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# 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

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## 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

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*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 impermeable 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 $g \cdot pot^{-1}$), MOP (3 $g \cdot pot^{-1}$), Urea (6 $g \cdot pot^{-1}$) were added to soils. Then

Phospho-gypsum, biochar and trichocompost were added (5 t/ha) in selective pots 125 $g \cdot pot^{-1}$, 125 $g \cdot pot^{-1}$ and 125 $g \cdot pot^{-1}$ according to treatments. Urea was applied in three split doses; first dose (6 $gm \cdot pot^{-1}$) after 10 days (26th January, 2017) of transplanting, second dose (6 $gm \cdot pot^{-1}$) was applied on (25th February, 2017) and third dose (6 $g \cdot pot^{-1}$) 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 $g \cdot plant^{-1}$.

**Harvest index (%) was determined** with the following formula

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

**Gas sampling collection**

A closed-chamber method was used to measure $CH_4$ 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 $CH_4$ 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. $CH_4$ 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 $CH_4$ concentration in the chamber. Each emission rate is based on 3 samples, r-squared of the linear regression of the $CH_4$ concentration against time is typically > 0.95. The samples were analyzed at Professor Muhammad Hussain Central Laboratory of Bangladesh Agricultural Uniyersity Mymensingh.

**$CH_4$ Emission Rate**

$CH_4$ 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 $CH_4$ $m^{-2}$ $hr^{-1}$);

$\rho$ = 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. $H_2SO_4$ and catalyst mixture ($K_2SO_4$:$CuSO_4$·$5H_2O$: 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 $H_3BO_3$ with 0.01 N $H_2SO_4$. 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 $H_2O_2$ 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).

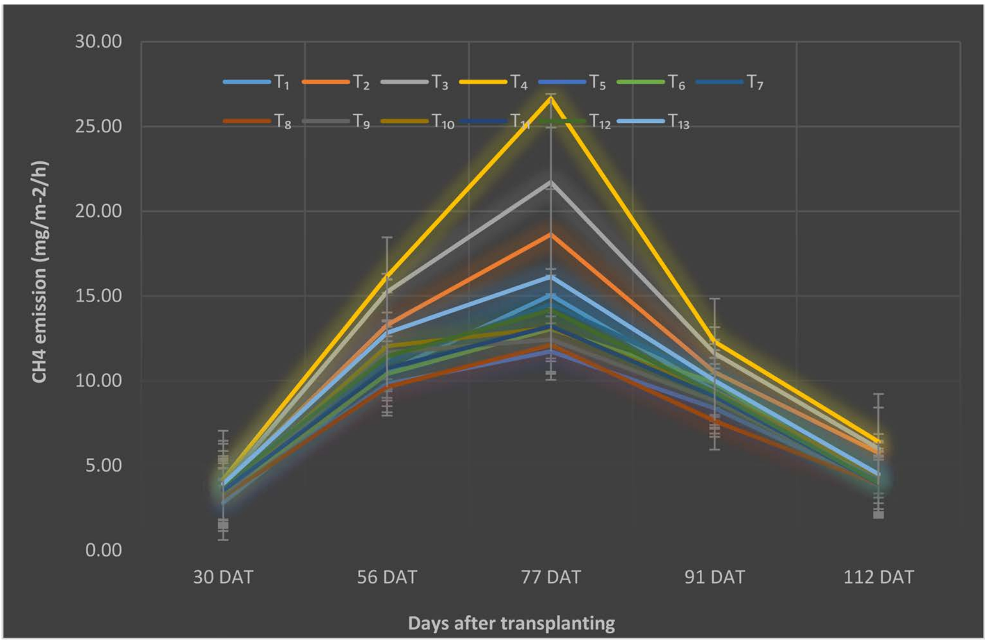
## 3. Results and Discussion

**$CH_4$ 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 $mg \cdot m^{-2} \cdot h^{-1}$ 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, $\mathbf{T_1}$ denotes 100% NPK (moderate soil), $\mathbf{T_2}$: 100% NPK + 25 mM NaCl stress, $\mathbf{T_3}$: 100% NPK + 50 mM NaCl stress, $\mathbf{T_4}$: 100% NPK + 75 mM NaCl stress, $\mathbf{T_5}$: 100% NPK + 25 mM NaCl stress + Phospho-gypsum (100 g/pot), $\mathbf{T_6}$: 100% NPK + 25 mM NaCl stress + Biochar (100 g/pot), $\mathbf{T_7}$: 100% NPK + 25 mM NaCl stress + Trichocompost (100 g/pot), $\mathbf{T_8}$: 100% NPK + 50 mM NaCl stress + Phospho-gypsum (100 g/pot), $\mathbf{T_9}$: 100% NPK + 50 mM NaCl stress + Biochar (100 g/pot), $\mathbf{T_{10}}$: 100% NPK + 50 mM NaCl stress + Trichocompost (100 g/pot), $\mathbf{T_{11}}$: 100% NPK + 75 mM NaCl stress + Phosphogypsum (100 g/pot), $\mathbf{T_{12}}$: 100%NPK + 75 mM NaCl stress + Biochar (100 g/pot), $\mathbf{T_{13}}$: 100% NPK + 75 mM NaCl stress + Trichocompost (100 g/pot).

