**International Journal of Life Science and Agriculture Research**

**ISSN (Print): 2833-2091, ISSN (Online): 2833-2105**

**Volume 02 Issue 09 September 2023**

**DOI: https://doi.org/10.55677/ijlsar/V02I09Y2023-01**

**Page No : 271-280**

# Improving Salt Leaching in a Simulated Saline Soil Column by Compost and Biochar in Vietnamese Mekong Delta

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**ABSTRACT:** The problem of seawater intrusion in recent years has been serious in the coastal provinces of the Vietnamese Mekong River Delta. For rice cultivation in salt-affected areas, more effective techniques are required to remediate the saline soils for lowing salinity to secure rice growth and productivity. The objective of this study was to evaluate the potential reclamation of compost and biochar in laboratory experiment using a saline soil sample from the rice cropping system. Our hypothesis was that the addition of compost and biochar might improve the infiltration rate, resulted in more effectively salts removing from saline soil. The experiment was set up with compost and biochar at rates of 5 g $kg^{-1}$, 10 g $kg^{-1}$ and 20 g $kg^{-1}$, respectively and 10 g $kg^{-1}$ compost combined with 10 g $kg^{-1}$ biochar. Soil chemical characteristics such as amount of $Na^+$, $K^+$, $Ca^{2+}$, and $Mg^{2+}$ cations removed from soil into eluent by leaching, soil availabe N, P after finishing leaching were analyzed. Results indicated that all compost and biochar amendments enhanced $Na^+$ leaching process. This study proved that material amendment such as 20g $kg^{-1}$ biochar and 10g $kg^{-1}$ compost plus 10g $kg^{-1}$ biochar could speed up water infiltration. Compost additions increase the available N and P content in the soil after leaching. Available N and P contents have not been improved in treatments supplemented with biochar.

**Published Online:**
**06 September 2023**

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**KEYWORDS:** biochar, compost, salt-affected soil, leaching.

## INTRODUCTION

The VMRD located in the south of Vietnam, is one of the most favorable areas for agricultural activities. Although the area of agricultural land in the VMRD is less than 30% of the country, it contributes more than 50% of national rice production and 30% of the value of agricultural production (Thanh, 2016). However, the problem of saline intrusion in recent years has been serious in the coastal provinces of the VMRD, causing the decrease in rice cultivated area, rice yield and quality. For rice cultivation in saline areas, it is essential to redue soil salinity to a suitable level for rice. In addition, most of soils for rice cultivation in the VMRD are high in clay content, leading to difficult for removing salts from those soils. Therefore, improving salt-affected soils is considered as an important part in the agricultural security program in the VMRD.

Successful amelioration of salt-affected soils involves a two-step procedure with application of a $Ca^{2+}$ source to displace $Na^+$ on clay surfaces, which promotes soil flocculation and subsequently followed by leaching to drain out salts from the soil profile (Gupta and Abrol, 1990). Several studies have also reported the benefits of using organic materials to remediate salt-affected soils by improving their physical, chemical and biological properties (Liang et al., 2005; Tejada et al., 2006; Walker and Bernal, 2008). The application of organic matter to saline soils can have different effects such as speeding up of NaCl leaching, decrease of the exchangeable sodium percentage and electrical conductivity and increase of water infiltration (El-Shakweer et al., 1998).

The efficiency of soil organic amendments applied on degraded soils, such as composts, in enhancing soil characteristics like soil structure, aggregate stability, hydraulic conductivity, and other chemical and biological qualities has long been researched (Ros et al., 2003; Tejada et al., 2009). Tejada et al. (2006) demonstrated that high molecular weight humic acids from composts were the key in improving the aggregation of soil particles. There are several special characteristics associated with biochar as high carbon [C] concentration, complex porous structure, high specific surface area, and various functional groups on the surface (Lehmann and Joseph, 2009). Previous research has shown that biochar amendment reduced soil bulk density (Jien and Wang 2013;

Ouyang et al., 2013), promoted soil aggregation (Soinne et al., 2014; Sun and Lu 2014), increased soil permeability (Jien and Wang 2013; Laird et al., 2010) and it can be a source of elements such as $Ca^{2+}$ and $Mg^{2+}$ (Laird et al., 2010), which aid in $Na^+$ exchange.

