Effect of Salinity on Inorganic Phosphorus Fixation in Sara and Bajoa Soil Series of Ganges Tidal Floodplains

Abstract

A laboratory incubation experiment with two soil series of Ganges Floodplain named Sara and Bajoa was conducted to determine the influence of salinity on inorganic phosphorus fractions and availability at field capacity moisture conditions. The purpose of the study is to know about nutrient availability in two distinct calcareous soil which is a major factor for growing crops. Several techniques have been developed to provide indices of soil nutrient content. The most frequently used method is the extraction of soil samples in the laboratory with solutions designed to measure operationally defined concentrations of one or more nutrients. There were four ~~salinity~~ treatments with different salinity levels(2 dSm^{-1}, 4 dSm^{-1}, 8 dSm^{-1} and 12 dSm^{-1}) for each series with three replications. For the Bajoa series, the Fe-Al-P content decreases with increasing salinity level before the 30th day but remains constant from the 30th to the 60th day. Yet, in Sara series the Fe Al-P content remains nearly constant. For both series, the Rs-P content decreases with the increasing salinity level. Again, for the Bajoa series,the Ca-P percentage tends to increase against two salinity levels (2dS/m and 4 dS/m) with time but with the increasing salinity level more(8 dS/m and 12 dS/m) the Ca-P percentage decreases. The percentage increases in the Sara series with the increasing salinity level.

Keywords: Phosphorus, nutrient availability, Sara series, Bajoa series, soil salinity, phosphate sorption.

Introduction:

Soil salinity issues are ~~prevalent~~dominant in the southwestern region of Bangladesh, particularly in Khulna,Satkhira, and Sundarbans, especially during the dry season. Soil salinity significantly impacts plantphosphorus availability, influenced by factors like specific ions, soil characteristics, and plantspecies. Phosphorus is one of the most essential elements in soil. Its nature in the soil is both intricateand monumental. Inorganic phosphorus (Pi) occurs mainly as $H_2PO_4^-$ and HPO_4^{2-}adsorbed onto the surfaces of oxides and hydroxides of Fe or Al, organic matter or boundto Ca. The adsorption of P in soils depends on soil pH and clay minerals(McBeath *et al*., 2005) Next to nitrogen, phosphorus (P) is the secondmost important macronutrient as an essential plant nutrient. It is a key nutrient for higherand sustained agricultural productivity (Duputel*et al*., 2013).Phosphorus is a vital mineral for biological functions and structural integrity in both plants and animals. In plants, it plays a crucial role in cell division and the development of growing tips. Although soils may contain hundreds to thousands of kilograms of phosphate per hectare, much of this phosphate is often unavailable to plants. The processes of adsorption, desorption, and precipitation in the soil regulate phosphorus availability (Sims *et al*., 2000). Phosphorus sorption isotherms, which relate the concentration of phosphorus in soil solution to the amount sorbed by the soil, are useful tools for accurately predicting crop phosphorus fertilizer needs (Amarh, 2021). These isotherms help assess optimal phosphorus levels for various crops and soils (Saeed *et al*., 2021). A key factor limiting phosphorus availability is its fixation by iron, aluminum, and calcium in the soil (McBeath *et al*., 2005), with up to 70-90% of phosphorus in the soil becoming fixed and difficult for plants to absorb. As a result, phosphorus deficiency reduces crop productivity by 30-40% (Vance *et al*., 2003), especially in calcareous soils and arid regions where salinity is a problem. Salt stress affects soil conditions like electrical conductivity (EC), sodium adsorption ratio (SAR), pH, structure, and aeration, further limiting phosphorus availability. Phosphorus bioavailability is more restricted in salt-affected soils compared to normal soils (Qadir *et al.*, 2005).