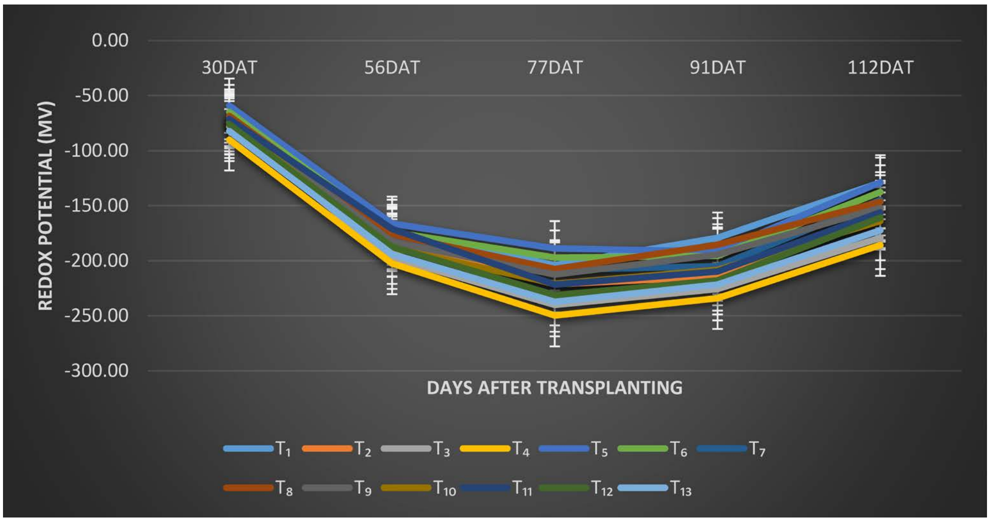
**Figure 1.** $CH_4$ emission during rice cultivation.