Although the application of compost and biochar has been studied extensively in the world, the specific application to salt-affected soils in the MRD needs to be further studied, especially on rice cultivation systems with high clay content in soils. We hypothesized that compost and biochar amendment could promote salt leaching, and the effect might vary with the rate of the added compost and biochar. Our objectives were to (1) determine the days required for washing soluble salts out of the saline soil column, (2) compare the discrepancies in facilitating salt leaching when adding different rate of compost and biochar and determine the content of available nitrogen and phosphorus of soil after finishing leaching.

## RESEARCH METHODS

### Research Tools and Materials

Random soil samples were collected from 0 to 20 cm depth with a high electrical conductivity value ($EC_{(1:5)}$>5.0 mS $cm^{-1}$) from a double rice cropping field in the Mekong River Delta. This was done to capture the variability of the soil across a particular site. Soil samples was transported to a greenhouse and was air dried. Soils were crushed and passed through a 2 mm sieve to attain homogeneity in their properties. Random sub samples were taken from air dried bulk soil and were analyzed for different soil properties (Table 1).

The compost used in the experiment was a commercial product made from sugarcane filter cake. Biochar was also a commercial product made from rice husk by slow pyrolysis at a maximum pyrolysis temperature of 700°C. Some chemical properties of compost and biochar are shown in Table 1.

**Table 1. Characteristics of soil and biochar used in this study**

| Characteristics | Soil | Compost | Biochar |
|---|---|---|---|
| $pH_{(1:5)}$ | 7.11 | 8.48 | 9.21 |
| $EC_{(1:5)}$ (mS $cm^{-1}$) | 7.93 | 6.75 | 0.99 |
| CEC ($cmol_c$ $kg^{-1}$) | 21.02 | 40.57 | 8.29 |
| Soluble Na ($cmol_c$ $kg^{-1}$) | 29.97 | 1.51 | 0.23 |
| Soluble Ca ($cmol_c$ $kg^{-1}$) | 1.64 | 5.57 | 0.14 |
| Soluble K ($cmol_c$ $kg^{-1}$) | 0.56 | 6.59 | 4.60 |
| Soluble Mg ($cmol_c$ $kg^{-1}$) | 4.08 | 8.71 | 0.34 |
| Exchangeable Na ($cmol_c$ $kg^{-1}$) | 3.66 | 0.52 | 0.24 |
| Exchangeable Ca ($cmol_c$ $kg^{-1}$) | 1.02 | 6.07 | 0.15 |
| Exchangeable K ($cmol_c$ $kg^{-1}$) | 0.73 | 2.63 | 3.51 |
| Exchangeable Mg ($cmol_c$ $kg^{-1}$) | 5.49 | 0.04 | 0.04 |

### Research Design

Soil was air-dried and sieved through a 2 mm mesh before it was used to make a soil column with a absorbant cotton wool layer of 0.5 mm at the bottom. A filter paper was used to cover the top of the soil columns. Application rate of compost and biochar were based on 30 g of dried soil weight. All amendments were applied at a rate of 10 t $ha^{-1}$, 20 t $ha^{-1}$, 40 t $ha^{-1}$ to 30 g of soil and were thoroughly mixed. The experiment was set up with 8 treatments and with 4 replicates for each treatment including:

(1) Control: Untreated soil
(2) 0.5%CP: Soil + 5 g $kg^{-1}$ compost
(3) 1%CP: Soil + 10 g $kg^{-1}$ compost
(4) 2%CP: Soil + 20 g $kg^{-1}$ compost
(5) 0.5%BC: Soil + 5 g $kg^{-1}$ biochar
(6) 1%BC: Soil + 10 g $kg^{-1}$ biochar
(7) 2%BC: Soil + 20 g $kg^{-1}$ biochar
(8) 1%CP+1%BC: Soil + 10 g $kg^{-1}$ compost + 10 g $kg^{-1}$ biochar

After adding 40 ml of deionized water into the soil columns, the columns were stably kept for 2 days by closing the bottom. Then, all the columns were opened for collecting eluent, together with recording the infiltration speed and EC of leachate for each washing time until finished. The washing process was repeated until when the EC in the leachate reached the value 0.5 - 2.0 mS cm-

[1]. The eluents were measured for the major salt ions in order to investigate the leaching sequence of ions. After the termination of leaching, soils in the columns were carefully emptied, oven dried, crushed to 2 mm size and were analyzed available P, N as described in Fig.1.

