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### **Research Article**

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# The effects of salinity on changes in characteristics of soils collected in a saline region of the Mekong Delta, Vietnam

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Abstract: Due to the impacts of climate change and the reduction in the flow of the Mekong River, saline intrusion into the inland has been an emergent and pressing issue. The purpose of this study is to analyze the effects of various saline conditions (0-25‰) on changes in some soil properties under laboratory conditions. Ten topsoil samples were collected from a depth of 0-20 cm in the dry seasons in the rice-corn rotation fields with low salinity, in Thanh Phu district, Ben Tre province, Vietnam. The examined criteria consisted of soil pH, soil electrical conductivity of the saturated paste extract (ECe), exchangeable Na, percentage of exchangeable Na, and content (%) of nitrogen and phosphorus. The results revealed that the pH range of soil decreased from 5.14-5.72 to 4.08-5.14 when the soil salinity increased from 0 to 25‰. At the salinity of 10% and higher, the available nitrogen began to decline. Meanwhile, the available phosphorus tended to decrease as the salinity increased past 12%. Some measures are also discussed, with the aim of ensuring sustainable rice farming in the circumstances of increased salinity.

**Keywords:** salinity intrusion, saline soils, sodicization, Mekong Delta

### 1 Introduction

Despite the long-lasting morphological stability of the Mekong Delta, the landscape of the region has recently witnessed drastic changes in the form of water withdrawal

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and land sinking [1,2]. It is forecasted that the combination of reduced supply of water and sediments, compaction, and thermosteric sea level rise may threaten the existence of this region in possibly less than a century [3]. This certainly spells disaster for the Vietnamese economy, given that the Mekong Delta plays a key role in agricultural and aquatic production of Vietnam [4]. The delta is characterized by the vast area of fertile, flat land with little to no forest coverage and approximately 65% of which is reserved for rice farming.

One of the main natural obstacles of the Mekong Delta is the saline water intrusion in the dry season, affecting not only agricultural production but also water supply and daily life for millions of people. At the seashore, salt in saline soils can locally be generated from sediments or by saline intrusion of seawater or supplied using saline water [5]. According to ref. [6], the accumulation of salt in the soil begins to occur when the evaporation of water exceeds the amount of water supplied to the soil because most irrigation water contains an amount of dissolved salt. After irrigation, water in the soil is absorbed by the crop or evaporates directly, leaving the salt in the soil.

Saline soils mainly contain soluble salt components including calcium (Ca<sup>2+</sup>), magnesium (Mg<sup>2+</sup>), sodium (Na<sup>+</sup>), potassium (K<sup>+</sup>), chloride (Cl<sup>-</sup>), bicarbonate (HCO<sup>3</sup>), or sulfate  $(SO_4^{2-})$  [7,8]. High salinity in the soils usually causes the phenomenon of sodicization. Saline sodic soil with a high accumulation of salt hinders crops growth. Other disadvantages include disturbance and imbalance in water and nutrient uptake and unfavorable physical properties [9]. The presence of salts in the soil is determined by the concentration of Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, and K<sup>+</sup>; and the ability of sodicization of the soil is determined by calculating the adsorption ratio of Na<sup>+</sup> on clay glue (sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) [10]. According to the US Department of Agriculture, soil is considered saline when the electrical conductivity (EC) of the saturated soil extract (EC saturation) is greater than 4 dS m<sup>-1</sup> at 25°C. Therefore, higher

dissolved salts in the soils will lead to higher conductivity [11].