Providing adequate P to plants can be difficult, especially in calcareous soil. In calcareous soils,inorganic phosphorus fractions are categorized into iron, aluminum-bound phosphate, reductantsoluble phosphate, and calcium-bound phosphate, with methods varying due to separationdifficulties. Phosphorus exists in soils in several forms, and understanding its different geochemical fractions is crucial for assessing long-term phosphorus availability. Sequential extraction techniques have been extensively used to predict phosphorus bioavailability, leachability, and the transformation of its chemical forms in both agricultural and contaminated soils (Sui *et al.*, 1999).The bioavailability of phosphate in soils is influenced by soil pH. Acidic soil has reduced Psolubility, improving with neutrality. Alkaline soil experiences reduced availability due to Preacting with calcium, with the lowest solubility at pH 8. Lime presence exacerbates this issue thus low P solubility in calcareous soil leads to poor fertilizer efficiency, stunting plants with shortenedinternodes and poor root systems, and yield loss without visible symptoms. Applying phosphorus fertilizer at standard rates using conventional methods may not always lead to the best yield or crop quality(Stark and Westermann, 2003).Understanding the relationship betweenphosphorus and soil salinity is crucial for crop productivity, nutrient management, sustainableagriculture, water quality, ecosystem health, and precision agriculture techniques, that's why thispaper aims to study the impact of salts on inorganic soil phosphorus fractions in two different soilseries, addressing the lack of research on salt-induced phosphorus transformations.

Comment [SS1]: Replace this reference with latest one

Materials and Methods

A laboratory incubation experiment was conducted using two soil types from the Ganges Floodplain to investigate the impact of salinity on the fractions and availability of inorganic phosphorus.

General Information of Studied Soil Series

Bajoa series

The Bajoa series, which are formed in a tidal floodplain basin, undergo seasonal shallow to moderate deep flooding. These soils, which are poorly drained, originate from tidal deposits. The subsoil consists of grey to olive-grey silty clay loam with a blocky structure that ranges from moderate to strong in the B horizon.They are classified into five phases: highland, non-saline medium highland, saline medium highland, medium lowland, and medium lowland with flood risk (Rahman, 2004). Additionally, Sarker *et al.* (2024) found that the phosphate sorption capacity of this soil is relatively low.

Sara series

The Sara series, formed in the levee deposit, are found from the tops to the middle of gently rolling ridges. They experience intermittent to shallow flooding and have imperfect to poor drainage. The soil is a light olive-brown to olive calcareous silt loam, typically with a weak prismatic and sub-angular blocky structure in the B horizon (Rahman, 2005).

Some Physical and Chemical Analysis of Soils

The physical and chemical properties of the soils were measured three times using conventional methods. One of the popular methods,the hydrometer method, as explained by Day (1965), was used to analyze the particle size of the soils.Marshall’s Triangular coordinate system was used to determine textural classes by fitting the values for % sand, % silt, and %

clay. The pH of the soil was measured electrochemically using a glass electrode pH meter, with a soil-to-water ratio of 1:2.5, as recommended by Jackson (1962).The soil's electrical conductivity (EC) was measured using a soil-to-water ratio of 1:5 with an EC meter, then converted to a 1:1 ratio following USDA (2004) guidelines. The EC (Soil: Water =1:5) value was determined by EC meter (USSLS, 1954).The soil organic carbon was measured using Walkley and Black's wet oxidation method as described by Jackson (1973), then the organic matter was calculated by multiplying the organic carbon percentage by the conversion factor of 1.724.The cation exchange capacity (CEC) of the soil was measured by the flame photometric method as described by Jackson(1962). Soil samples were digested using a mixture of HNO_3 and $HClO_4$ in a 2:1 ratio, following the procedure described by Jackson (1973), to determine total phosphorus (P), potassium (K), and sulfur (S). The total phosphorus content in the soil was analyzed using the vanadomolybdate yellow color method, on the other hand, the total nitrogen of the sample was measured using the micro Kjeldahl method, as outlined by Jackson (1973), The complexometric titration method was used to determine water soluble plus exchangeable calcium and magnesium (Schwartzenbach*et al*., 1946) Water soluble plus exchangeable Sodium(Na) content of the root and shoot sample was also measured by the Flame emission spectroscopic (FES) method.