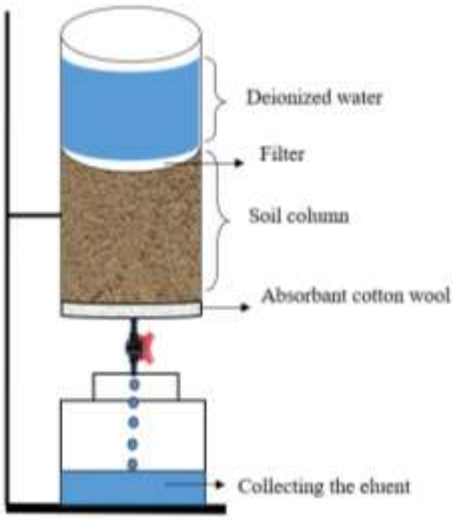



**Figure 1. Experimental apparatus**

**Research Procedure**

Volume of the collected eluent: data was collected at 30, 60, 120, 180 and 360 minutes after opening the soil column.

Soluble Na, K, Ca and Mg: were determined with flame photometry. Available P was determined by Olsen method (Olsen et al., 1954). Analysis of N-$NH_4^+$ and N-$NO_3^-$ used Kjeldahl method (Hidayat, 1978).

All data analysis was the average of four replicates. Significant difference among the treatments was assessed by one-way analysis of variance, and then expressed as the least significant difference (LSD 0.05) with the SPSS V.22 software.

## RESULTS AND DISCUSSION

**Collecting the Eluent**

The result in Figure 2 showed that of all treatments, applying of 2%BC, 1%CP+1%BC, 1%BC, 2%CP, 0.5%BC, 1%CP and 0.5%CP significantly increased volume of the collected eluent from 30 to 360 minutes, compared to that in non-added soil. However, there was no significant difference between 2%CP with 1%BC and 0.5%CP with 1%CP in the ability to improve volume of the collected eluent (Figure 2). Phuong et al. (2019) reported that applying of biochar significantly increased speed of drainage by 4 times compared to that in non-added soil. The drainage results in this study showed that biochar addition accelerated salt washing through dramatically increased volume of the collected eluent.

