The Main Ion Concentrations in Surface Soil Layer in Nam Dinh Province of the Red River Delta, Northern Vietnam

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Abstract: This study aims to clarify the main ion concentrations in paddy field surface soil from 0 to 100 cm in depth along the coast of the Red River Delta, Northern Vietnam, represented by Nam Dinh Province. There is a relation between total dissolved solid (TDS) and Na^+ concentration. Na^+ and Cl^- concentrations in paddy fields increase gradually and the abundance of Cl^- concentration in soil proclaims the influence of seawater intrusion. Washing is reported to reduce the high salinity in the cultivation-layer soil of paddy fields. Furthermore, the impact of seawater intrusion on soil salinity of coastal paddy fields has been considered. The top soil layer of coastal salt-affected paddy fields has the highest sodium absorption ratio (SAR) values, and shows the strongest salinity influence in both the flood season and the dry season. Soil samples near the Day River mouth have high SAR values with considerable Na^+ concentrations in the dry season. The exchange selectivity between Ca^{2+} , Mg^{2+} and Na^+ has also been studied by considering changes in the SAR under different conditions of soil composition and land cover. In coastal agricultural land, the SAR in the surface soil layer can be used to evaluate the influence of salinity. The SAR in cultivated soil is used to assess the influence of salinity problems on the paddy field.

Key words: The Red River Delta, coastal agricultural land, ion concentrations, TDS (Total Dissolved Solid), SAR (Sodium Absorption Ratio)

Introduction

The Red River Delta is located in Northern Vietnam. Its agricultural and ecological conditions limit the Red River Delta to being used mainly for paddy cultivation of rice. The delta is approximately 12,500 km², with a coastline more than 160 km in length and seven river mouths (Le 1997).

The Red River Delta's coastal agricultural area that belongs to Nam Dinh Province (Figure 1) is mainly paddy field. In Nam Dinh Province, maximum temperature reaches its lowest value (10.4°C) in March. The total of sunshine hours is very low, from 1.2 to 1.5 hour per day in the dry season from January to March (Figure 2). Furthermore, river discharge, described in terms of the average value of the water level in the Dao River, is insufficient, and rainfall is also rare (Figure 3).

The coastal area is affected by erosion due to typhoons and seawater intrusion in the dry sea-

son. Typhoons and tropical storms are frequent between July and October, and have increased in recent years, causing strong coastline erosion (Matsumoto et al. 2001). Coastal erosion has been reported along the coastline between the Red River mouth and the Ninh Co River mouth (Haruyama and Vu 2002). On the other hand, the deposition land located at the mouths of the Red River, the Ninh Co River and the Day River receives sediment continuously by flow transportation. It is reported that the area surrounded by the Red River and Ninh Co River suffers from severe seawater intrusion in the dry season (Vu et. al. 1991). However, the damage caused by the salinity problem in this area has not been managed or reported in detail.

Besides, with the impact of seawater intrusion in the dry season along the lower part of the rivers, high salinity soil has been reported to influence land cover change (Dinh and Haruyama 2002a, 2002b). The irrigation system operated mainly by tide power and the expanse of salty water cultivation had an effect on soil salinity of

Figure 1. The research site—The coastal area of the Nam Dinh Province, The Red River Delta.

Figure 2. Maximum temperature and sunshine hour in the Van Ly Station, Nam Dinh Province—2000.

Figure 3. Daily rainfall in the Van Ly Station and water level in the Dao River, Nam Dinh Province—2000.

paddy fields (Dinh et al. 2003). Despite the fact that the irrigation system is designed to manage seawater intrusion, insufficient attention has been paid to soil salinity problems along the coast of the Red River Delta.

In this study, salinity or total dissolved sodic (TDS) can be used to indicate the saltiness, which is caused by salt particles dissolved in irrigation water or absorbed on soil particle surfaces. The soil salinity and main ion concentrations absorbed on surface soil can be used to evaluate the salinity problem in paddy fields (Kim 1998). The concentration of ions in agricultural soil depends on such natural factors as soil particle size, chemical content of irrigation water, and human activities, including land use, fertilizer use, and irrigation-drainage systems (Bresler et al. 1982; Spark 1995).

