	88.42^{bcd}	4.3^f	27.6^{de}	15.78^{bcd}	584.67^{fg}	5.5^{ef}	8.6^d	4.0^e	36.54^a	4.1	0.761
T$_{12}$	87.74^{bcd}	4.6^f	26.7^e	15.24^{cd}	453.33^g	6.0^{ef}	9.0^d	3.9^e	28.75^{bc}	4.5	0.691
T$_{13}$	86.28^{cd}	4.3^f	24.8^e	14.77^{cd}	439.33^g	4.8^f	8.5^e	3.5^e	23.77^c	4.7	0.979
LSD$_{0.05}$	6.57	4.02	4.10	2.62	327.50	4.05	4.30	2.62	5.10	2.1	0.25
CV (%)	4.35	19.72	7.55	9.36	13.39	11.39	9.54	13.78	7.55	4.8	13.6
Level of significance	*	**	**	**	**	***	***	**	**	**	***

** indicates significant at 1% level of probability, *indicates significant at 5% level of probability, CV indicates Co-efficient of variation, treatments with same letters do not differ significantly, but different letters differ significantly.

application significantly increased the above mentioned plant growth and yield components of rice under different salt stress conditions. However, salinity with 50 mM to 75 mM NaCl stress severely affected rice growth and yield components, eventhough phospho-gypsum, biochar and trichocompost applied.

It is important to mention that phospho-gypsum amendments significantly increased plant height at 25 mM NaCl stress condition (Table 1). Soil salinity caused a decrease in the number of panicles per hill of BINA dhan-10 (Table 2). Panicles number drastically decreased at 50 mM and 75 mM soil salinity levels. However, phospho-gypsum, biochar and trichocompost amendments increased the number of panicles/hill under salt stress conditions. Number of panicles ranged from 24.66 in T$_1$ (100% NPK) to 3.66 in T$_4$ (100% NPKSZn + 75 mM NaCl stress). It was observed that phospho-gypsum, biochar and trichocompost amendments in 25 mM NaCl level significantly increased the panicles/hill compared to those of only 25 mM NaCl treated plants. It has been shown that the number of panicles per hill in rice decreased with salinity level 6 - 10 dS·m^{-1} [35], at salinity of 8.5 dS·m^{-1} in eighteen advanced rice genotypes [36]. Soil salinity caused a significant decrease in chlorophyll content, panicle length and the number of filled grains per hill in BINA dhan-10 (Table 2), however phos-

pho-gypsum, biochar and trichocompost amendments in saline soils treatments (T_5 to T_{13}) improved the mentioned yield parameters. Phospho-gypsum amendments at 25 mM NaCl salinity level significantly increased the number of filled grains compared to only 25 mM NaCl salt stress condition [37].

Plants exposed to salinity levels showed decreased grain yield in BINA dhan-10 (Table 1). Interesting to mention that phospho-gypsum, biochar and trichocompost amendments significantly increased grain yield under salt stress condition. At 25 mM NaCl salt stress condition phospho-gypsum amendment showed the highest grain yield of rice among the treatments. It has been shown that the gypsum application alone or combined with zinc (Zn) increased rice grain yield in saline soil, while decreased soil salinity level [38]. Rice genotypes IR 55179, IR 71889, IR 71902 and IR 72048 showed relatively good performance in terms of grain yield at lower salinity levels (4 and 8 dS·m^{-1}) by losing 12% - 26% at 4 dS·m^{-1} and 41% - 47% for IR 55179 and IR 71889 at 8 dS·m^{-1} [39]. It was observed that harvest index of rice decreased with increasing salinity levels, however phospho-gypsum, biochar and trichocompost amendments in salinity stressed treatments (T_5 to T_{13}) increased harvest index. The highest harvest index (38.49%) was found in the treatment T_1 (100% NPK), while the lowest harvest index (24.90%) was found in T_4 (100% NPKSZn + 75 mM NaCl stress). It has

Table 2. Effect of soil amendments on nutrients uptake by rice grain (g/plant).