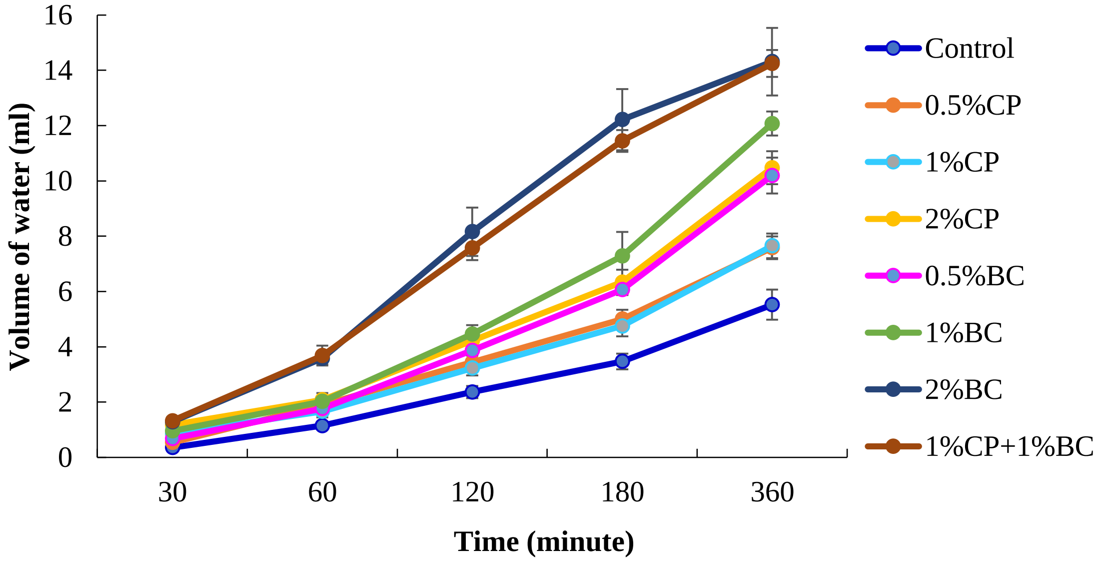



**Figure 2. Volume of the collected eluent from 30 to 360 minutes**

It is commonly known that compost application improves soil properties, which is connected with an increase in the organic carbon content. The beneficial effects of compost on soil properties depend on soil texture and moisture conditions, as well as on the origin of organic matter (De Leon-Gonzales et al., 2000; Drozd, 2003). The application of organic matter in salt-affected soil promotes flocculation of clay minerals, which is an essential condition for the aggregation of soil particles. The added organic matter aid to glues the tiny soil particles together into larger water stable aggregates. Thus, allowing an enhancement of soil porosity and aeration (Tejada et al., 2008). In addition, the improvement in the leaching rate of biochar may be caused mainly by the change in the soil physical structure. With porous structure and huge surface area, biochar increases the soil porosity and soil leaching (Al-Wabel et al., 2013, Barners et al., 2014; Yue et al., 2016).

**Electrical Conductivity of the Eluent**

The EC value in the solution simultaneously decreased from the 1st wash to the 4th wash. The treatments added biochar and compost both had higher EC than the control treatment (Table 2). Thereby, it was shown that the addition of biochar and compost had an effect on reducing EC in the soil as well as shortening the time of salinization in the soil. The improvement in the rate of salinity leaching out of the soil can mainly be attributed to the change in soil physical structure.

Besides, the results of Table 2 show that, the EC value of the control treatment decreased to 1.2 mS $cm^{-1}$, it took up to 32 days. Meanwhile, the treatments with the addition of compost and biochar reduced the EC value to less than 1.2 mS $cm^{-1}$ in only 10 to 23 days. For the treatment adding 2% biochar and adding a combination of 1% compost with 1% biochar, the EC value was less than 1 mS $cm^{-1}$ over a period of 10 days.

**Table 2. Electrical Conductivity of the Eluent and leaching time**

| Treatments | 1st leaching | | 2nd leaching | | 3rd leaching | | 4th leaching | |
|---|---|---|---|---|---|---|---|---|
| | EC (mS $cm^{-1}$) | Time (days) | EC (mS $cm^{-1}$) | Time (days) | EC (mS $cm^{-1}$) | Time (days) | EC (mS $cm^{-1}$) | Time (days) |
| Control | 31.54de | 4 | 11.81bc | 8 | 6.09ab | 10 | 1.20a | 11 |
| 0.5%CP | 35.32bc | 3 | 9.21de | 6 | 5.65bc | 7 | 1.03bc | 9 |
| 1%CP | 33.82cd | 3 | 10.86cd | 6 | 6.25ab | 5 | 1.13ab | 7 |
| 2%CP | 37.46ab | 2 | 9.31de | 4 | 4.50d | 4 | 1.19ab | 5 |
| 0.5%BC | 35.49bc | 2 | 10.01de | 4 | 4.78cd | 6 | 1.06abc | 7 |
| 1%BC | 32.30de | 2 | 12.72b | 3 | 5.84ab | 4 | 0.84d | 5 |
| 2%BC | 29.73e | 1 | 14.66a | 3 | 6.74a | 3 | 0.86d | 3 |
| 1%CP+1%BC | 39.37a | 1 | 8.90e | 3 | 2.91e | 3 | 0.90cd | 3 |

**Dissolved cations concentrations in leachate**

The concentration of dissolved $Na^+$ in eluent of leaching four times was highest of 2%CP and 2%BC treatments, respectively. According to Wong et al. (2010), saline soils containing high concentrations of soluble salts will adversely affect crop production. In particular, the presence of many $Na^+$ ions will cause some disadvantages to the physical, chemical and nutritional properties of the soil. The excess of $Na^+$ content in the soil can lead to the destruction of the structure of the soil because the scattered clay molecules reduce the soil cell size, leading to a decrease in water permeability and aeration of the soil, the soil becomes compacted. Flexible, easy to compact in contact with water and harden when dry (Ann McCauley, 2005). According to Olk and Casman (2002) dispersion on saline soil will reduce or prevent plant growth, reduce the rate of organic matter decomposition. The formation of planks on the soil surface also causes loss of organic matter, so the organic matter content in saline soils is low (Nelson and Oades, 1998). High concentrations of $Na^+$ ions also reduce the plant's ability to take up water, thereby affecting plant cells and plant growth (Muneer and Oades, 1989). Thereby, the use of compost and biochar with appropriate dosage helps to remove $Na^+$ ion from the soil at a high level compared to other treatments in the salinization process which is the most important goal of saline soil improvement.