Saline soils with high salt concentration lead to unfavorable physical, chemical, and biological properties [12]. Saline soils contain high levels of Na<sup>+</sup> ions in the soil's absorption complex, causing disturbance and imbalance in the uptake of water and nutrients for crops and disadvantages in soil physical properties [13]. Soil salinity can also indirectly affect crops by causing nutrient deficiencies or nutrient imbalances in plants, such as the imbalance in ratio of Na<sup>+</sup>/Ca<sup>2+</sup> [14] or directly exert toxicity in plants by excessive absorption of ions such as Na<sup>+</sup>, Cl<sup>-</sup>, B<sup>+</sup>, and  $SO_4^{2-}$  [15–18]. On agricultural land, salinity hinders water-plant interaction by introducing excess salt in the root, which reduces the amount of water available to the plant and causes the plant to use more energy to remove the salt and absorb water.

Fluctuations of saline and flooding factors directly affect the production and daily life of people. As a basis for future orientation of agricultural land use in the Mekong Delta, assessing the impact of salinity on changes in soil properties under laboratory conditions is essential to improve the efficiency of land use and ensure sustainable farming conditions. In this study, we assessed the influence of salinity variations on essential soil nutrient indicators such as pH, EC, Na+ exchange, ESP, available nitrogen, and available phosphorus. The results are expected to aid in devising strategies that are appropriate to specific crops to cope with different salinity levels in the region.

### 2 Materials and methodology

### 2.1 Collection of soil samples

Soil samples were collected in rice-corn rotation farming fields located in the low salinity ecological zone in Thanh Phu district, Ben Tre province, Vietnam. The highest salinity of water in canals and ditches is around 4-5% in the dry season. Soil samples were taken in accordance with ISO 10381-2:2002 and then stored and brought to the laboratory in accordance with ISO 11464:2006. Topsoil is collected at a depth of 0-20 cm. Sampling points follow the zigzag pattern, and 10 soil samples were collected for an area of 0.1 Ha. Samples were then mixed well, and a representative sample was taken for analysis.

Soil is classified into the following six major groups according to the Vietnam standards: (1) red and vellow soil; (2) alluvial soils include alluvial soil of Red River

system, alluvial soil of Mekong river system and other alluvial soil of other river systems; (3) faded gray soil includes faded gray soil on acid magma and sandstone and faded gray soil on ancient alluvial; (4) acid sulfate soil; (5) salty soil; and (6) coastal sandy soil. In each major group, the soil quality indicators of nonorganic contents include three main indexes, which are exchangeable calcium content (TCVN 9236-1-2012), exchangeable magnesium content (TCVN 9236-2-2012), and exchangeable sodium content (TCVN 9236-3-2012).

### 2.2 Experimental

The experiment was arranged at room temperature (30  $\pm$ 2°C). The soil is chopped to a size of about 2cm and placed in a glass jar (1,000 mL) with a weight of 1.5 kg dry soil/jar. The soil was submerged in saline solutions with different salinity of 0% (control sample), 2, 4, 6, 8, 10, 12, and 25‰, with four replicates, a depth of 5 cm. Saline water is made from artificial seawater (instant ocean) and distilled water. A 2% saline solution is made from 2 g of instant salt (instant ocean) into 1L of water. Other treatments were identically prepared. Soil samples were collected by small hand drills at 1, 2, 4, 6, and 12 weeks after saltwater intrusion, and the soil was dried in natural conditions and minced through 0.5 mm sieve.

### 2.3 Measurement of soil indicators

The soil analysis methods are detailed in Table 1, and the main component of instant ocean water and natural is shown in Table 2.

The standards used for the analysis of phosphorus, Na<sup>+</sup>, Mg<sup>2+</sup>, and Ca<sup>2+</sup> were potassium dihydrogen phosphate KH<sub>2</sub>PO<sub>4</sub> (CAS 7778-77-0), sodium chloride NaCl (CAS 7647-14-5), magnesium chloride MgCl<sub>2</sub>·6H<sub>2</sub>O (CAS 7791-18-6), and calcium carbonate CaCO<sub>3</sub> (CAS 471-34-1), respectively. All standards were purchased from Merck and their purity were in the range of 99.0-101.0%.