To represent the existence of ions in soil and the relationship between soil and ions, a number of indexes have been calculated and applied in soil science. The Sodium Adsorption Ratio (SAR) has been used to characterize the sodium status of soil solutions. Petersen et al. (1996) mentioned that clay particles and organic matter are the main contributors to the cation exchange capacity (CEC). In the SAR, Na^+ concentration related to the total concentration of Ca^{2+} and Mg^{2+} and SAR can be used to evaluate the cation adsorption selectivity of soil particles to Ca^{2+} , Mg^{2+} and Na^+ . Na^+ and Ca^{2+} exchange selectivity differed according to clay minerals and clay content (Endo et al. 2002). The relation between the SAR and soil components has also been considered. Although direct relations between electrical conductivity and soil texture, or between the SAR index and soil texture, have not been clarified, the median average pore diameter of aggregates decreases when the SAR increases (Lebron et al. 2002).

To prevent the salinity problem, soil "washing" has been used for a long time in almost all salt-affected paddy fields in Nam Dinh Province. The salt particles are washed out from surface soil by irrigating the soil from 3 to 5 times before transplanting.

This study focuses on changes in salinity and in concentrations of main inorganic ions in top soil from 0 to 100 cm in depth along the coast of the Red River Delta in Nam Dinh Province. This

study was designed to clarify the soil salinity and the main (Ca^{2+} , Mg^{2+} , Na^+ and Cl^-) ion concentrations in the top soil of paddy fields, as well as the interactions between these ion concentrations and soil particles in different conditions of soil composition and land cover. The exchange selectivity between Na^+ and Ca^{2+} and Mg^{2+} has also been studied by considering the SAR value in the surface soil layer, which can be used to evaluate soil salinity.

Methodology

In this study, survey trips and samplings were carried out from August 28th to August 31st, 2002, in the flood season, during the growth period of rice plants and from February 22nd to March 1st, 2003, in the dry season, after the transplantation period. Soil samples from paddy fields and shrimp ponds in Giao An (GA), Giao Thien (GT), Hai Phuc (HP), Nghia Lac (NL), Nghia Thang (NT), Hai Trieu (HT), Hai Ninh (HN), Nam Dien (ND) and Nong Truong Rang Dong (NTRD) villages were collected in the flood and dry seasons. Using portable boring equipment soil samples were taken to a depth of 100 cm, in 20 cm sections at each of nine locations far from residential areas (Figure 4 and Table 1). The salinity of irrigation water in the sampled rice paddies was measured using portable equipment (DKK-TOA, CM-21M salinity and temperature measurers).

The process of soil analysis took place in the laboratory as follows (Figure 5). To measure soil pH, there are three main methods: $\text{pH}_{\text{CaCl}_2}$, pH_{KCl} and $\text{pH}_{\text{H}_2\text{O}}$. Because all soil samples were agricultural soils, pH_{KCl} was measured to limit fertilizer's influence on the accuracy of the pH value. Electric conductivity (EC) of the soil samples also has been measured and used to calculate the TDS values. The main (Ca^{2+} , Mg^{2+} , Na^+ and Cl^-) ion concentrations in the soil samples were analyzed (Jones 2001).

The SAR was used in this study to represent the existence of ions in soil and the relationship between soil and ions. The SAR is calculated by equation below:

Figure 4. Soil sampling map.

Table 1. Name and location of the soil sampling places

Name	Symbol	Place	Latitude	Longitude	Dry season	Flood season
Giao An	GA	R	20°15.289'N	106°30.496'E	x	x
Giao Thien	GT	R	20°17.095'N	106°33.195'E	x	x
Hai Phuc	HP	R	20°12.659'N	106°21.024'E	x	x
		P	20°12.305'N	106°21.027'E		x
Hai Trieu	HT	R	20°05.625'N	106°15.925'E	x	x
Hai Ninh	HN	R	20°06.280'N	106°13.676'E	x	x
Nghia Lac	NL	R	20°06.481'N	106°11.740'E	x	x
Nghia Thang	NT	R	20°00.311'N	106°10.537'E	x	x
Nong Truong Rang Dong	NTRD	R	19°58.521'N	106°06.250'E	x	
Nam Dien	ND	R	19°58.018'N	106°05.675'E	x	
		P	19°58.543'N	106°08.351'E		x

R: Rice field; P: Shrimp pond

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}] + [Mg^{2+}]}{2}}} \quad (1)$$

Soil particle size was analyzed using a Shimadzu SALD-3000S grain-sizer. The composition of soil samples (percent of sand, silt, and clay) was cal-

culated based on soil particle size obtained from analysis. The proportion of clay to sand and silt was calculated by the equation below:

$$Clay\ ratio = \frac{[Clay]}{[Sand] + [Silt]} \quad (2)$$

Figure 5. The soil analytical work.