Treatments	N	P	K	S	Zn
T_1	0.427[a]	0.185[a]	0.134[a]	0.102[a]	0.005[a]
T_2	0.348[c]	0.146[abcd]	0.109[b]	0.060[b]	0.003[bc]
T_3	0.157[f]	0.065[ef]	0.048[e]	0.027[de]	0.002[cde]
T_4	0.035	0.015[f]	0.011[f]	0.006[f]	0.0004[bcde]
T_5	0.395[ab]	0.174[a]	0.128[a]	0.089[a]	0.004[b]
T_6	0.385[b]	0.158[ab]	0.127[a]	0.067[b]	0.003[bc]
T_7	0.351[c]	0.147[abc]	0.114[ab]	0.063[b]	0.003[bc]
T_8	0.205[de]	0.110[bcde]	0.084[c]	0.055[bc]	0.0023[bcd]
T_9	0.244[de]	0.091[cde]	0.079[cd]	0.040[cd]	0.0020[bcde]
T_{10}	0.195[e]	0.083[de]	0.063[d]	0.036[d]	0.0020[bcde]
T_{11}	0.058[g]	0.025[f]	0.016[f]	0.011[ef]	0.0005[de]
T_{12}	0.05[g]	0.027[cde]	0.022[f]	0.011[ef]	0.0007[de]
T_{13}	0.044[g]	0.020[f]	0.014[f]	0.007[f]	0.0005[e]
LSD$_{0.05}$	0.075	0.053	0.017	0.017	0.002
CV (%)	19.92	29.89	28.32	28.32	40.84
Level of significance	**	**	**	**	**

** indicates significance at 1% level of probability, treatments with same letters do not differ significantly, but different letters differ significantly.

been reported that harvest index decreased with increasing salinity levels, while gypsum application significantly increased harvest index of rice [40]. Exogenous proline application increased growth and yield components of rice cultivars (BINA Dhan 8 and BRRI Dhan 29) at 25 mM NaCl stress, however, a drastic reduction in growth and yield of rice cultivars were observed at 50 mM NaCl stress [41].

Nutrients uptake by grain

It was found that N, P, K, S and Zn uptake by rice grain were significantly higher in non-saline control treatment (T_1) compared to the saline treatments (Table 2).

Nutrients uptake by rice grain were decreased with increasing salinity levels. The least nutrients uptake by grain was recorded in highly saline Treatment T_4. At 25 mM salinity level, phospho-gypsum, biochar and trichocompost amended rice plants showed higher nutrients uptake capability in rice grain compared to other saline treatments. The ratio of Na^+/K^+ increased in the roots and shoots of rice seedlings (BRRI Dhan 47) under salt-stressed (200 mM NaCl) condition, while decreased with Ca supplementation [42]. Salt-stressed seedlings supplemented with exogenous Ca recovered from water loss, chlorosis and growth inhibition. It is assumed that Na displaced Ca from cell membrane, thereby increased intracellular Na^+ under high NaCl stress conditions. As a consequence, Na content exceeded that of K and resulted a higher Na/K ratio as well as nutrient imbalance in rice plant under salt-stress conditions [43].

Effect of soil amendments on soil properties

After rice harvest soil organic carbon (SOC) content was found 1.22% to 1.84% (Table 3), where maximum SOC content (1.84%) was recorded in non-saline control treatment (T_1) and the least SOC (1.22%) was found in T_4 treated potted soil (100% NPKSZn + 75 mM salinity).

It was observed that SOC content was decreasing with increasing salinity levels. Soil amendments with phospho-gypsum, biochar and trichocompost in all salinity levels increased soil organic carbon contents compared to non-amended saline soil. The higher organic carbon content was recorded in T_5, T_6 and T_7 treatments compared to T_2 (25 mM salinity level). Among the salinity treated pots treatment T_6 (100% NPKSZn + 25 mM NaCl stress + Biochar (100 g/pot)showed the maximum SOC accumulation, while the lowest SOC content was recorded in T_4 (100% NPKSZn + 75 mM NaCl). Biochar, phospho-gypsum and trichocompost amended soils showed higher SOC contents compared to Non-amended soils. Total N content in post-harvest soil varied significantly (Table 3), the maximum T-N (0.24% to 0.25%) was found in T1 (100% NPKSZn in Non-saline control), T_5 (100% NPKSZn + 25 mM NaCl + phospho-gypsum 100 g/pot) and T6 (100% NPKSZn + 25 mM NaCl + Biochar) treated soil, while the lowest TN (0.14%) was observed in highly salinity treated soil (T4 100% NPKSZn + 75 mM NaCl). The total N content increased significantly with the application of phospho-gypsum, biochar and trichocompost in all salinity levels. Soil pHand electrical conductivity (EC) varied significantly among the treatments,

Table 3. Effect of soil amendments on post-harvest soil properties.

