PHILIPP AGRIC SCIENTIST
Vol. 103 No. 3, 168-178
September 2020

ISSN 0031-7454

Physicochemical Characteristics of Soils in a Salt-Affected Lowland Rice Environment and Implication to Productivity

Jocelyn D. Labios*, Joy Eloiza M. Rosales and Pearl B. Sanchez

Soil Science Division, Agricultural Systems Institute, College of Agriculture and Food Science, University of the Philippines Los Baños, College, Laguna 4031, Philippines

*Author for correspondence; e-mail: jdlabios@up.edu.ph; Phone: +63 917 504 1053; +63 49 536 3229

There is lack of useful information that provides thorough understanding of the extent and severity of soil problems in salt-affected coastal lowland rice areas and their effect on farmer productivity. Soil physicochemical characterization was conducted in eight coastal rice fields in Balayan, Batangas, Philippines with varying distances from a source of saltwater intrusion. Soil, plant, and water samples were collected and analyzed from August 2014 to April 2015. Key farmer interviews were conducted. Soil organic matter was high in the wet season (WS) until the dry season (DS). Levels of soil nitrogen and phosphorus (P) were high at the end of WS and DS, indicating residuals from fertilization, and higher in fields closer to the swamp. The cation exchange capacity and base saturation in all sites were high. Zinc levels were low and may be due to high soil P. Results showed mildly alkaline soil at pH 7.4–7.7 across seasons. Soil electrical conductivity was higher in fields closer to the swamp and highest at end of WS. High exchangeable sodium percentage (ESP) indicates the presence of a high proportion of sodium in all fields regardless of distance from the swamp and at mean= 17.68% is higher than the limit set for sodic soil (15% ESP). Rice yields were within the range of varietal potential, including salinity tolerant variety Salinas, except in the field closest to the swamp which may be related to high ESP and soil sodium levels. This coastal lowland rice agroecosystem is classified as productive and the soil relatively fertile but prone to salinity and sodicity through saltwater intrusion from nearby swamps. Continued monitoring must be done so that farmers may be advised on soil fertility status and appropriate management options to sustain productivity.

Key Words: coastal saline soils, lowland rice, salinity, sodicity, salt-affected areas, saltwater intrusion

Abbreviations: BS – base saturation, CEC – cation exchange capacity, DS – dry season, EC – electrical conductivity, ESP – exchangeable sodium percentage, SOM – soil organic matter, WS – wet season

INTRODUCTION

A worldwide estimate by the Food and Agriculture Organization in 2011 states that 34 million ha (or 11% of irrigated areas) are affected by some level of salinity, while an additional 60–80 M ha are affected to some extent by waterlogging and related salinity (FAO 2011). Van Lynden and Oldeman (1997) cited three possible causes of salinization in South and Southeast Asia, namely: intrusion of sea water, improper irrigation methods, and evaporation of saline groundwater. In 2015, experts acknowledged the extent and severity of salinization as a threat to global soil resources and cited the unavailability of accurate and recent statistics (FAO and ITPS 2015). The experts reported that salt-affected soils are also developing in certain coastal areas in monsoon zones in South and Southeast Asia, mainly through saltwater intrusion.

In the Philippines with its 18,400 km long coastline, 400,000 ha are of coastal saline soils (Guerrero 1977), half of which is severely salt affected (Asio et al. 2009). This area comprises 100,000 ha under mangrove forests, about 175,000 ha used for fishponds, and about 125,000 ha that are largely idle. Not included in this estimate are productive agricultural lands with salinity threats, at varying levels, due to the causes mentioned earlier. Some of the regions in the Philippines which are considerably saline include Cagayan Valley, Bicol, Iloilo, Palawan, Negros, Samar, Leyte and Surigao (Asio et al. 2009). However, there appears to be a lack of updated and specific information that will provide an understanding of the extent and severity of this soil problem and its effect on farmer productivity.

Most agricultural crops are salt-sensitive, including rice (Singh et al. 2010), and especially modern rice varieties (Thomson et al. 2010). High levels of soluble salts affect plants by osmotic effects, specific ion toxicity, and nutritional imbalances, thus limiting growth and reducing yield (Weil and Brady 2017; Abrol et al. 1988). PhilRice (2001) cited severe constraint in rice production due to soil salinity citing the Bicol and Cagayan Valley regions. Almaden et al. (2019) acknowledged the problem and analyzed rice farmers' adaptation to what they conclude as a slow onset hazard of saltwater intrusion in rice areas in Vietnam and in Misamis Occidental, Philippines. To underscore this problem, efforts are intensifying to develop rice varieties that will adapt to adverse soil conditions including increasing salinization and related soil problems (Platten et al. 2013). Significant progress was also made in developing salt-tolerant genotypes of rice (Ismail and Horie 2017; Gregorio et al. 2013; Singh et al. 2010; Thomson et al. 2010).