### 2.4 Statistical and data analysis

Mean and standard deviations were derived using Microsoft Excel. ANOVA and LSD analysis of 5% to compare the differences in soil chemistry properties of

Table 1: Methods of analyzing soil parameters

Analytical indicator	Reference method	Standard method				
pH, EC	Extracted with distilled water, extract ratio 1:2.5 (soil:water) and measured by pH,					
	EC meter					
Nitrogen	Guabekki and Bremner (1986) [19]	ISO 11261:1995				
Phosphorus	Olsen (1954) [20]	ISO 18645:2016				
Na <sup>+</sup> , Mg <sup>2+</sup> , Ca <sup>2+</sup>	Atomic absorption spectrum (AAS)	ISO 11464: 2006				
TOC (total organic carbon)	Walkley-Black (1934) [21]	ISO 10694:1995				
CEC (cation exchange capacity)	The measure is determined by a buffer of BaCl $_2$ 0.1 M [22]	ISO 23470:2018				
ESP (exchange sodium	The method is based on the ratio of Na <sup>+</sup> adsorbed and cation exchange capacity of					
percentage)	the soil (CEC, cmol/kg). ESP(%) = $\frac{[Na^+]}{CEC} \times 100$					

treatments. Using the Duncan test, evaluate the difference in soil and water parameters. The final data were processed on SPSS 20 statistical software.

**Ethical approval:** The conducted research is not related to either human or animal use.

### 3 Results and discussion

## 3.1 Comparison of typical properties of instant ocean, natural seawater, and soil properties before experiment

In Table 3, the initial salinity of the soil according to the EC criteria can be evaluated as nonsaline if the electrical conductivity (EC) of the extract at saturated soil is less than 4 mS/cm at 25°C [23]. According to Boyd, the pH value

Table 2: Main component of instant ocean water and natural (Unit: ppt)

Ion	Instant seawater	Natural seawater
Na <sup>+</sup>	10.78	10.781
$K^+$	0.42	0.399
$Mg^{2+}$	1.32	1.284
Ca <sup>2+</sup>	0.4	0.411
$Sr^{2+}$	0.008	0.007
Cl-	19.29	19.353
SO <sub>4</sub> <sup>2+</sup>	2.66	2.712
HCO <sup>3-</sup>	0.2	0.126
Br <sup>-</sup>	0.056	0.067
$B(OH)_3$	_	0.025
F	0.001	0.001

of soil from 6.5 to 7.5 is suitable for the growth and development of cultured shrimp and aquatic organisms [24].

In the Mekong Delta region, soil having pH values ranging from 6.5 to 8 are suitable for aquaculture, so it is reasonable to see the pH values of the tested soil were at low levels [25], which can adversely affect fisheries and require measures to raise the pH, such as lime administration. The SAR determined by the concentrations of Na<sup>+</sup>, Ca<sup>2+</sup>, and Mg<sup>2+</sup> of the sodic soil was greater than 13; thus, the soil in the area taken is suitable for crop cultivation. Regarding soil nutrients, the P content in common soil is in the range of 10–100 mgP/and in association with the insoluble soil composition [26]. Therefore, the nutrition of the tested soil could be concluded to be at low level.

### 3.2 Effect of salinity on changes in some soil properties under laboratory conditions

Higher salinity in agricultural production land caused by coastal saline intrusion induces drastic changes in soil characteristics and affects the structure and crop plants and animals. In this laboratory experiment, nonsaline soils, the soil on which rice and corn are currently grown, were treated with varying salinity (from 2 to 25‰) to monitor the variations in soil characteristics. This treatment is to simulate 3 months of high salinity in the dry season.