Table 2. Salinity of irrigation water at the soil sampling places

Location	GA	GT	HP	HT	HN	NL	NT	NTRD	ND
Salinity (mg/l)	400	500	1500	300	200	200	300	700	900

Results

Salinity of irrigation water at the soil sampling places

The salinity of irrigation water at 9 soil-sampling locations in the dry season is shown in Table 2. Four locations had salinity values in the irrigation water equal to or higher than 500 mg/l are GT, HP, NTRD and ND.

Particle size of the soil samples

All of the soil samples were subjected to particle size analysis. The content of the soil samples was mainly divided into three parts: clay, sand, and silt, depending on the particle size dis-

tribution of each sample. The clay ratio was calculated using the values for clay, sand, and silt contents and Equation 2. Of the soil samples, the GT soil samples had the lowest clay ratio value, less than 0.1, while other soil samples had clay ratios ranging from 0.2 to over 0.5 (Figure 6).

Analysis of the top soil and the SAR

All 90 of the soil samples collected in flood and dry seasons were analyzed in the laboratory. The pH_{KCl} values ranged from mildly acidic to mildly alkaline in paddy field soil samples and were mildly alkaline in shrimp pond soil samples, as shown in Figure 7.

The Ca^{2+} , Mg^{2+} , Na^{+} and Cl^{-} concentrations of the soil samples collected in the flood season are shown in Figure 8 and the ion concentrations of

Figure 6. Clay ratio of the soil samples in the Nam Dinh Province.

Figure 7. pH_{KCl} of the soil samples in the Nam Dinh Province.

Figure 8. Ca^{2+} , Mg^{2+} , Na^{+} and Cl^{-} concentrations of the soil samples in flood season.

the soil samples collected in the dry season are shown in Figure 9. Ca^{2+} concentrations varied from 0.5 g/l to 4.0 g/l in both flood season and dry season, but the Ca^{2+} concentrations in the dry season were more consistent. Mg^{2+} concentrations were small, less than 0.5 g/l in the dry season and around 0.5 g/l in the flood season. Na^{+} and Cl^{-} concentrations appear not to differ between the flood and the dry seasons. Generally, Ca^{2+} concentrations were lower in top soil at shrimp ponds than in paddy fields, while the

concentrations of Mg^{2+} , Na^{+} and Cl^{-} in the top soil at shrimp pond were higher. (Figure 8 and Figure 9).
The TDS of the soil samples in the flood and dry seasons are described in Figure 10. In the paddy fields, the TDS of soil samples are slightly higher in the dry season than in the flood season. The TDS of soil samples was definitely higher in shrimp ponds than in paddy fields. The TDS was lower in the upper soil layer than in the lower layer in paddy fields, while the converse

Figure 9. Ca^{2+} , Mg^{2+} , Na^{+} and Cl^{-} concentrations of the soil samples in dry season.

Figure 10. TDS of the soil samples in flood and dry seasons.

was true in shrimp ponds; this is caused by the washing process applied in paddy fields.

The SAR of the soil samples was calculated using the Ca^{2+} , Mg^{2+} , Na^{+} concentrations and Equation 1, and are shown in Figure 11. Being affected by the concentrations of Ca^{2+} , Mg^{2+} and Na^{+} , the SAR values are different in the flood

season and the dry season. However, the SAR values of soil samples in shrimp pond are still the highest, because of the relatively high concentration of Na^{+} in soil samples of shrimp ponds.

Figure 11. SAR of the soil samples in flood and dry seasons.

Figure 12. The relation between TDS and Na ion concentration of the soil samples in rice field—dry and flood seasons.