Treatments	Organic carbon (OC %)	Total N (%)	EC (dS/m)	Soil pH	Available P (ppm)	Available S (ppm)	Exchangeable K (meq/100 g)	Exchangeable Na (meq/100 g)	Exchangeable Ca (cmol+ Kg⁻¹)	Available Zn (ppm)	Available Mn (ppm)	Available Fe (ppm)	K⁺/Na⁺ ratio (soil)	Ca⁺/Na⁺ ratio (soil)
T₁	1.84ᵈᵉ	0.25ᵃ	0.275	7.16ᵈᵉᶠ	25.6ᵇᶜ	20.65ᵇ	**0.47**ᵃᵇ	2.70ᵉ	3.07ᶜᵈ	0.0105ᶜ	**0.055**ᵃ	**0.076**ᵃ	4.54	3.27
T₂	1.64ᵉᶠ	0.19ᵇ	4.1	7.30ᵇᶜ	21.3ᶜ	15.35ᶜᵈ	0.31ᶠ	3.50ᵇᶜ	2.52ᵈ	0.0199ᵃ	0.045ᵇ	0.065ᵇ	4.15	3.02
T₃	1.46ᶠᵍ	0.16ᶜᵈ	6.7	7.35ᵇ	20.6ᶜ	12.73ᵈ	0.24ᵉ	3.80ᵃᵇ	2.39ᵈ	0.0105ᶜ	0.040ᶜ	0.060ᶜ	3.67	2.68
T₄	1.22ᵍ	0.14ᵈ	10.3	**7.48**ᵃ	19.8ᶜ	10.52ᵈ	0.18ᶠ	3.95ᵃ	1.97ᵈ	0.0107ᶜ	0.038ᶜ	0.058ᵈ	3.25	2.33
T₅	1.73ᵃ	0.25ᵃ	**3.3**	**6.90**ᵍ	29.7ᵃᵇ	**24.75**ᵃ	0.45ᵃᵇ	3.05ᵈ	5.63ᵃ	0.0109ᶜ	**0.052**ᵃᵇ	**0.075**ᵃ	**5.30**	**5.65**
T₆	1.79ᵃᵇ	0.24ᵃ	3.8	7.20ᶜ	31.6ᵃᵇ	21.36ᵃᵇ	**0.49**ᵃ	3.15ᶜᵈ	4.56ᵃᵇ	0.0112ᵇᶜ	0.050ᵃᵇ	0.068ᵃᵇ	**5.29**	**5.56**
T₇	1.75ᵃᵇᶜ	0.22ᵃᵇ	3.9	7.15ᵈ	30.23ᵃᵇ	20.67ᵇ	0.41ᵇ	3.20ᶜᵈ	4.17ᵇᶜ	0.0159ᵃᵇ	0.048ᵃᵇ	0.066ᵃᵇ	**5.09**	**5.13**
T₈	1.55ᵃᵇᶜ	0.21ᵃᵇ	4.6	7.15ᵈ	30.34ᵃᵇ	20.74ᵇ	0.36ᶜ	3.20ᵇᶜᵈ	5.44ᵃᵇ	0.0116ᵇᶜ	0.047ᵃᵇ	0.067ᵃᵇ	4.70	4.72
T₉	1.6ᵃᵇᶜᵈ	0.19ᵇ	5.1	7.25ᵇᶜ	33.82ᵃ	18.65ᵇᶜ	0.38ᵇᶜ	3.30ᶜ	4.65ᵃᵇ	0.0107ᶜ	0.047ᵃᵇ	0.065ᵇ	4.45	4.67
T₁₀	1.55ᵇᶜᵈ	0.18ᵇᶜ	5.3	7.19ᶜᵈ	32.47ᵃ	16.3ᶜ	0.35ᶜ	3.40ᵇᶜ	4.32ᵃᵇ	0.0096ᶜ	0.045ᵇ	0.062ᵇᶜ	4.25	4.36
T₁₁	1.35ᵈᵉ	0.16ᶜᵈ	8.5	7.20ᶜᵈ	28.61ᵃᵇ	17.8ᵇᶜ	0.30ᵈ	3.56ᵇᶜ	5.32ᵃᵇ	0.0110ᵇᶜ	0.039ᶜ	0.065ᵇ	4.10	4.25
T₁₂	1.38ᶜᵈᵉ	0.18ᵇᶜ	8.9	7.30ᵇᶜ	29.73ᵃᵇ	15.36ᵈ	0.35ᶜ	3.58ᵇᶜ	4.58ᵃᵇ	0.0122ᵇᶜ	0.042ᵇᶜ	0.063ᵇᶜ	3.95	4.11
T₁₃	1.30ᵉᶠ	0.16ᶜᵈ	9.3	7.33ᵇ	29.02ᵃᵇ	12.09ᵉ	0.30ᵈ	3.70ᵇ	4.46ᵃᵇ	0.0114ᵇᶜ	0.040ᵇᶜ	0.060ᶜ	3.78	4.02
LSD₀.₀₅	0.352	0.053	2.35	0.106	5.71	5.05	0.139	0.598	1.17	0.004	0.008	0.006	0.39	0.35
Level of Sig.	**	**	**	**	**	**	**	**	**	**	**	**	**	**