### 3.2.1 Soil pH

The results presented in Table 4 show that the soil pH is low, ranging from 4.0 to 5.6 on average. With increasing

Table 3: Some soil properties before the experiment

EC (mS/cm)	рН	Na <sup>+</sup> exchange (cmol/kg)	Available N (mg/kg)	Available P (mg/kg)	CEC (cmol/kg)
2.41	6.15	1.85	8.41	1.67	12.7

salinity, high saline treatments of 12 and 25% resulted in the pH values that are significantly different from those of the control and of lower salt concentrations. When salinity is increased, cation exchange between Na<sup>+</sup> and H<sup>+</sup> can lead to increased concentration of H+ ions in soil solution, in turn lowering the soil pH. Over the period of 2-12 weeks of saltwater intrusion, soil pH tends to increase slightly. This increase in pH is negligible and has not yet reached the neutral pH value. When the soil is flooded, reducing reactions occur with the participation of soil microorganisms. The reduction reaction consumes H<sup>+</sup> ions, contributing to an increase in soil pH. However, under high salinity conditions, soil microbial activity is reduced, causing very minor pH increases. On the other hand, the buffering capacity of the soil may contribute to limiting this increase in soil pH.

### 3.2.2 Conductivity of soil (EC)

The results presented in Figure 1 show that, when salinity increases, conductivity of saline soils also increases significantly (Table 5). In some treatments, the period in which rapid acceleration in salinity occurred may be lower than 2 weeks. However, after 2 weeks the salinity is almost unchanged. When the soil was submerged for 2‰ for 2 weeks, the EC of the saturated soil extract

solution was slightly higher than 4 mS/cm, reaching the threshold of saline soils [27]. When the salt concentration increases from 4 to 25‰ after 2 weeks of saltwater flooding, the salinity of the soil also increases, the value of EC of the saturated paste extract (ECe) ranged from 7 to 46 mS cm<sup>-1</sup>. Thus, when saline soils are inundated with a salt concentration of 2‰, the soil can become saline. An inundation with the salt concentration higher than this value may aggravate the salinity issue of the soil, thus impairing the

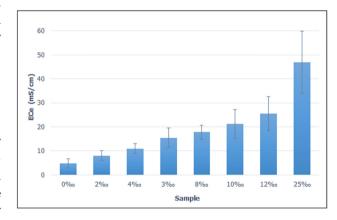


Figure 1: Effect of saltwater salinity on EC of the saturated paste extracts (ECe) after 12 weeks of salinity treatment.

Table 4: Changes in soil pH over time due to saltwater intrusion and salt concentration

Experiments		Time (v	F test	LSD (5%)	CV%		
	2	4	6	12			
0‰	5.21abB	5.14bA	5.64aAB	5.72A	*	1.7	6.2
2‰	5.32aB	5.46aAB	5.43abAB	5.78A	*	1.6	8.7
4‰	5.33a	5.27ab	5.34ab	5.49	ns	5.1	6.7
6‰	5.06abB	5.07bAB	5.30abAB	5.56A	*	1.4	10.7
8‰	5.33a	5.10b	5.35ab	5.48	ns	5.2	4.8
10‰	4.86b	5.11b	5.45ab	5.55	ns	3.4	11.3
12‰	4.46b	4.53c	5.22b	5.34	ns	4.4	5.4
25‰	4.08b	4.44c	5.14b	5.28	ns	7.9	8.8
F-test	*	*	*	ns			
LSD (5%)	0.56	0.27	0.33	0.56			
CV%	6.96	3.70	4.28	6.96			

Notes: Lowercase letters indicate Tukey's test between salinity treatments. Upper letters indicate Tukey's test over time. The same letters in the same column or row indicated no significant difference. ns: undifferentiated; (\*): difference with significance level of 5%.