Discussion

Relation between total dissolved solid and Na^+ concentration in 0–100 cm soil layers in paddy fields

To consider the influence of salt water, TDS and Na^+ concentration were investigated. The TDS values in the soil samples from paddy fields increased when the Na^+ concentration increased (Figure 12). In both dry and flood seasons, TDS in collected soil samples ranged widely, from 100 to 1600 mg/l. Na^+ concentrations also varied con-

siderably, from approximately 0.1 g/l to 1.3 g/l. However, the TDS value and Na^+ concentration of soil were slightly higher in the dry season than in the flood season. The relationships are described by the function (3) for the dry season and by the function (4) for the flood season:

$$Y = 1182X - 33.025 \quad \text{with } R^2 = 0.8737 \quad (3)$$

$$Y = 1124.2X - 11.89 \quad \text{with } R^2 = 0.949 \quad (4)$$

Generally, it is observed that high TDS soil has a high Na^+ concentration. Soil samples that have high TDS and high Na^+ concentration are representative of salt-affected paddy fields. In the flood season, the soil samples collected in paddy

Figure 13. The relation between Na and Cl ion concentrations of the soil samples in rice field—dry and flood seasons.

fields at HP and GT had very high TDS values and Na^+ concentrations. The TDS and Na^+ ion concentrations in HP and ND were much higher in the dry season. The salinity of irrigation water was also the highest in HP, followed by ND, NTRD, and GT, GA (Table 2).

Comparison of the relation between TDS and Na^+ concentration shows a slight difference in the two trends in the flood season and the dry season. Although top soil at NTRD has quite high Na^+ concentrations, their TDS is not so high. It has been mentioned that Na^+ is more easily adsorbed by soil pores than Ca^{2+} and Mg^{2+} . On the other hand, the clay ratio in NTRD varies from 0.2 to 0.25 (Figure 6) and the ion adsorption ability is lower in NTRD soil than in other soils.

Relation between Na^+ and Cl^- concentrations in 0–100 cm soil layers in paddy fields

It is reported that Na^+ and Cl^- concentrations are higher in salt-affected areas, where Na^+ concentrations rise to approximately 1.4 g/l, and Cl^- concentrations to 3.5 g/l. However, based on the analysis of this study, the relation between Na^+ and Cl^- concentrations in top soil appears to be logarithmic (Figure 13). Na^+ concentrations on soil surfaces are limited by the existence of Ca^{2+} and Mg^{2+} and by the CEC, while Cl^- concentrations can increase gradually and do not depend directly on the CEC. The functions of trend lines in both the dry season (5) and the flood season (6) are:

$$Y = 0.4612 \ln(X) + 0.7538 \quad \text{with } R^2 = 0.8206 \quad (5)$$

$$Y = 0.354 \ln(X) + 0.67 \quad \text{with } R^2 = 0.8993 \quad (6)$$

Because all of the soil samples have been taken far from residential area, Na^+ and Cl^- concentrations are not affected by residential wastewater, which is considered to have high concentrations of Na^+ and Cl^- due to the use of detergents and salt in daily activities. Thus the high concentrations of Na^+ and Cl^- demonstrate the impact of seawater intrusion on paddy fields in HP, GT and ND when considering the salinity of irrigation water in Table 2.

The relatively high Na^+ concentrations in soil samples from ND in the dry season differ slightly from the Na^+ and Cl^- concentrations in the flood season compared with the dry season. The Day River's mouth has a high Na^+ concentration in the surface soil, since all of the samples collected at ND and NTRD had high Na^+ concentrations in proportion to salinity and Cl^- concentration.

The influence of the “washing method” on decreased soil salinity for rice cultivation

The relation between Na^+ and Cl^- concentrations in the soil samples was used once again to investigate this influence. Soil samples were divided into two layers: the 0–20 cm layer and the 20–100 cm layer in both the flood season (Figure

Figure 14. The Na and Cl ion concentrations of the soil samples in 0–20 cm layer and 20–100 cm layer in rice field—Flood season.

Figure 15. The Na and Cl ion concentrations of the soil samples in 0–20 cm layer and 20–100 cm layer in rice field—Dry season.