It is increasingly recognized that use of poor-quality irrigation water may be causing salt stress in inland areas (Thomson et al. 2010). On the other hand, saltwater intrusion can affect more areas near coastal environments and the situation is expected to become more serious with rising sea levels due to climate change (Mellouland and Collin 2006; Wassman et al. 2004). Further research should be conducted in agricultural ecosystems located in close proximity to saline coastal areas which, by their position in the landscape, are threatened by salinization. The gap in information must be addressed beginning with the current status of salt-affected and salinity-threatened locations which, when studied for important crop production areas, may provide a basis for management decisions and future recommendations for sustainability of production systems.

This research was conducted to provide current and specific information on the state of soil resources in a selected lowland rice area that represents a salt-affected ecosystem by studying the physical and chemical characteristics of soils in the area. Focus was given to characteristics that are indicators of soil salinity. The effects of environmental factors and production practice were assessed in relation to the observed soil characteristics. From these findings, specific soil constraints that may affect productivity as a result of saltwater intrusion from a tributary source to the rice fields were identified. Data and findings from this study are important inputs to evaluating management alternatives for sustained productivity in salt-affected and salinity-threatened lowland rice areas.

METHODOLOGY

Location of the Study

The study area is located in Barangay Navotas, Balayan, Batangas, Philippines. The municipality of Balayan is geographically located at latitude 14° 53′ N and longitude 120° 43′ E and is bounded by the municipalities of Tuy, Calaca, Calatagan and Lian, and on the south by Balayan Bay. It is classified under climate type 1 with two pronounced seasons, dry from November to April and wet for the rest of the year. The temperature averages 28 to 30°C and the average annual rainfall is 1864 mm (Municipality of Balayan 2015). For its existing land use, Balayan is generally agricultural, with a total 6817 ha (or 62.7% of the total land area) planted to various crops. The other lands are composed of built-up areas, forested areas, open grasslands and swamps and marshes, specifically in Barangays Navotas and San Piro. The dry season for rice cropping occurs during November to April and the wet season during May to October.

Eight rice fields with varying distances from the coast and swamp were selected for this study. Selection was based on the proximity of the rice fields to the source of saltwater intrusion that is the swamp, where saltwater inundation occurs regularly with rising tidewaters. The distance of the fields from the coast ranged from 426 to 547 m while the distance from the swamp ranged from 12.2 to 340.8 m. The aerial image of the study site and the location of selected fields were numbered and identified according to their proximity to the swamp (Fig. 1). Field 1 is nearest to the swamp while Field 8 is farthest from the swamp and closer to the residential areas. Table 1 shows the coordinates, distances and elevation of the sampling fields.

Soil Sampling and Analysis

Soil samples were collected from the eight selected rice fields during three periods: at the start of the wet season

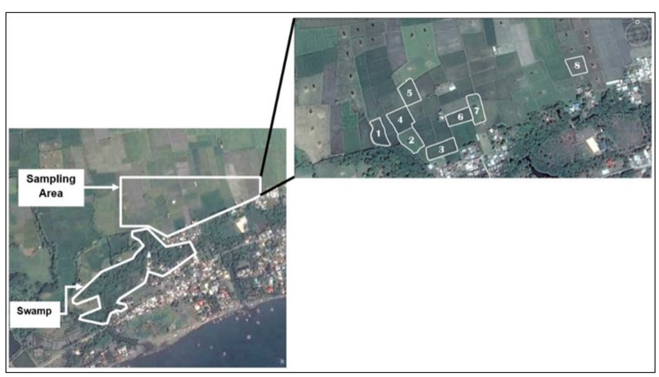

Fig. 1. Aerial image of study site and selected fields (Google Earth 2015).

Table 1. Coordinates, distances from coastline and swamp, and elevation of eight sampling fields in Barangay Navotas, Balayan, Batangas.