Table 5: The EC (1:2.5) change in soil according to salinity and salinity duration

Experiments		Time (weeks)				LSD (5%)	CV%
	2	4	6	12			
Control	1.31g	1.48g	1.47h	1.28h	ns	6.6	15.0
2‰	2.19f	1.91g	2.12g	2.40g	ns	11.2	13.9
4‰	2.68f	2.49f	3.05f	3.10f	ns	16.3	13.7
6‰	3.17fA	3.54eA	3.72eAB	3.83eA	*	2.4	9.1
8‰	4.42d	4.35d	4.81d	4.49d	ns	10.2	7.4
10‰	5.41c	5.49c	5.56c	5.61c	ns	3.4	4.4
12‰	6.21b	6.57b	6.29b	6.60b	ns	3.6	7.4
25‰	11.52a	12.12a	11.75a	12.39a	ns	11.9	4.9
F	*	*	*	*			
LSD (5%)	0.51	0.55	0.37	0.39			
CV%	8.31	8.41	5.69	5.37			

Notes: Lowercase letters indicate Tukey's test between salinity treatments. Upper letters indicate Tukey's test over time. The same letters in the same column or row indicated no significant difference. ns: undifferentiated; (\*): difference with significance level of 5%.

growth and development of crops. Therefore, further measures should be taken to improve saline soils [28].

#### 3.2.3 Correlation of EC of soil extract EC (1:2.5) and ECe

Plotting the data of EC (1:2.5) against ECe (Figure 2) shows a strong correlation ( $R^2 = 0.95^{**}$ ) between two variables. The estimated equation was  $EC = 0.302 \times ECe +$ 0.357. The graph shows that the ECe values are generally higher than the EC values. This is possibly due to higher salt concentration of the latter method, which is caused by involvement of water that led to a moisture of around 70-80%. According to the evaluation scale of soil salinity, ECe value is the standard value to evaluate. However, to extract saturated soil, an air compression system is needed to extract saturated water in the soil, which is time-consuming and may present further difficulties to the process. Therefore, the availability of a well-estimated relationship between ECe and EC (1:2.5) could help predicting ECe values using only EC (1:2.5). From the data, it was shown that the EC/ECe ratio between EC/ECe varies from 0.27 to 0.44, averaged at 0.32. This result is consistent with a previous study where 603 acres of saline-rice soil in the Mekong Delta were surveyed, showing a strong correlation between ECe and EC 1:1.25  $(R^2 = 0.89)$ , with an average EC/ECe ratio of 0.41 [29].

### 3.2.4 Exchangeable sodium and sodicization in soil

The results presented in Table 6 show that when the soil is submerged in saline water, exchangeable Na<sup>+</sup> in the

soil increases with salinity concentration and the difference is statistically significant. An increase in Na<sup>+</sup> exchange results in a higher ESP value. In saline soils, the percentage of Na in the absorption system (ESP) is a numerical value that evaluates the soil sodicization. When this value exceeds 15%, physicochemical and biological properties of the soil could be compromised, and crop nutrition could be impaired. The analysis results show that when the soil is submerged with a salinity of 2–4‰, the ESP in the soil was lower than 15%, thus the soil sample was not considered as sodicized. When the salinity treatment was 6‰, the ESP value of the soil exceeded the ESP threshold of sodicization, at above 15% (Table 7). When salinity was higher than 6‰, soil pH became lower than 8.5, ECe was higher than 4 mS cm<sup>-1</sup>, and

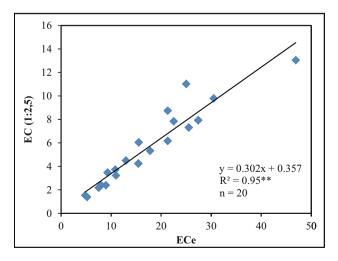


Figure 2: Correlation between EC (1:2.5) and ECe saturation extract.