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 $dS \cdot m^{-1}$ treatment was lower than that of EC 9.48 $dS \cdot m^{-1}$ 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 $m^{-2} \cdot day^{-1}$) compared with outside the saline patch (209 - 544 mg $CH_4$ $m^{-2} \cdot day^{-1}$) [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, $\mathbf{T_4}$: 100% NPK + 75 mM NaCl stress, $\mathbf{T_5}$: 100% NPK + 25 mM NaCl stress + Phospho-gypsum (100 g/pot), $\mathbf{T_6}$: 100% NPK + 25 mM NaCl stress + Biochar (100 g/pot), $\mathbf{T_7}$: 100% NPK + 25 mM NaCl stress + Trichocompost (100 g/pot), $\mathbf{T_8}$: 100% NPK + 50 mM NaCl stress + Phospho-gypsum (100 g/pot), $\mathbf{T_9}$: 100% NPK + 50 mM NaCl stress + Biochar (100 g/pot), $\mathbf{T_{10}}$: 100% NPK + 50 mM NaCl stress + Trichocompost (100 g/pot), $\mathbf{T_{11}}$: 100% NPK + 75 mM NaCl stress +Phosphogypsum (100 g/pot), $\mathbf{T_{12}}$: 100%NPK + 75 mM NaCl stress + Biochar (100 g/pot), $\mathbf{T_{13}}$: 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 ($T_5$) potted soil, while highly reduced condition (−202.33 mV) was found in treatment $T_4$ (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 $T_1$ pot (100% NPKSZn), while the highly reduced condition of soil Eh (−245 mV) was recorded in saline treatment $T_4$ (100% NPK + 75 mM NaCl) pot. At ripening stage (112 DAT), the lowest reduction was found in treatment $T_5$ (−128.68 mV), while maximum reduced condition was recorded in treatment $T_4$ (−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 $dS \cdot m^{-1}$ [35], at salinity of 8.5 $dS \cdot m^{-1}$ 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 phospho-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 $dS{\cdot}m^{-1}$) by losing 12% - 26% at 4 $dS{\cdot}m^{-1}$ and 41% - 47% for IR 55179 and IR 71889 at 8 $dS{\cdot}m^{-1}$ [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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T$_1$** | 1.84$^{de}$ | 0.25$^{a}$ | 0.275 | 7.16$^{def}$ | 25.6$^{bc}$ | 20.65$^{b}$ | **0.47**$^{ab}$ | 2.70$^{e}$ | 3.07$^{cd}$ | 0.0105$^{c}$ | **0.055$^{a}$** | **0.076**$^{a}$ | 4.54 | 3.27 |
| **T$_2$** | 1.64$^{ef}$ | 0.19$^{b}$ | 4.1 | 7.30$^{bc}$ | 21.3$^{c}$ | 15.35$^{cd}$ | 0.31$^{f}$ | 3.50$^{bc}$ | 2.52$^{d}$ | 0.0199$^{a}$ | 0.045$^{b}$ | 0.065$^{b}$ | 4.15 | 3.02 |
| **T$_3$** | 1.46$^{fg}$ | 0.16$^{cd}$ | 6.7 | 7.35$^{b}$ | 20.6$^{c}$ | 12.73$^{d}$ | 0.24$^{e}$ | 3.80$^{ab}$ | 2.39$^{d}$ | 0.0105$^{c}$ | 0.040$^{c}$ | 0.060$^{c}$ | 3.67 | 2.68 |
| **T$_4$** | 1.22$^{g}$ | 0.14$^{d}$ | 10.3 | **7.48$^{a}$** | 19.8$^{c}$ | 10.52$^{d}$ | 0.18$^{f}$ | 3.95$^{a}$ | 1.97$^{d}$ | 0.0107$^{c}$ | 0.038$^{c}$ | 0.058$^{d}$ | 3.25 | 2.33 |
| **T$_5$** | 1.73$^{a}$ | 0.25$^{a}$ | **3.3** | **6.90$^{g}$** | 29.7$^{ab}$ | **24.75**$^{a}$ | 0.45$^{ab}$ | 3.05$^{d}$ | 5.63$^{a}$ | 0.0109$^{c}$ | **0.052$^{ab}$** | **0.075**$^{a}$ | **5.30** | **5.65** |
| **T$_6$** | 1.79$^{ab}$ | 0.24$^{a}$ | 3.8 | 7.20$^{c}$ | 31.6$^{ab}$ | 21.36$^{ab}$ | **0.49**$^{a}$ | 3.15$^{cd}$ | 4.56$^{ab}$ | 0.0112$^{bc}$ | 0.050$^{ab}$ | 0.068$^{ab}$ | **5.29** | **5.56** |
| **T$_7$** | 1.75$^{abc}$ | 0.22$^{ab}$ | 3.9 | 7.15$^{d}$ | 30.23$^{ab}$ | 20.67$^{b}$ | 0.41$^{b}$ | 3.20$^{cd}$ | 4.17$^{bc}$ | 0.0159$^{ab}$ | 0.048$^{ab}$ | 0.066$^{ab}$ | **5.09** | **5.13** |
| **T$_8$** | 1.55$^{abc}$ | 0.21$^{ab}$ | 4.6 | 7.15$^{d}$ | 30.34$^{ab}$ | 20.74$^{b}$ | 0.36$^{c}$ | 3.20$^{bcd}$ | 5.44$^{ab}$ | 0.0116$^{bc}$ | 0.047$^{ab}$ | 0.067$^{ab}$ | 4.70 | 4.72 |
| **T$_9$** | 1.6$^{abcd}$ | 0.19$^{b}$ | 5.1 | 7.25$^{bc}$ | 33.82$^{a}$ | 18.65$^{bc}$ | 0.38$^{bc}$ | 3.30$^{c}$ | 4.65$^{ab}$ | 0.0107$^{c}$ | 0.047$^{ab}$ | 0.065$^{b}$ | 4.45 | 4.67 |
| **T$_{10}$** | 1.55$^{bcd}$ | 0.18$^{bc}$ | 5.3 | 7.19$^{cd}$ | 32.47$^{a}$ | 16.3$^{c}$ | 0.35$^{c}$ | 3.40$^{bc}$ | 4.32$^{ab}$ | 0.0096$^{c}$ | 0.045$^{b}$ | 0.062$^{bc}$ | 4.25 | 4.36 |
| **T$_{11}$** | 1.35$^{de}$ | 0.16$^{cd}$ | 8.5 | 7.20$^{cd}$ | 28.61$^{ab}$ | 17.8$^{bc}$ | 0.30$^{d}$ | 3.56$^{bc}$ | 5.32$^{ab}$ | 0.0110$^{bc}$ | 0.039$^{c}$ | 0.065$^{b}$ | 4.10 | 4.25 |
| **T$_{12}$** | 1.38$^{cde}$ | 0.18$^{bc}$ | 8.9 | 7.30$^{bc}$ | 29.73$^{ab}$ | 15.36$^{d}$ | 0.35$^{c}$ | 3.58$^{bc}$ | 4.58$^{ab}$ | 0.0122$^{bc}$ | 0.042$^{bc}$ | 0.063$^{bc}$ | 3.95 | 4.11 |
| **T$_{13}$** | 1.30$^{ef}$ | 0.16$^{cd}$ | 9.3 | 7.33$^{b}$ | 29.02$^{ab}$ | 12.09$^{e}$ | 0.30$^{d}$ | 3.70$^{b}$ | 4.46$^{ab}$ | 0.0114$^{bc}$ | 0.040$^{bc}$ | 0.060$^{c}$ | 3.78 | 4.02 |
| LSD$_{0.05}$ | 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. **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 NaC stress + Phospho-gypsum (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). 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 T$_4$ (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 phosphogypsum) 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 to75 mM NaCl.

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## Conflicts of Interest

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

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