Field No.	Coordinates	Distance from Coastline (m)	Distance from Swamp (m)	Elevation (m)
1	13°55'51.92"N 120°42'51.51"E	468	11.4	7.6
2	13°55'51.83"N 120°42'52.64"E	458	12.2	7.6
3	13°55'51.48"N 120°42'54.54"E	426	44.2	7.6
4	13°55'53.20"N 120°42'52.09"E	504	48.9	6.7
5	13°55'54.69"N 120°42'52.43"E	547	95.9	5.5
6	13°55'53.19"N 120°42'55.47"E	458	109.8	5.5
7	13°55'53.62"N 120°42'56.52"E	435	136.9	7.0
8	13°55'56.37"N 120°43'2.83"E	453	340.8	5.5

(SWS) in August 2014, at the end of the wet season (EWS) in December 2014, and at the end of the dry season (EDS) in April 2015. The purpose of this timing of sampling is to document the differences that may be observed due to the absence or abundance of water that can contribute to the effect of saltwater intrusion, periods of washing or dilution, salt accumulation, and dryness.

About 1 kg of composite soil sample (from 5–8 sampling spots) was collected from the top 15 cm layer from each field using a soil auger. The samples were air-dried, pulverized, passed through a 2-mm sieve, and stored for subsequent soil analysis. Soil texture was determined (hydrometer method), as well as pH (soil-water slurry using electrode pH meter), electrical conductivity (EC, 1:1 soil-to-water method), cation exchange capacity (CEC, ammonium acetate method), and organic matter content (OM, Walkley and Black method). Laboratory tests for total nitrogen (Kjeldahl method), available phosphorus (Olsen method), and exchangeable cations Na, Ca, Mg, K (flame photometer and EDTA titration methods) were also accomplished.

Determination of Chemical Composition of Water Samples

Water samples were collected from the swamp near the study area at the start of the wet season (August), during high tide, and in the dry season (March) during low tide. Samples were kept refrigerated until they were sent to the Bureau of Soil and Water Management for analysis of pH, EC, contents of Na, Ca, Mg, N, P, K, Zn, Fe, sulfate, chloride, and bicarbonate.

Collection and Analysis of Plant Samples

Concentrations of potassium and sodium were determined using four plants obtained from the crop cut areas in each field. Grains and straw were separated and weighed, air-dried and then oven-dried at 70°C. The oven-dried samples were weighed, ground and placed in glycine bags. The ground samples were dry-ashed and chemical analyses were done for potassium and sodium content. To obtain the plant uptake, the concentrations were multiplied by grain yield and straw yield.

Other Data Collection

Key informant (KI)-farmer interviews and field observations were conducted to collect specific data, which included: (a) cropping system: type of crops planted, cropping pattern, farmer's management practices, (b) production history, crop yield or production data, (c) irrigation and water management, irrigation practices, frequency and duration of water application, soil drainage system, (d) sources of irrigation water during wet and dry seasons, quality of irrigation water, and (e) other relevant socioeconomic data, for example, access to existing and/or new irrigation sources, infrastructure support in the community, and others. An interview instrument was designed for this activity.

Analysis of Data

Simple correlation analyses were done, where appropriate, using Excel program of Microsoft Office 2010. Data were also subjected to analysis of variance and least significant difference test at 5% level was used to compare means.

RESULTS AND DISCUSSION

Physical and Chemical Characteristics of the Soil in Selected Sampling Fields

The characteristics of soils not readily subject to change, such as texture and cation exchange capacity (CEC), are

Table 2. Physicochemical characteristics of soils in the sampling fields.

Field No.	Distance from Swamp (m)	Texture	CEC (cmolc kg^{-1})
1	11.4	Clay	57.00
2	12.2	Sandy clay Loam	36.72
3	44.2	Sandy clay Loam	38.53
4	48.9	Sandy clay Loam	40.11
5	95.9	Sandy clay Loam	35.16
6	109.8	Sandy clay Loam	39.38
7	136.9	Sandy clay Loam	38.11
8	340.8	Sandy clay Loam	34.43

presented in Table 2 for eight selected sampling fields in Barangay Navotas, Balayan, Batangas. Most of the soils in the study area are of sandy clay loam texture except in Field 1 which has clay texture. This field is the closest to the swamp which is only 11 m away from it. Roots of nipa palms which cover the swamp areas aid in trapping fine sediments deposited in the field when inundation occurs. In Field 1, there were more silt and clay-sized particles (29% sand, 24% silt and 47% clay) than in Field 2 which had a higher percentage of sand-sized particles (59% sand, 15% silt and 26% clay). Soil CEC is very high in all fields, with soil in Field 1 having the highest, attributed to higher clay content of the soil.

Soil characteristics that are routinely analyzed as indicators of soil fertility were measured to describe the existing soil condition in the sampling fields at the time of study. These are soil organic matter content (% SOM), total nitrogen (% N), soil available phosphorus (P, in ppm) and base saturation (% BS). Table 3 shows the result of correlation analyses between these soil characteristics and the distance from the potential source of saltwater intrusion, which is the swamp.