**Table 3. Amount of dissolved $Na^+$ in leachate**

| Treatments | 1st leaching | 2nd leaching | 3rd leaching | 4th leaching |
|---|---|---|---|---|
| | $cmol_c$ $kg^{-1}$ | | | |
| Control | 14.85de | 9.70bc | 7.41a | 0.76ab |
| 0.5%CP | 16.77cd | 8.01c | 6.48ab | 0.80a |

| | | | | |
|---|---|---|---|---|
| 1%CP | 14.40e | 10.50ab | 6.92ab | 0.78a |
| 2%CP | 20.47a | 7.83c | 5.79b | 0.74ab |
| 0.5%BC | 17.75bc | 7.94c | 5.99b | 0.55de |
| 1%BC | 14.77de | 11.31ab | 6.03b | 0.66bc |
| 2%BC | 14.16e | 12.29a | 6.75ab | 0.47e |
| 1%CP+1%BC | 19.22ab | 8.18c | 3.90c | 0.60cd |

Besides, the concentration of dissolved $K^+$ in the solution through 4 times of salt washing was highest in the treatments combining 1%CP with 1%BC, 2%BC supplement and 2%CP adding treatment compared with the control treatment according to the results (Table 4).

**Table 4. Amount of dissolved $K^+$ in leachate**

| Treatments | 1$^{st}$ leaching | 2$^{nd}$ leaching | 3$^{rd}$ leaching | 4$^{th}$ leaching |
|---|---|---|---|---|
| | $cmol_c\ kg^{-1}$ | | | |
| Control | 0.47c | 0.14bcd | 0.21b | 0.02b |
| 0.5%CP | 0.49c | 0.12d | 0.17bcd | 0.03a |
| 1%CP | 0.50c | 0.15bc | 0.20bc | 0.03a |
| 2%CP | 0.67b | 0.12cd | 0.18bc | 0.03ab |
| 0.5%BC | 0.52c | 0.13bcd | 0.17bcd | 0.03a |
| 1%BC | 0.53c | 0.15b | 0.17cd | 0.02b |
| 2%BC | 0.53c | 0.20a | 0.27a | 0.03ab |
| 1%CP+1%BC | 0.78a | 0.11d | 0.13d | 0.03a |

In addition, the concentration of dissolved $Ca^{2+}$ in the solution through 4 times of salt washing tended to be higher in the treatments adding 1% and 2% compost, respectively, compared with the control treatment. In which, the treatment supplemented with 2% biochar had the lowest concentration of dissolved $Ca^{2+}$ in the washing solution (Table 5).

**Table 5. Amount of dissolved $Ca^{2+}$ in leachate**

| Treatments | 1$^{st}$ leaching | 2$^{nd}$ leaching | 3$^{rd}$ leaching | 4$^{th}$ leaching |
|---|---|---|---|---|
| | $cmol_c\ kg^{-1}$ | | | |
| Control | 0.88cd | 0.58ab | 0.13bc | 0.02c |
| 0.5%CP | 0.94bc | 0.44cd | 0.14ab | 0.03b |
| 1%CP | 0.96bc | 0.50bc | 0.16a | 0.04a |
| 2%CP | 1.21a | 0.53abc | 0.12bc | 0.03b |
| 0.5%BC | 1.06b | 0.38d | 0.11c | 0.02c |
| 1%BC | 0.85cd | 0.60a | 0.14ab | 0.02cd |
| 2%BC | 0.76d | 0.58ab | 0.14ab | 0.01d |
| 1%CP+1%BC | 0.90cd | 0.41d | 0.07d | 0.02c |

The results of Table 6 show that the concentration of dissolved $Mg^{2+}$ in the solution through 4 times of salt washing of the treatment supplemented with 2% compost was at the highest level. Meanwhile, the treatments supplemented with biochar had lower $Mg^{2+}$ content in the wash solution compared to other treatments.