Table 6: Effect of salt concentration and treatment duration on percentage of exchangeable Na (ESP) in the soil

Experiments		Time (	F test	LSD (5%)	CV%		
	2	4	6	12			
Control	2.66e	7.36h	7.08g	6.48g	ns	11.30	36.89
2‰	9.28d	12.74g	8.66g	7.87g	ns	13.26	24.89
4‰	10.86dAB	19.47fA	10.07gB	14.02eAB	*	4.20	11.69
6‰	18.64c	21.65e	14.40e	19.13de	ns	15.30	8.16
8‰	23.53b	24.70d	17.79d	21.54cd	ns	12.53	9.19
10‰	25.54b	27.72c	21.89c	26.50c	ns	11.42	7.05
12‰	25.77b	33.39b	24.64b	35.65b	ns	16.20	15.09
25‰	51.58a	53.05a	42.52a	55.31a	ns	13.64	3.27
F	*	*	*	*			
LSD (5%)	2.97	1.39	2.28	3.93			
CV%	9.68	3.80	13.61	12.29			

Notes: Lowercase letters indicate Tukey's test between salinity treatments. Upper letters indicate Tukey's test over time. The same letters in the same column or row indicated no significant difference. ns: undifferentiated; (\*): difference with significance level of 5%.

ESP (%) was higher than 15, indicating that the soil had become saline sodic [30].

Thus, when the soil is intruded with salinity at 2‰, the soil becomes saline and its ECe will be higher than 4 mS/cm. At saltwater intrusion of 6‰, the soil begins to become saline sodic because its ESP reaches as high as 18%, according to the classification sodic saline soils [12,31]. In general, plants are adversely affected by salinity, and the detriment becomes especially worse in saline sodic soils due to impeded absorption of water and nutrients of plants, which is caused by the high osmotic pressure of the soil solution. Crops that are affected by salinity and saline sodic soils manifest as dehydrated, drought-affected plants. High Na<sup>+</sup> salt concentration causes nutrient imbalance and hinders the nutrient uptake of crops, leading to significantly reduced yields [32]. A high concentration of Na<sup>+</sup> in the soil results in high Na/K, Na/Ca, and Na/Mg ratios, which cause disruption in nutrient metabolism and protein synthesis. Therefore, it is necessary to take measures to reduce salinity through saline washing and reduce Na<sup>+</sup> in soil as well as Na<sup>+</sup> saturated in the absorption complex.

### 3.2.5 Available nitrogen content in soil

The available nitrogen content in soil after 2 weeks of saltwater treatment decreased significantly compared to that of the control sample. The protein content was increasing with salt concentration at low salinity.

Table 7: Effect of salt concentration and treatment duration on exchangeable Na (cmol/kg) in soil

Experiments		Time	(weeks)	F test	LSD (5%)	CV%	
	2	4	6	12			
Control	0.34eB	0.94hA	0.9gC	0.82gC	*	0.40	54.4
2‰	1.18dA	1.62gA	1.1gB	1.00gA	*	1.50	26.3
4‰	1.38dB	2.47fA	1.28gC	1.78eB	*	0.60	30.8
6‰	2.37cA	2.75eA	2.01dB	2.43deA	*	0.46	9.8
8‰	2.99bA	3.14dA	2.26dB	2.74deA	*	0.32	7.1
10‰	3.24bA	3.52cA	2.78cB	3.37cA	*	0.41	7.5
12‰	3.27bA	4.24bA	3.13bB	4.53bA	*	1.30	15.2
25‰	6.55aB	6.74aA	5.4aB	7.03aA	*	0.42	1.8
F	*	*	*	*			
LSD (5%)	0.38	0.14	0.29	0.49			
CV%	9.99	3.16	13.62	12.29			

Notes: Lowercase letters indicate Tukey's test between salinity treatments. Upper letters indicate Tukey's test over time. The same letters in the same column or row indicated no significant difference. ns: undifferentiated; (\*): difference with significance level of 5%.

However, as the salt concentration increases above 10‰, the nitrogen content in saline soils significantly decreases (Table 8). After 4-6 weeks of salinity treatment, the available nitrogen content significantly increased. However, prolonging the treatment for more than 6 weeks causes the available nitrogen content to decline. This result shows that despite the salinity, microbiological activity in the mineralization process of nitrogen still occurs over time and that soil microorganisms can adapt to a change from fresh to saline stage of the soil environment, thus promoting the mineralization of nitrogen [33,34].