Comment [SS2]: Correct spelling ??

Incubation Experiment

An incubation experiment was carried out in the laboratory of Soil Water and Environment Discipline at Khulna University to determine the effect of saline water treatments on inorganic phosphorus fractions and the availability of the two different soil series at field capacity moisture conditions.

Comment [SS3]: Incubation period ??

The salinity treatments were 2 dSm^{-1}, 4 dSm^{-1}, 8 dSm^{-1} and 12 dSm^{-1}.A 100g soil sample was incubated in a 500 ml plastic container, and sealed with parafilm to reduce water loss. The oven-dry weight of the soil was measured gravimetrically, and samples were collected at 0, 30, and 60 days to study the transformation of various forms of inorganic phosphorus.

Table 1: Name of treatment code

Treatment's code	**Treatments** EC (dS m^{-1})
T_1	2
T_2	4
T_3	8
T_4	12

Methods for Fractionation of Inorganic Phosphorus

Inorganic phosphorus fractions were determined using the methods outlined originally by Chang and Jackson (1957). The current investigation adopted modifications as reported by Kuo (1996). In their original fractionation scheme, Chang and Jackson (1957) proposed six inorganic-P fractions of soil. The fractionation procedure of Chang and Jackson (1957) was modified in two stages as suggested by Peterson and Cory (1966) and Williams *et al*. (1967). The procedure involved the extraction of the soil with 1N NH_4Cl, 0.5N NH_4F, 0.1N NaOH, 0.5N H_2SO_4, 0.3N sodium citrate (with solid sodium dithionite), and finally with 0.1N NaOH for the extraction of Fe Al-phosphate, Ca-phosphate, and reductant soluble phosphate respectively.

Extraction of Al and Fe Phosphate

Soil sample (0.5 g, oven-dry basis) was put into a50 ml centrifuge tube. Iron and aluminum phosphates were extracted by adding 25 ml of 0.1M NaOH and 1M NaCl solution to centrifuge tubes. The tubes were sealed with stoppers, shaken by hand, and then placed on a mechanical shaker for 17 hours. The samples were centrifuged at 2000 rpm for 15 minutes. After centrifugation, the supernatant was transferred into a 50 ml volumetric flask. The soil was washed twice with 12.5 ml of saturated NaCl and centrifuged again. The washings were combined with the extract and brought to volume, after which the phosphorus in the extract solution was analyzed.

Extraction of Reductant Soluble Phosphate

20 ml of 0.3 M sodium citrate and 2.5 ml of 1 M NaHCO3 were added to the soil residues left after extracting iron-phosphate. The suspension was heated in a water bath at 85°C, and then 1.0 g of sodium dithionite was introduced. The suspension was stirred vigorously to extract the reductant-soluble phosphorus and heated for an additional 15 minutes. It was then centrifuged at approximately 2000 rpm for 15 minutes, and the supernatant was transferred to a 50 ml volumetric flask. The soil was washed twice with 12.5 ml of saturated NaCl, and the washings were centrifuged. These washings were combined with the extract and brought to volume. The extract was exposed to air to oxidize the sodium dithionite, and the supernatant solution was then preserved for analysis.

Extraction of Calcium Phosphate

To the residues in the centrifuge tube, 25 ml of 0.5 M HCl was added, and the tubes were sealed and shaken for 1 hour. The suspension was then centrifuged at 2000 rpm for 10 minutes. The supernatant was decanted into a 50 ml volumetric flask. The soil was washed twice with 12.5 ml of saturated NaCl each time and centrifuged again. The washings were combined with the extract and diluted to the final volume. The supernatant solution was collected for phosphorus determination.