**Table 6. Amount of dissolved $Mg^{2+}$ in leachate**

| Treatments | 1st leaching | 2nd leaching | 3rd leaching | 4th leaching |
|---|---|---|---|---|
| | $cmol_c\ kg^{-1}$ | | | |
| Control | 4.00de | 2.67ab | 1.03a | 0.04d |
| 0.5%CP | 4.50cd | 2.28bc | 0.64cd | 0.09b |
| 1%CP | 4.48cd | 2.46ab | 0.53d | 0.14a |
| 2%CP | 5.65a | 2.26bc | 0.89b | 0.05d |
| 0.5%BC | 4.85bc | 1.89cd | 0.61cd | 0.08b |
| 1%BC | 3.97de | 2.68ab | 0.73c | 0.04d |
| 2%BC | 3.74e | 2.92a | 0.60cd | 0.04d |
| 1%CP+1%BC | 5.30ab | 1.67d | 0.39e | 0.06c |

The results of analysis of the content of soluble cations in the washing solution show that, in the process of salt washing, the addition of 2% compost has the ability to shorten the salt washing process and at the same time wash some soluble cations such as $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$ were higher than the control and other treatments. This may be due to the high content of cations in the input compost, so when added to the soil in high doses, the cations are also soluble in water and washed out.

In addition to compost, the addition of 2% biochar also showed a significant effect in shortening the time of salt washing, removing the high content of $Na^+$ in the soil following the washing water, but the $Ca^{2+}$ and $Mg^{2+}$ content in the washing water. was quite low compared to the control treatment. This is quite important for the improvement of saline soil, especially in the process of salt washing, it is always desirable to remove harmful cations such as $Na^+$ and retain beneficial cations such as $Ca^{2+}$ and $Mg^{2+}$. According to Warrence et al. (2003), if the soil contains alkaline cations such as $Ca^{2+}$ and $Mg^{2+}$, it will play the role of making the fine soil particles stick together into a block. This process is called flocculation and is beneficial in terms of soil aeration, favoring the growth of plant roots. Based on this feature, in order to improve the structure and reunification of saline soil, it is necessary to increase the content of $Ca^{2+}$ and $Mg^{2+}$ cations in the soil solution.

**Availbe P of Soil after Leaching**

Results Figure 3 shows that the content of available phosphorus increased in the treatments with the addition of compost (0.5%CP, 1%CP, 2%CP, 1%CP+1%BC) and significant difference with the control treatment. This result is consistent with the study of Lakhdar et al. (2008), compost amendments most frequently are used to provide essential P. According to Muhammad et al. (2007) During the decomposition of organic matter, the slowly available P is converted to a useful form in the soil.

Phosphorus is one of the most essential plant nutrients. Salinity and sodicity can affect forms and dynamics of this nutrient in soil (Dominguez et al., 2001). The bioavailability of P is strongly tied to soil pH (Hopkins and Ellsworth, 2005). The pH between 5.5 and 7 constitutes the optimum range for P release (Engelstad and Terman, 1980) There is considerable evidence in the literature dealing with the increase phosphorus solubility following organic material application (Sanyal and De Datta, 1991). In saline soil Muhammad et al. (2007) found an increase of $NaHCO_3$-extractable P following 1% of compost amendment. Presumably while decomposing organic matter releases humic acid, which in turn convert unavailable soil phosphates into available forms. Such being the case, compost or other organic if applied with high-grade phosphate minerals must work as very effective phosphate fertilizers (Sekhar and Aery, 2001).

However, the useful phosphorus content in the 0.5%, 1%, 2% biochar treatments was not statistically different from the control treatment. Biochar also has the potential to alter P sorption and thus P bioavailability in soil by several mechanisms: P can be sorbed on biochar compounds formed during pyrolysis containing specific elements such as Ca, Mg, Fe or Al (Yao et al. 2013; Joseph et al., 2015; Chen et al. 2011; Shepherd et al. 2017), which may decrease the availability of P in soil.