It has been shown that increased salinity stress could lead to smaller microbial community, less metabolic efficiency, and worsened activity of extracellular enzymes such as b-glucosidase, alkaline phosphatase, and arylsulfatase [35]. The exponentially negative relationships between the number of microbial communities and concentrations of dissolved salts could be elaborated through two main mechanisms: the osmotic effect and the effect of specific ions. While the salinity-induced osmotic stress could reduce microbial mass mainly through cell drying and lysis, the effect of ion mainly involves higher energy consumption of microbes to synthesize more organic osmolytes, such as proline and glycine betaine, which are required for ameliorating the stress effects [36]. Such energy waste might lead to reduced microbial growth [37]. In addition, fungi tend to be more susceptible than bacteria to salt stress [38,39]. As a result, increased salinity may also affect the fungibacteria community structure [38,40].

### 3.2.6 Content of available phosphorus in soil

The analytical results presented in Table 9 show that the available phosphorus content in the soil is very poor. The phosphorus available in the soil tends to increase with extended saline period tends to decrease when the salinity increases more than 12‰. This shows that the phosphorus available in saline soils is very low because phosphate anions can be precipitated by reacting with Ca<sup>2+</sup> and Mg<sup>2+</sup> cations, which are abundant in saltwater. From this result, it could be observed higher salinity seemed to associate with lower phosphorus available in the soil. which is nutritionally disadvantageous for crops.

According to the Vietnamese standards of soils quality – index values of total phosphorus content in the soils of Vietnam (TCVN 7374: 2004) for each soil type is as follows:

The results show that the study area consists of mostly saline soil (65.1%) and acid sulfate soil (5.09%), the rest belongs to insignificant alluvial soil (1.13%). Corresponding to the standards of phosphorus quality limit in soil, saline soil has phosphorus content of about 0.08-0.20% (corresponding to 0.08-0.20 mg/kg of soil) and alkaline soil. The amount of phosphorus is about 0.03-0.08 (0.03-0.08 mg/kg soil, respectively). From the results of Table 10, it shows that the phosphorus content of the soil samples is at medium to fair level compared to the Vietnamese standard for soil groups.

According to the salinity scale described by Landon, the soil having ECe ranging from 8.22 to 13.11 mS cm<sup>-1</sup> was classified as saline soil [41]. Generally, high ECe might impair the growth of most rice varieties, especially

<b>Table 8:</b> Changes in the value of available nitrogen (mg/kg) in the soil over the time of salinity and salt concentrate	nitrogen (mg/kg) in the soil over the time of salinity and salt concentration
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Experiments		Time (w	F test	LSD (5%)	CV%		
	2	4	6	12			
Control	26.43bC	77.68aA	72.54A	50.29bB	*	0.50	40.5
2‰	20.66cdC	73.74abA	73.71A	50.27bB	*	0.30	40.0
4‰	22.15bcdC	67.18bAB	81.17A	56.69aB	*	0.43	41.9
6‰	20.40cdC	69.95abA	70.37A	55.48abB	*	0.12	39.6
8‰	25.16bcC	68.53abA	78.64A	56.65aB	*	0.30	37.1
10‰	31.95aC	72.91abA	78.61A	56.90aB	*	0.10	38.4
12‰	17.39dC	72.92abA	75.15A	54.17abB	*	0.40	42.5
25‰	19.76dC	74.62abA	75.12A	53.76abB	*	0.50	43.1
F	*	ns	ns	*			
LSD (5%)	5.26	10.09	11.95	5.77			
CV%	15.69	9.58	10.82	7.29			

Notes: Lowercase letters indicate Tukey's test between salinity treatments. Upper letters indicate Tukey's test over time. The same letters in the same column or row indicated no significant difference. ns: undifferentiated; (\*): difference with significance level of 5%.