Method of Phosphorus determination from the extracts

Inorganic phosphorus was measured by the ascorbic acid blue color method of Murphy and Riley (1962). 4 ml of 0.8 M H_3BO_3 was added to ammonium fluoride extract just before color development. Reductant soluble phosphate was determined after oxidation of dithionite by allowing the flask to stand exposed to the atmosphere (Williams *et al*., 1967) before color development. The difficulty, however, arose during the determination of phosphorus from the extract. To oxidize the dithionite, the samples needed to be heated with H_2O_2.

Results and Discussion

The inorganic P including iron aluminium P, calcium bound P, and residual P is the major contributor to total P in soil. The ~~amount~~number of different forms of inorganic P in soil depends on the nature of soil quality.

Inorganic Phosphorus Fractions in Soil

The modified fractionation scheme of soil inorganic phosphorus of Chang and Jackson (1957) as reported by Kuo (1996) was used to quantify the fractions of soil P as affected by different salinity level. The values of different discrete forms of inorganic P at various time intervals are presented in Fig 1.

Fe and Al Bound Phosphate

The Fe Al-P contents of the soils at different time intervals as affected by application of different salinity levels are presented in Fig1 and Fig 2. In Bajoa series the Fe-Al-P content decreases with increasing salinity level and remain constant from 30th to 60th day. The percent (81.6%) decrease of Fe-Al-P content in the salinity level of 12 dS/m is higher than the percent (87.5%) decrease of 2 dS/m. In Sara series the Fe Al-P content remain nearly constant. there is no significant effect of salinity levels on Fe-Al-P contents.

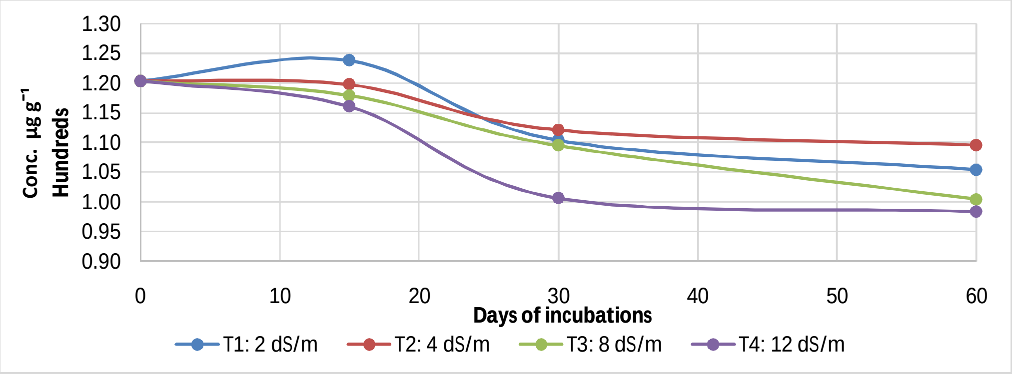

Fig. 1 Changes in Fe Al-P content in Bajoa series under different salinity treatments

Comment [SS4]: dSm^{-1} correct this in all figures

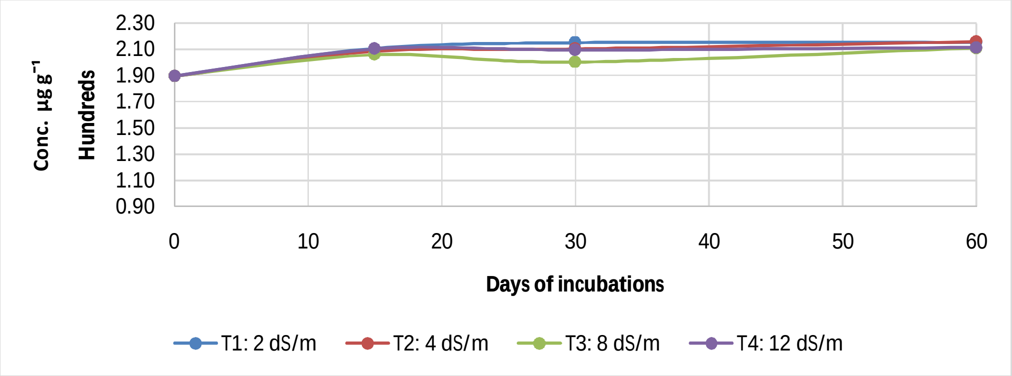

Fig. 2 Changes in Fe Al-P content in Sara series under different salinity treatments