14) and the dry season (Figure 15). Comparison of the two layers shows that the 0–20 cm layer always has low Na^+ and Cl^- concentrations, while GT and HP soil samples in the flood season and ND, NTRD, and HP soil samples in the dry season have high concentrations of Na^+ and Cl^- in the 20–100 cm layer. The resulting Na^+ and Cl^- concentrations are quite low in almost all of the 0–20 cm soil samples, where the Na^+ ion concentration is less than 0.4 g/l and the Cl^- ion concentration is less than 0.6 g/l. The washing method used in paddy fields, especially in

salt-affected rice paddies, reduces soil salinity in the surface soil layer in the flood season. The Na^+ and Cl^- concentrations of 0–20 cm soil samples in salt-affected area such as HP and GT are diminished, although concentrations remain higher in the deeper layer. It can be said that HP and GT have a higher salt-affected potential than other places, but the effect of salinity can be controlled in the flood season (Figure 14). Irrigation and washing are also done in the dry season, when the Na^+ concentration is less than 0.4 g/l and the Cl^- concentration is less than

Figure 16. The SAR index and Clay ratio of the soil samples in flood and dry seasons.

0.6 g/l. The 0–20 cm layer in HP and ND, where the salinity problem affects rice yields, has higher concentrations of Na^+ and Cl^- (Figure 15).

SAR and clay ratio of soil samples in the coastal area of the Red River Delta

The relationship indicated by the SAR between these ion concentrations and soil composition in paddy fields and shrimp ponds was relied on heavily to describe the influence of land use on the chemical characteristics of soil in coastal agricultural land. The SAR under different conditions of land use, such as paddy fields and shrimp ponds was intensively investigated.

The relation between SAR and the clay ratio in soil samples was observed in different types of land use: shrimp ponds in ND and HP; high potential salt-affected paddy fields in HP, GT, ND and NTRD; and paddy fields in GA, NL, NT, HT and HN. Based on this classification, three groups can be seen clearly in the flood season samples: Group F1 includes paddy fields in GA, NL, NT, HT, and HN; Group F2 includes salt-affected paddy fields in HP and GT; Group F3 includes the top soil of shrimp ponds in ND and HP. Two groups can be identified in the dry season samples: Group D1 includes paddy fields in GA, GT, NL, NT, HT, and HN; Group D2 includes salt-affected paddy fields in ND, HP, and NTRD

(Figure 16).

SAR in shrimp ponds The value of the SAR varies from 0.6–1.0 in the ND and HP shrimp ponds (Figure 16). The selective adsorption of Na^+ is higher than that of Ca^{2+} and Mg^{2+} in shrimp ponds compared to paddy fields. Na^+ is easily adsorbed on the soil particle surface and is easily washed out (Figure 8). The higher the clay ratio of a soil sample, the higher the SAR of the soil sample. This explanation can be confirmed by comparing the SAR and the clay ratio of ND and HP. In the soil samples of ND, the clay ratio was quite low, ranging only from 0.2 to 0.23, while the clay ratio in HP ranges from 0.26 to 0.42. One HP soil sample had a quite high clay ratio (0.35), but relatively low SAR (0.61). This soil sample belonged to the 0–20 cm soil layer of the HP sampling location. Normally, seawater is used for aquaculture and such water conditions in shrimp ponds as pH and the EC value are often controlled, depending on the variety and growth of shrimp. Inorganic calcium chemicals are used to maintain mildly alkaline conditions—good eutropic and healthy conditions for shrimp breeding (Whangchai et al. 2004). Interviews by the author on the survey trips provided similar information. In the research site, calcium oxide (CaO) and calcium hydroxide ($\text{Ca}(\text{OH})_2$) were always used for this purpose. This may have caused an abnormal Ca^{2+} concentration in the

top layer soil (Figure 8).

SAR in the highly salt-affected paddy fields The soil samples from salt-affected areas such as GT and HP in the flood season and NTRD, ND, and HP in the dry season had high SAR values. The relationship between SAR and clay ratio in salt-affected paddy fields in the flood season is shown in Figure 16. With higher clay ratios, soil samples in HP paddy fields had higher SAR values. In this group, SAR value ranged from 0.2 (the lowest measured in GT samples) to 0.82 (the highest measured in HP samples). A soil sample from the top surface layer of a paddy field in HP also gave a fairly low SAR. This suggests that the top surface soil layer is always more strongly affected by the washing process than the deeper soil layer is. This agrees with previous findings that the Na^+ concentration in the top surface soil layer is washed out by the washing process. In the dry season, the relation between the SAR and the clay ratio is similar. The clay ratio varies from 0.2 to 0.47 and the SAR varies from 0.15 to 0.52. The clay ratio also seems, in the light of changes in the clay ratio and the SAR of the soil samples, to have a slight effect on the SAR.