Here, ** indicates significant at 1% level of probability; NS denotes Non-significant. T₁ denotes 100% NPK (moderate soil), T₂: 100% NPK + 25 mM NaCl stress, T₃: 100% NPK + 50 mM NaCl stress, T₄: 100% NPK + 75 mM NaCl stress, T₅: 100% NPK + 25 mM NaCl stress + Phospho-gypsum (100 g/pot), T₆: 100% NPK + 25 mM NaCl stress + Biochar (100 g/pot), T₇: 100% NPK + 25 mM NaCl stress + Trichocompost (100 g/pot), T₈: 100% NPK + 50 mM NaCl stress + Phospho-gypsum (100 g/pot), T₉: 100% NPK + 50 mM NaCl stress + Biochar (100 g/pot), T₁₀: 100% NPK + 50 mM NaCl stress + Trichocompost (100 g/pot), T₁₁: 100% NPK + 75 mM NaC stress + Phospho-gypsum (100 g/pot),T₁₂: 100% NPK + 75 mM NaCl stress + Biochar (100 g/pot), T₁₃: 100% NPK + 75 mM NaCl stress + Trichocompost (100 g/pot). In each column treatments means followed by same letters do not differ significantly.

probably due to salinity levels and the effects of phospho-gypsum, biochar and trichocompost on soil during rice cultivation (Table 3). The higher soil pH values were recorded in saline treatments T2 (100% NPKSZn + 25 mM NaCl), T3 (100% NPKSZn + 50 mM NaCl), and T₄ (100% NPKSZn + 75 mM NaCl), while soil amendments with PG, biochar, and Trichocompost lowered pH value. This may be due to acidifying effect of organic acids produced from the decomposition of organic materials and Phosphogypsum. Although soil EC increased with the increasing salinity levels however, soil amendments with phospho-gypsum, biochar and trichocompost at varying salinity levels improved tolerance to salinity by reducing soil pH and EC value. Under highly saline condition, the highest EC value (10.3 dS/m) recorded in T4 (100% NPK + 75 mM NaCl) treatment, which was decreased to 8.5, 8.9, 9.3 dS/m due to phospho-gypsum, biochar and trichocompost amendments. At moderate salinity level T2 (100% NPK + 25 mM NaCl), EC value was 4.1 dS/m, which was decreased to 3.3, 3.8 and 3.9 dS/m with phospho-gypsum, biochar and trichocompost amendments, respectively.

At 50 mM NaCl salinity level, EC value was 6.7 dS/m, which was decreased to 4.6, 5.1 and 5.3 dS/m with phospho-gypsum, biochar and trichocompost amendments, respectively. The decrease in EC values with soil amendments may be due to the displacement of Na^+ with Ca^{2+} ion from the exchange site or due to leaching of soluble salts. It was found that gypsum application in combination with calcium chloride improved the soil chemical properties by reducing the EC, and soil pH [44]. Furthermore, gypsum amendments with or without farm manure and commercial humic acid substances significantly decreased the soil pH (8.26%), electrical conductivity (EC 6.35 dS/m to 2.65 dS/m) and sodium adsorption ratio (SAR 26.56 to 11.60), while increased root length (9.17 cm to 22.6 cm) and paddy yield (695.7 kg/ha to 1644 kg/ha) under [45].