Reductant Soluble Phosphate

The Rs-P contents of the soils at different time intervals as affected by the application of different salinity levels are presented in Fig. 3 and Fig. 4. In the Bajoa series with the increasing salinity level the Rs-P content decreases. Though at the salinity level of 2 dS/m the

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Rs-P content increases but this cannot stay long with increasing salinity level. In Sara series, it also shows the same result as the Bajoa series. With the increasing salinity level, it shows a periodic decrease of Rs-P content.

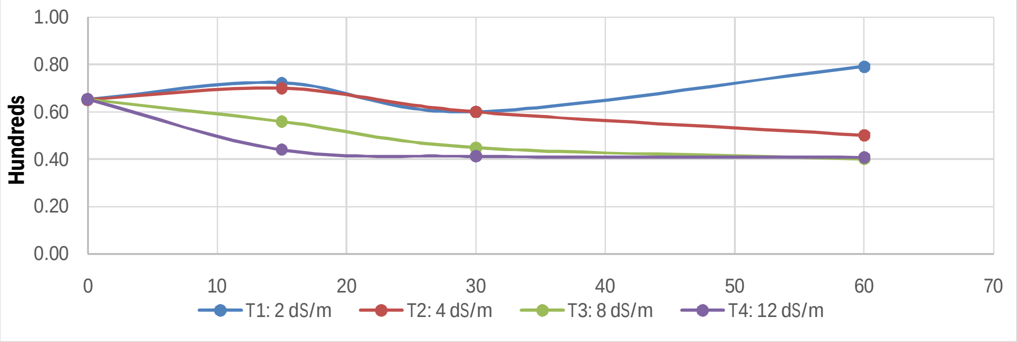

Fig. 3 Changes in RS-P content of Bajoa series under different salinity treatments

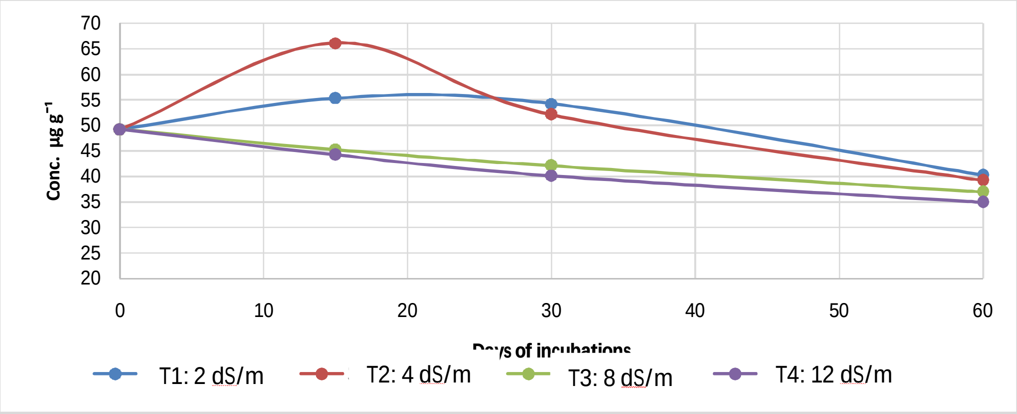

Fig. 4 Changes in RS-P content in Sara series under different salinity treatments

Calcium Phosphate

The Ca-P contents of the soils at different time intervals as affected by the application of different salinity levels are presented in Fig 5 and Fig 6. In the Bajoa soil series against two salinity levels (2dSm^{-1} and 4 dS m^{-1}), the Ca-P percentage (110.37 and 112.17) % tends to increase. But with the increasing salinity level of 8 dSm^{-1} and 12 dSm^{-1}, the Ca-P percentage (95.39 and 90.24) % decreases. In Sara soil series with the increasing salinity level, the Ca-P percentage (from 109.18 to 135.23) % increases.