SAR in paddy fields In rice paddies, it is reported that a salinity of irrigation water over 500 mg/l may cause spotty stands of crops, uneven, stunted growth, and poor yields. In fact, the SAR of all the 0–20 cm layers at almost all sampling locations was very low, from less than 0.1 to 0.2 in both the flood and the dry seasons (Figure 16). Due to the impact of such soil improvement practices as washing, no soil sample had a SAR higher than 0.2, although the clay ratio varied widely from 0.07 to 0.53. The low SAR values suggest that Na^+ concentrations were much lower than the Ca^{2+} and Mg^{2+} concentrations. On the other hand, the SAR values of deeper soil layers (20–100 cm) are almost always higher than 0.2 in places that have high salinity in irrigation water: HP, NTRD, and ND (Table 2). The salinity of irrigation water at HP, NTRD, and ND are 1500 mg/l, 700 mg/l and 900 mg/l, higher than 500 mg/l, the maximum allowable salinity for paddy fields. Thus the SAR value could be used to consider the soil salinity in coastal paddy fields of the research area, where there is a high potential for salinity prob-

lem. For any paddy field with a SAR of the surface soil layer higher than 0.2, irrigation and washing should therefore be considered properly to prevent salinity problems.

Conclusions

This study investigated the surface soil layer from 0 to 100 cm in depth of paddy fields and shrimp ponds in Nam Dinh Province of the Red River Delta. The conclusions are stated below:

1. There is a linear relation between total dissolved solid and Na^+ concentration. Soil samples that have high TDS and high Na^+ concentration are representative of saline soil areas influenced by seawater. Na^+ and Cl^- concentrations in soil samples also are related logarithmically. The Cl^- concentrations increase gradually and do not depend directly on the cation exchange capacity of the soil. Soil washing of paddy fields influences surface soil salinity.
 2. The most highly salt-affected paddy fields are Hai Phuc, Giao Thien, Nam Dien and Nong Truong Rang Dong. The soil samples from these paddy fields have the highest SAR values and are the most strongly affected by salinity in both the flood season and the dry season. Soil samples from paddy fields of Nam Dien and Nong Truong Rang Dong have high SAR values with considerable Na^+ concentrations.
 3. Change in the SAR in different places and under different conditions of land use can show the relative selective adsorption of Ca^{2+} , Mg^{2+} , and Na^+ ions on soil particle surfaces, as well as the influence of seawater intrusion.
 4. In coastal agricultural land, the SAR in the surface soil layer can be used to evaluate the influence of salinity. In this study, the SAR value 0.2 can be considered to represent a paddy field unaffected by salinity. For any paddy field with a SAR of the surface soil layer higher than 0.2, irrigation and washing should therefore be considered properly to prevent salinity problems.
- Further studies should be carried out to understand more clearly the mechanism of salinity problems in saline soils, the impact of high concentrations of Na^+ , Cl^- , and other ions on agricultural activities, and responses by residents. The influence of salinity in the surface soil layer of cultivated land on inhabitants' life styles

should also be investigated to clarify the complicated relationship between human activities and the changing natural environment.

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Content of legend in equations and functions

- (1): $[Na^+]$: Na^+ concentration in millimoles per liter.
 $[Ca^{2+}]+[Mg^{2+}]$: Total Ca^{2+} and Mg^{2+} concentration in millimoles per liter.
- (2): [Clay]: content in percent of clay in a soil sample.
 $[Sand]+[Silt]$: Total content in percent of sand and silt in a soil sample.
- (3), (4): Y is the TDS (mg/l) in the soil sample ($Y>0$).
X is Na^+ concentration (g/l) in the soil sample ($X>0$).
- (5), (6): Y is the Na^+ concentration (g/l) in the soil sample ($Y>0$).
X is the Cl^- concentration (g/l) in the soil sample ($X>0$).