A significant decrease in EC of saline-sodic soils with organic amendments was reported [46], which could be due to accelerated leaching of soluble salt ions with organic matter amendments. The available Phosphorus (P) and Sulphur (S) contents were found decreasing with increasing salinity levels (**Table 3**), however, biochar, phospho-gypsum and trichocompost amendments increased their availability in all salinity levels. The highest P content in soil (33.82 ppm) was observed in T_9 (100% NPK + 50 mM NaCl + Biochar) and the lowest value (19.8 ppm) was recorded in T_4 (100% NPK + 75 mM NaCl). The highest S content of (24.67 ppm) was observed in treatment T_5 and the lowest S content (13.52 ppm) was recorded in T_4. Phospho-gypsum amendments in saline soil effectively reduced salinity by increasing S content in soil. The exchangeable potassium (K) and exchangeable Ca contents were found decreasing with increasing salinity levels (**Table 3**), however, biochar, phospho-gypsum and trichocompost amendments increased their availability in all salinity levels. The maximum exchangeable K level was observed at 25 mM salinity level with biochar, phospho-gypsum and trichocompost amendments (**Table 3**). Exchangeable Ca content soil ranged from 1.97 - 5.63 meq/100g. The maximum value was found from T_5 treatment and lowest in treatment T_4 respectively. The content of exchangeable Ca varied significant due to the application of phospho-gypsum. In this experiment, the exchangeable Na varied 2.56 - 4.03 meq/100 g (**Table 3**) where the least exchangeable Na^+ was found in non-saline control treatment (T_1) and the higher exchangeable Na^+ ions were found in saline treatments (T2, T3 and T_4). However, phospho-gypsum, biochar and trichocompost amendments in saline soil effectively decreased exchangeable Na^+ content in soil, while increased Ca^{2+} ion in the exchangeable site. It has been reported that biochar incorporation increased potato yield and ameliorated soil salinity stress by adsorbing Na^+ under 25 mM and 50 mM salinity levels [47]. In this study, the molar ratios of K^+/Na^+, and Ca^+/Na^+ in the extract of phospho-gypsum, biochar and trichocompost amended saline soils were found higher compared to non-amended saline soil (**Table 3**). The highest ratios of K^+/Na^+ and Ca^+/Na^+ were observed at 25 mM salinity level with phospho-gypsum amendments followed by biochar and trichocompost amendments. It was also showed that the addition of Ca^{2+} (through gypsum or phos-

phogypsum) significantly enhanced the selectivity for K^+ over Na^+ in rice at 25 mM NaCl salinity level [43]. Application of gypsum decreased exchangeable Na concentration in soil, while increased Zn availability in saline soil. Biochar application to saline-sodic paddy soil improved soil salinity stress, reduced plant sodium (Na) uptake and increased rice yield and quality in saline-sodic soil [47].

In our experiment, Zn availability was found higher in the organic amended potted soils compared to non-amended saline soil. The available Mn and Fe contents were increased in the amended potted saline soils (Table 3). It has been reported that biochar absorbs leachate, thereby enrich organic matter, total soluble N, available P, K, and nutrient retention capacity of soil. The increase in K, Ca, Mg, and CEC in biochar-applied soils was probably due to the presence of cation exchange sites on the surface of biochar. In this study, addition of NaCl to maintain salinity levels at 25 mM or 50 mM or 75 mM seriously affected the uptake of water, essential nutrients for rice growth and soil properties, which ultimately hampered grain yield and yield scaled methane emission.

4. Conclusion

This study confirmed that CH_4 emissions were suppressed with phospho-gypsum and biochar amendments within the salinity level 25 mM to 50 mM, however, beyond this salinity limit soil amendments could not effectively control CH_4 emission rates. The least yield scaled CH_4 (0.167 g CH_4/g yield) emission (GHGI) was found in non-saline control (T1) treatment, which significantly increased with salinity levels 25 mM to 75 Mm and the maximum GHGI (1.19 g CH_4/g yield) was recorded in T4 treatment (100% NPKSZn + 75 mM NaCl). It was also found that rice plant growth and yield components such as plant height, number of panicle·hill^{-1}, panicle length, chlorophyll contents, number of filled grains, grain yield and harvest index were significantly increased with biochar, phospho-gypsum and trichocompost amendments under 25 mM NaCl salinity level, beyond which (under 50 - 75 mM) a sharp decrease in growth and yield components were recorded. The overall soil properties such as organic matter content, soil pH, redox status (Eh), available P, available S, exchangeable K^+, exchangeable Ca^{2+}, etc. were improved with the biochar, phospho-gypsum and trichocompost amendments. At 25 mM NaCl salinity level the amendments were found most effective in reducing exchangeable Na^+, EC and soil pH. On an average, the application of phospho-gypsum, biochar and trichocompost with 25 mM NaCl stressed condition showed better performance in terms of rice growth, yield and soil properties compared to other treatments. Therefore, the present study confirmed that phospho-gypsum, biochar and trichocompost amendments in saline soils improved tolerance to salinity in rice by increasing K^+/Na^+, Ca^{2+}/Na^+ ratios, while decreasing yield scaled CH_4 emissions within the salinity level 25 mM to 75 mM NaCl.

Acknowledgements

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Szabolcs, I. (1989) Salt Affected Soils. CRC Press, Boca Raton.