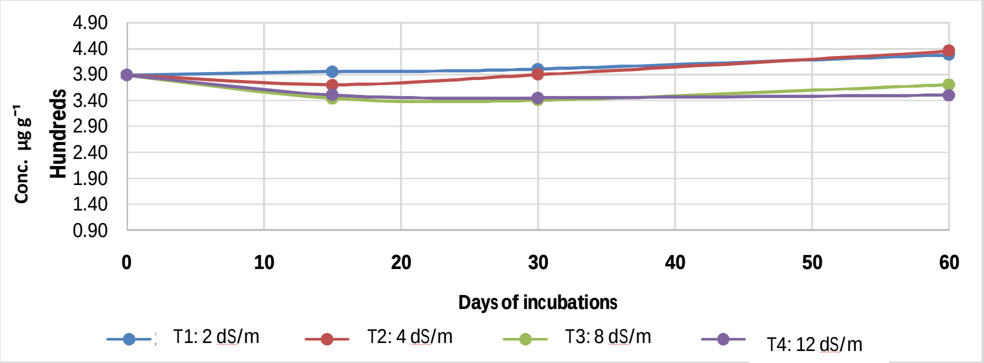

Fig. 5 Changes in Ca-P content in Bajoa series under different salinity treatments

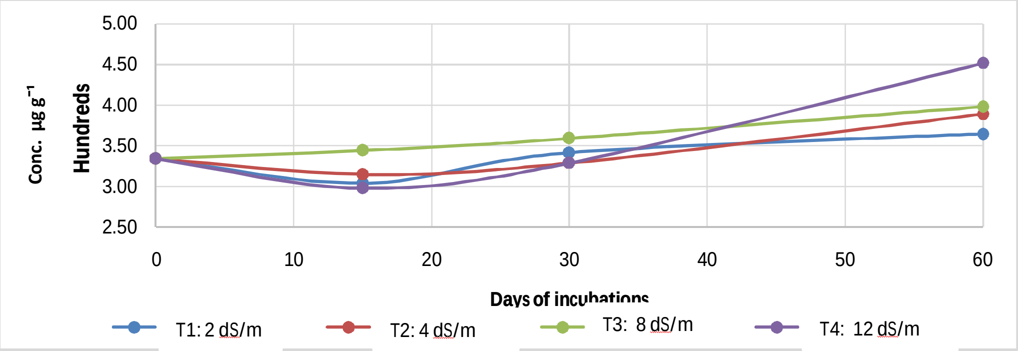

Fig. 6 Changes in Ca-P content in Sara series under different salinity treatments

Conclusion

An incubation experiment was conducted in the laboratory. The effect of four salinity levels (2 dS/m, 4 dS/m, 8 dS/m, and 12 dS/m) was observed on two different soil series (Bajoa and Sara) P transformation and availability through four cycles (0 day, 15th day, 30th day and 60th day). The changes in the P fractions follow the following sequences:

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Ca-P>Fe, Al-P> Rs-P in Sara series (pH 7.56)

Ca-P>Fe, Al-P> RS-P in Bajoa series (pH 6.97)

The transformation of inorganic P occurred rapidly due to the influence of salinity. In Sara and Bajoa series, the availability of P fractions decreases with the increasing salinity levels. Both series show the almost same behavior in the case of increasing salinity. Salinity reduces the availability of P fractions to plants. Since P is a complicated but significant element, it is obligate to have more research work on its mechanism so that the transformation and availability of P fractions can be acquainted.

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