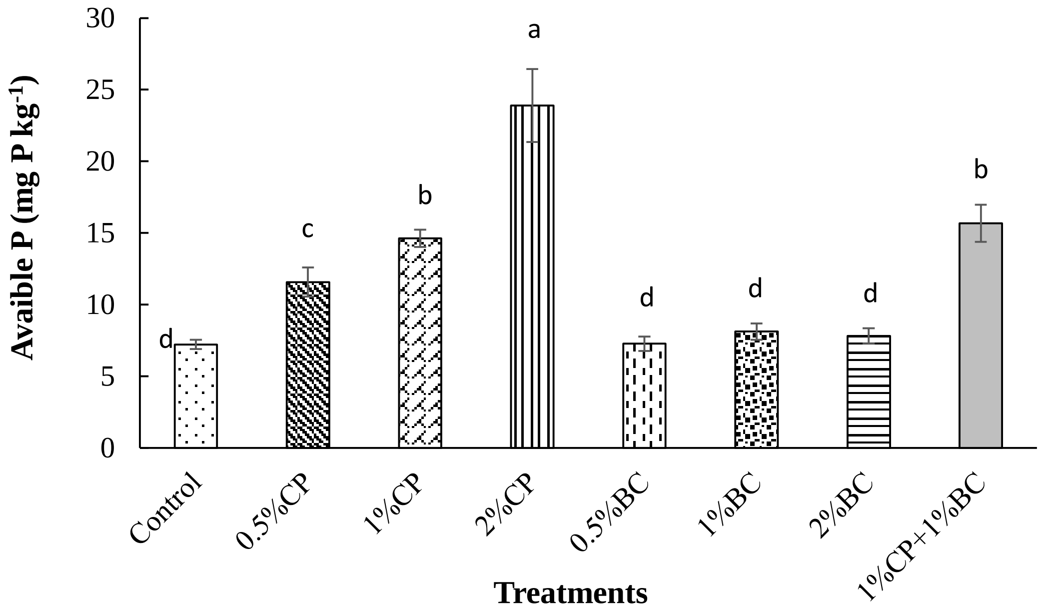



**Figure 3. Available P of soil after leaching**

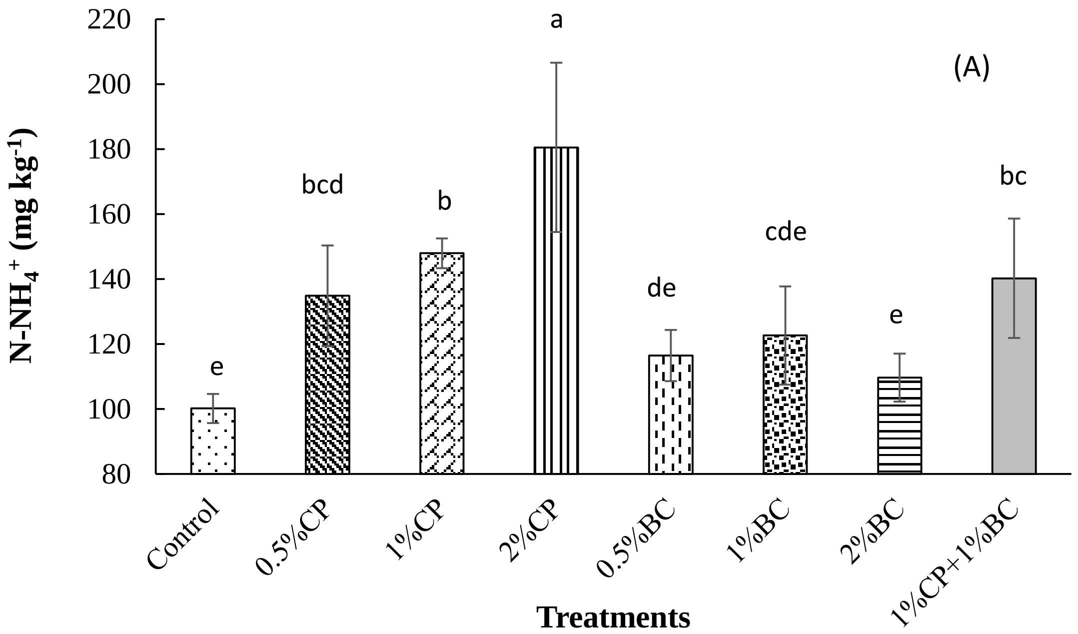
**Available N of Soil after Leaching**

Results Figure 4 showed that the content of N-$NH_4^+$ increased in the treatments with the addition of compost (0.5%CP, 1%CP, 2%CP, 1%CP+1%BC) and significant difference with the control treatment. This result is consistent with the study of Lakhdar et al., (2008), compost amendments most frequently are used to provide essential nutrients such as N.