[2] Maji, B. and Bandyopadhyay, B.K. (1991) Micro-Nutrient Research in Coastal Salt Affected Soils. *Journal of Indian Society of Coastal Agricultural Research*, **9**, 219-223.

[3] Nazar, R., Iqbal, N., Massood, A., Syeed, S. and Khan, N.A. (2011) Understanding the Significance of Sulfur in Improving Salinity Tolerance in Plants. *Environmental and Experimental Botany*, **70**, 80-87. https://doi.org/10.1016/j.envexpbot.2010.09.011

[4] SRDI (2010) Saline Soils of Bangladesh. SRMAF Projects, Ministry of Agriculture, Bangladesh, 1-60.

[5] IPCC (2007) The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Working Paper No. 57, Cambridge University Press, Cambridge, UK.

[6] Haque, S.A. (2006) Salinity Problem and Crop Production in Coastal Regions of Bangladesh. *Pakistan Journal of Botany,* **38**, 1359-1365.

[7] Mishra, B. and Battachargy, R.K. (2001) Varietal Tolerance to Alkalinity in Rice. In: *Proceedings of International Symposium on Salt Affected Soils*, Central Soil Salinity Research Institute, Karnal, 502-507.

[8] Siringam, K., Jantawang, N., Cha-um, S. and Kirdmanee, C. (2011) Salt Stress Induced Ion Accumulation, Ion Homeostasis, Membrane Injury and Augar Contents in Salt-Sensitive Rice (*Oryza sativa* L. spp. Indica) Roots under Isoosmotic Conditions. *African Journal of Biotechnology*, **10**, 1340-1346.

[9] Surekha, R.P., Mishra, B., Gupta, S.R. and Rathore, A. (2008) Reproductive Stage Tolerance to Salinity and Alkalinity Stresses in Rice Genotypes.

[10] Rahman, M.S., Haque, M.A. and Islam, M.T. (2015) Salinity Affects Flag Leaf Chlorophyll and Yield Attributes of Rice Genotypes. *Journal of Bioscience and Agriculture Research*, **4**, 80-85. https://doi.org/10.18801/jbar.040215.46

[11] Mahdy, A.M. (2011) Comparative Effects of Different Soil Amendments on Amelioration of Saline-Sodic Soils. *Journal of Soil and Water Research*, **6**, 205-216. https://doi.org/10.17221/11/2011-SWR

[12] Gupta, R.K. and Abrol, I.P. (1990) Salt-Affected Soils: Their Reclamation and Management for Crop Production. In: Lal, R. and Stewart, B.A., Eds., *Advances in Soil Science. Advances in Soil Science*, Vol 11, Springer, New York, 223-288. https://doi.org/10.1007/978-1-4612-3322-0_7

[13] Bachelet, D. and Neue, H.U. (1993) Methane Emission from Wetland Rice Areas of Asia. *Chemosphere*, **26**, 219-237. https://doi.org/10.1016/0045-6535(93)90423-3

[14] Lehmann, J. and Joseph, S. (2009) Biochar for Environmental Management: Science and Technology. Earthscan, London, 1-12.

[15] Clark, G., Dodgshun, N., Sale, P. and Tang, C. (2007) Changes in Chemical and Biological Properties of a Sodic Clay Subsoil with Addition of Organic Amendments. *Soil Biology and Biochemistry*, **39**, 2806-2817. https://doi.org/10.1016/j.soilbio.2007.06.003

[16] Zhang, W.M., Meng, J., Wang, J.Y., Fan, S.X. and Chen, W.F. (2013) Effect of Biochar on Root Morphological and Physiological Characteristics and Yield in Rice.

Acta Agronomica Sinica, **39**, 1445-1451.
https://doi.org/10.3724/SP.J.1006.2013.01445

[17] Abrishamkesh, S., Gorji, M., Asadi, H., Bagheri-Marandi, G.H. and Pourbabaee, A.A. (2015) Effects of Rice Husk Biochar Application on the Properties of Alkaline Soil and Lentil Growth. *Plant, Soil and Environment*, **61**, 475-482.
https://doi.org/10.17221/117/2015-PSE

[18] Ghafoor, A., Murtaza, G., Ahmad, B. and Boers, T.M. (2008) Evaluation of Amelioration Treatments and Economic Aspects of Using Saline-Sodic Water for Rice and Wheat Production on Salt-Affected Soils under Arid Land Conditions. *Irrigation and Drainage*, **57**, 424-434. https://doi.org/10.1002/ird.377

[19] Muhammad, D. and Khattak, R.A. (2011) Wheat Yield and Chemical Composition as Influenced by Integrated Use of Gypsum, Pressmud and FYM in Saline-Sodic Soil. *Journal of the Chemical Society of Pakistan*, **33**, 82-86.