Table 9: Effect of salinity treatment duration and available phosphorus concentration (mg/kg) in soil

Experiments		Time (		F test	LSD (5%)	CV%	
	2	4	6	12			
Control	0.13abC	0.34aAB	0.37aA	0.24aBC	*	0.30	41.7
2‰	0.20a	0.26ab	0.28bcd	0.23a	ns	14.21	26.5
4‰	0.08bB	0.21abA	0.29bA	0.22aA	*	0.32	47.0
6‰	0.12ab	0.23ab	0.29bc	0.16b	ns	12.30	68.4
8‰	0.15ab	0.14b	0.21d	0.17b	ns	19.50	28.8
10‰	0.15ab	0.18ab	0.22cd	0.16b	ns	11.45	33.9
12‰	0.10bB	0.16bAB	0.25bcdB	0.19abAB	*	0.40	39.7
25‰	0.11bB	0.18abAB	0.21cdA	0.19abAB	*	1.30	34.1
F	*	*	*	*			
LSD (5%)	0.07	0.06	0.06	0.04			
CV%	44.13	53.42	18.11	14.41			

Notes: Lowercase letters indicate Tukey's test between salinity treatments. Upper letters indicate Tukey's test over time. The same letters in the same column or row indicated no significant difference. ns: undifferentiated; (\*): difference with significance level of 5%.

at the young seedling the reproductive stage [42]. On the other hand, the response of rice plant to salinity might be different depending on the variety and the salinity level and maximum tolerable salinity might be high as much as 4‰ [43]. Therefore, suggested strategies to improve the tolerance of rice might include adoption of salinity-tolerant varieties and supplementation of Ca<sup>2+</sup> or lime to balance Na<sup>+</sup> [44–46].

Available nitrogen and phosphorus are important indicators in evaluating the capability of soil in providing organic nutrients [47]. Previous reports have shown that the available nitrogen largely determines rice productivity [48,49], possibly via mediation of its demands for macronutrients [50]. According to Wood and Lass, low available nitrogen is indicative of limited organic nutrients, which is the main causes for low productivity of rice growing in saline soils [51]. Elevated salinity also lowers available nitrogen through mineralization and increased mortality of microorganisms, in turn leading to the deficiency of rice nutrient intake [52]. The mechanism by

Table 10: The phosphorus content limitations for each soil type

Soil group	Total phosphorus (P <sub>2</sub> O <sub>5</sub> %)				
	Value range	Average			
1. Red soil	From 0.05 to 0.60	0.30			
2. Alluvial soil	From 0.05 to 0.30	0.10			
3. Faded gray soil	From 0.03 to 0.06	0.04			
4. Acid sulfate soil	From 0.03 to 0.08	0.04			
5. Salty soil	From 0.08 to 0.20	0.09			
6. Coastal sandy soil	From 0.03 to 0.05	0.04			

which phosphorus affects rice productivity is similar to that of nitrogen [53]. Therefore, the application of organic fertilizers, which are rich in nitrogen and phosphorus, could be considered as a suitable salinity-coping measure in saline rice paddy fields.

### 4 Conclusion

This study simulated the effect of salinity intrusion on some soil characteristics under laboratory conditions. Obtained results indicate that prolonged exposure to salinity caused evident consequences to soils. After 2 weeks of salinity treatment with a concentration of 4‰, the soil became saline. With 6 weeks of treatment, sodicization occurred. For sustainable farming of rice and corn, the soil salinity is recommended not to exceed 4‰; and higher salinity might significantly cause deficiency in nutrients, particularly available nitrogen and phosphorus. The recommended measures for sustainable rice cultivation in the saline soil include adoption of salinity-tolerant varieties and administration of lime, which is a source of Ca<sup>2+</sup> that could indirectly balance Na<sup>+</sup> in salted rice plants, and organic fertilizers. In addition, the development of diversified farming model is advised to cope with different salinity levels in the region.

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