In addition, the content of N-$NH_4^+$ tended to increase in the 0.5%, 1%, 2% biochar treatments, but not significant difference from the control treatment.

Results Figure 4 shows that the highest N-$NO_3^-$ concentration in the 2% organic fertilizer treatment was significant difference from the biochar treatments, but not statistically different from the control treatment and other treatments.

It is well known that salinity soil limit soil fertility. In fact, most salt-affected soils are deficient in nitrogen (N), phosphorus (P), and potassium (K) (Lakhdar et al., 2008). Addition of compost in such soil enriches the rhizosphere with micro- and macro-nutrient elements and counteracts nutrient depletion (Lakhdar et al., 2008). Weber et al. (2007) reported that the continuous release of nitrogen from compost into the soil improves not only the soil fertility, but also the conditions of organic matter mineralization.



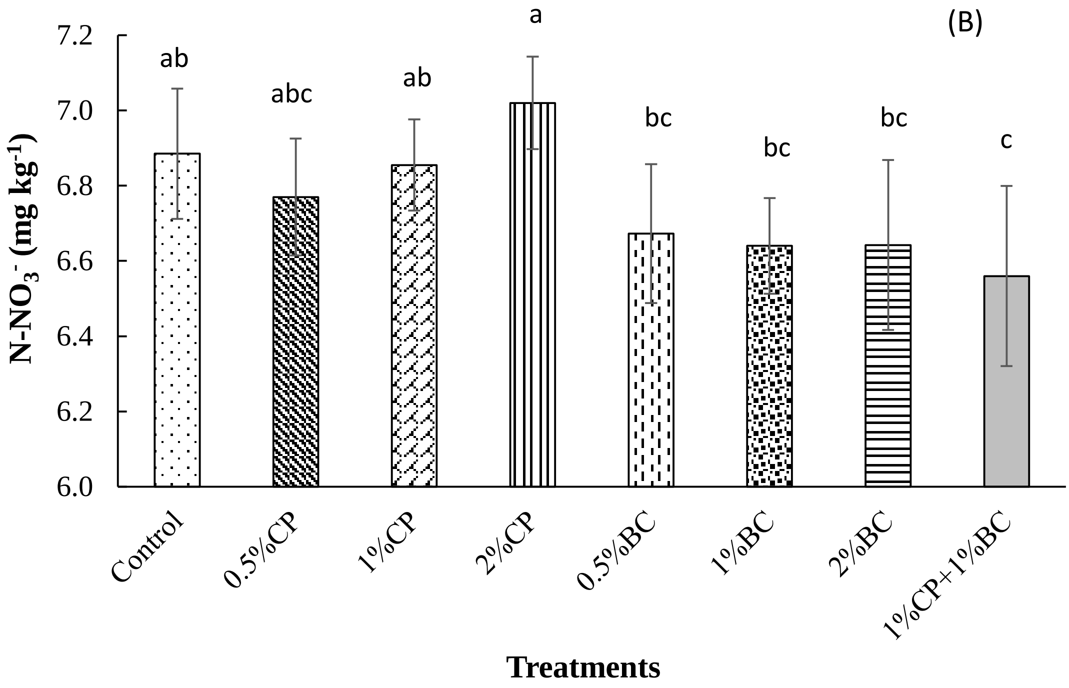



**Figure 4. Available N of soils after leaching (a) and (b)**

**CONCLUSION**

This study evaluated the relative importance of chemical mechanisms by which compost and biochar aid in the reclamation of salt-affected soils. All compost and biochar amendments enhanced $Na^+$ leaching process. This study proved that material amendment such as 20g $kg^{-1}$ biochar and 10g $kg^{-1}$ compost plus 10g $kg^{-1}$ biochar could speed up water infiltration and lead to much faster salt leaching and less time required for reducing salt concentration to a suitable level for rice cultivation. Compost additions increase the available N and P content in the soil after leaching. Available N and P contents have not been improved in treatments supplemented with biochar.

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