[20] Hori, Inubushi KK, Matsumoto S, Wada H (1993) Competition for Hydrogen between Methane Formation and Sulfate Reduction in the Paddy Soil. *Japanese Journal of Soil Science and Plant Nutrition*, **1**, 572-572.

[21] Ali, M.A., Lee, C.H., Kim, S.Y. and Kim, P. (2009) Effect of Industrial By-Products Containing Electron Acceptors on Mitigating Methane Emission during Rice Cultivation. *Waste Management*, **29**, 2759-2764.
https://doi.org/10.1016/j.wasman.2009.05.018

[22] Khattak, S.G., Haq, I.U., Malik, A., Khattak, M.J., Naveedullah (2007) Effect of Various Levels of Gypsum Application on the Reclamation of Salt Affected Soil Grown under Rice Followed by Wheat Crop. *Sarhad Journal of Agriculture*, **23**, 675-680.

[23] Evelin, H., Kapoor, R. and Giri, B. (2009) *Arbuscular mycorrhizal* Fungi in Alleviation of Salt Stress: A Review. *Annals of Botany*, **104**, 1263-1280.
https://doi.org/10.1093/aob/mcp251

[24] Estrada, B., Aroca, R., Barea, J.M. and Ruiz-Lozano, J.M. (2013) Native *Arbuscular mycorrhizal* Fungi Isolated from a Saline Habitat Improved Maize Antioxidant Systems and Plant Tolerance to Salinity. *Journal of Plant Science*, **201-202**, 42-51.
https://doi.org/10.1016/j.plantsci.2012.11.009

[25] Anonymous (2007) IPM Lab Biopesticide ed. M. B. Meah, IPM Lab, Bangladesh Agricultural University, Mymensingh.

[26] Ali, M.A., Kim, P.J. and Inubushi, K. (2015) Mitigating Yield-Scaled Greenhouse Gas Emission through Combined Application of Soil Amendments: A Comparative Study between Temperate and Subtropical Rice Paddy Soils. *Science of the Total Environment*, **529**, 140-148. https://doi.org/10.1016/j.scitotenv.2015.04.090

[27] Ali, M.A., Lee, C.H. and Kim, P.J. (2007) Effect of Phospho-Gypsum on Reduction of Methane Emission from Rice Paddy Soil. *Korean Journal of Environmental Agriculture*, **26**, 131-140. https://doi.org/10.5338/KJEA.2007.26.2.131

[28] Theint, E.E., Bellingrath-Kimura, S.D., Oo, A.Z. and Motobayashi, T. (2016) Influence of Gypsum Amendment on Methane Emission from Paddy Soil Affected by Saline Irrigation Water. *Frontiers in Environmental Science*, **3**, Article No. 79.
https://doi.org/10.3389/fenvs.2015.00079

[29] Lim, C.H., Kim, S.Y., Jeong, S.T., Kim, G.Y. and Kim, J. (2013) Effect of Salt Concentration on Methane Emission in a Coastal Reclaimed Paddy Soil Condition. *Korean Journal of Environmental Agriculture*, **32**, 252-259.
https://doi.org/10.5338/KJEA.2013.32.4.252

[30] Supparattanapan, S., Saenjan, Cecile Q, Maeght, J.L. and Olivier, G. (2019) Salinity and Organic Amendment Effects on Methane Emission from a Rain-Fed Saline

Paddy Field. *Soil Science and Plant Nutrition*, **55**, 142-149.
https://doi.org/10.1111/j.1747-0765.2008.00330.x

[31] Abdelgadir, E.M., Oka, M. and Fujiyama, H. (2005) Nitrogen Nutrition of Rice Plants under Salinity. *Biologia Plantarum*, **49**, 99-104.
https://doi.org/10.1007/s10535-005-0104-8

[32] Delaune, R.D., Smith, C.J. and Patrick Jr., W.H. (1983) Methane Release from Gulf Coast Wetlands. *Tellus*, **35B**, 8-15.
https://doi.org/10.1111/j.1600-0889.1983.tb00002.x

[33] Bartlett, K.B., Bartlett, D.S., Harriss, R.C. and Sebacher, D.I. (1987) Methane Emissions along a Salt Marsh Salinity Gradient. *Biogeochemistry*, **4**, 183-202.
https://doi.org/10.1007/BF02187365

[34] Denier van der Gon, H.A.C. and Neue, H.U. (1994) Impact of Gypsum Application on the Methane Emission from a Wetland Rice Field. *Global Biogeochemical Cycles*, **8**, 127-134. https://doi.org/10.1029/94GB00386

[35] Islam, M.T., Sharma, P.C., Gautam, R.K., Singh, D., Singh, S., Panesar, B. and Ali, S. (2011) Salt Tolerance in Parental Lines of Rice Hybrids through Physiological Attributes Molecular Markers. *International Journal of Experimental Agriculture*, **2**, 1-7.

[36] Ali, Y., Aslam, Z., Ashraf, M.Y. and Tahir, G.R. (2004) Effect of Salinity on Chlorophyll Concentration, Leaf Area, Yield and Yield Components of Rice Genotypes Grown under Saline Environment. *International Journal of Environmental Science & Technology*, **1**, 221-225. https://doi.org/10.1007/BF03325836

[37] Kaniz, F. and Khan, M.H.R. (2013) Reclamation of Saline Soil Using Gypsum, Rice Hull and Saw Dust in Relation to Rice Production. *Journal of Advanced Scientific Research*, **4**, 1-5.

[38] Hafez, E.M., Hassan, E.H.A.E.I., Gaafar, I.A. and Seleiman, M.A. (2015) Effect of Gypsum Application and Irrigation Intervals on Clay Saline-Sodic Soil Characterization, Rice Water Use Efficiency, Growth, and Yield. *Journal of Agricultural Science*, **7**, No. 12. https://doi.org/10.5539/jas.v7n12p208

[39] Girma, B.T., Ali, H.M. and Gebeyaneh, A.A. (2017) Effect of Salinity on Final Growth Stage of Different Rice (*Oryza sativa* L.) Genotypes. *Asian Journal of Agricultural Research*, **11**, 1-9. https://doi.org/10.3923/ajar.2017.1.9

[40] Khan, R., Gurmani, A.R., Khan, M.S. and Gurmani, A.H. (2008) Effect of Gypsum Application on Rice Yield under Wheat Rice System. *International Journal of Agriculture & Biology*, **4**, 535-538.

[41] Papon, K.D., Murata, Y., Haque, M.A. and Ali, M.A. (2015) Effect of Soil Salinity and Exogenous Proline Application on Rice Growth, Yield, Biochemical and Antioxidant Enzyme Activities. *EC Agriculture*, **2**, 229-240.

[42] Rahman, A., Nahar, K., Hasanuzzaman, M. and Masayuki, F. (2016) Calcium Supplementation Improves Na^+/K^+ Ratio, Antioxidant Defense and Glyoxalase Systems in Salt-Stressed Rice Seedlings. *Frontiers in Plant Science*, **7**, 609.
https://doi.org/10.3389/fpls.2016.00609

[43] Wu, G.Q. and Wang, S.M. (2012) Calcium Regulates K^+/Na^+ Homeostasis in Rice (*Oryza sativa* L.) under Saline Conditions. *Plant, Soil and Environment*, **58**, 121-127.
https://doi.org/10.17221/374/2011-PSE

[44] Khan, M.Z., Azom, M.G., Sultan, M.T., Mandal, S., Islam, M.A., Khatun, R., Billah, S.M. and Ali, A.H.M.Z. (2019) Amelioration of Saline Soil by the Application of Gypsum, Calcium Chloride, Rice Husk and Cow Dung. *Journal of Agricultural Chemistry and Environment*, **8**, 78-91 http://www.scirp.org/journal/jacen.

https://doi.org/10.4236/jacen.2019.82007

[45] Shaaban, M., Abid, M. and Abou-Shanab, R.A.I. (2013) Amelioration of Salt Affected Soils in Rice Paddy System by Application of Organic and Inorganic Amendments. *Plant, Soil and Environment*, **59**, 227-233.
https://doi.org/10.17221/881/2012-PSE

[46] Akhtar, S.S., Andersen, M.N. and Liu, F. (2015) Biochar Mitigates Salinity Stress in Potato. *Journal of Agronomy and Crop Science*, **201**, No. 5.
https://doi.org/10.1111/jac.12132

[47] Feng, J., Cheng, R., Qul, A.A., Yan, Q.G., Li, Y.G., Jian, B.L., Dong, H., Xian, Q.Z., Xu, L. and Xi, W.S. (2018) Effects of Biochar on Sodium Ion Accumulation, Yield and Quality of Rice in Saline-Sodic Soil of the West of Songnen Plain, Northeast China. *Plant, Soil and Environment*, **64**, 612-618.
https://doi.org/10.17221/359/2018-PSE