Across all periods of sampling during the wet and dry seasons, high negative correlations were observed for total N and available P, while low negative correlations were shown for SOM and % BS. Table 4 shows the comparison of mean levels during three periods of sampling, at the start of wet season (SWS), end of wet season (EWS), and end of dry season (EDS). Across all sampling fields, soil organic matter level was low at SWS 2014, averaging 1.99% (Table 4). By EWS, SOM increased to medium levels in all fields (mean= 2.69%) and was maintained until EDS. This relative increase in SOM may indicate build-up of organic matter during the wet season when decomposition is slower. Correlation analysis showed higher levels in fields nearer the swamp (Table 3). The farmer's practice of incorporating rice straw in the field may have increased SOM content, similar to what was observed in past studies by Ponnamperuma (1984). Key informant interviews revealed that farmers also applied soil conditioner every cropping season. The soil conditioner is compost that has undergone a long process of decomposition and contains 90% to 95% organic matter based on its analysis (Organic and Natural Inputs n.d.). Sharma (2001) observed that saline soils have lower organic matter content than normal soil. Mindari et al. (2015) obtained similar levels of organic matter (0.9% to 2.46%) in saline rice soils sampled during the wet season.

A high negative correlation was observed between total soil N and distance from the swamp so that when summarized across seasons, soil levels were higher in fields closer to the swamp (Table 3). Mean level across sampling periods was 0.26% in Field 1 and 0.14% in Field 8. Total soil nitrogen ranged from very low to medium, averaging 0.10% at SWS (Table 4). At EWS, total soil N increased to very high levels and averaged 0.28%. At the last sampling for the study or at the end of the DS (EDS), total N was maintained at high levels with mean= 0.22%. This trend follows that of the increase in levels observed in SOM which contributes a small percentage to soil N. As stated in the interview of key informant farmers, it is common practice to apply nitrogen fertilizers at the rate of 46 to 115 kg N ha^{-1} during the dry season and 46 to 150 kg N ha^{-1} during the wet season, and this may have affected the observed soil levels.

Correlation analysis indicated that soil available phosphorus level was highest in sites closest to the swamp (Field 1), with mean at 53.4 ppm, and was lower farther from it (Table 3). However, P levels were generally high to very high in the fields in all sampling periods ranging from 18.9 to 48.29 ppm (Table 4). The variations from field to field may be attributed to differences in fertilizer management practices by individual farmers. Grattan and Grieve (1999) observed that available P is low in saline soil due to high pH, where P is bound to Ca to form Ca phosphate. However, flooding can result in an increase in available P in lowland rice soils, where reduction of ferric (Fe^{3+}) phosphate to ferrous (Fe^{2+}) phosphate and dissolution of Ca phosphate occurs (Snyder and Slaton 2002). In the sampling areas, the mean pH is 7.6, thus the soil is classified to be of mild alkalinity.

Base saturation in all sampling sites was very high regardless of distance from the swamp, and no

Table 3. Correlation coefficients between different soil properties and distance from swamp, measured in three sampling periods.

Soil Property	Sampling Period			
	Start of Wet Season	End of Wet Season	End of Dry Season	Average
Organic matter (OM, %)	-0.11	-0.66	-0.49	-0.46**
Total nitrogen (%N)	-0.07	-0.81	-0.61	-0.74****
Available phosphorus (ppm P)	-0.42	-0.19	-0.69	-0.70****
Base saturation (% BS)	0.28	0.53	0.02	0.42*

****strong, negative correlation
**weak, negative correlation
*weak, positive correlation

Table 4. Mean values of soil properties across sampling sites measured during three sampling periods.

Soil Property	Sampling Period[1]		
	Start of Wet Season	End of Wet Season	End of Dry Season
Organic matter (OM, %)	1.99[b]	2.69[a]	2.24[ab]
Total nitrogen (%N)	0.1[b]	0.28[a]	0.22[ab]
Available phosphorus (ppm P)	30.04[ns]	18.9[ns]	48.29[ns]
Base saturation (% BS)	86.9[ns]	72.13[ns]	82.07[ns]

[1]Means followed by a common letter in a row with the same superscript letters are not significantly different at 5% LSD.

differences were observed among levels across sampling periods (Tables 3 and 4). This result indicates that non-acid cations dominated the exchange complex and that a high base saturation percentage indicates the tendency toward neutrality and alkalinity and the relative fertility of the soil.

Exchangeable Cations

In general, the exchange sites of soils are occupied by non-acid or basic cations potassium (K^+), Na^+, calcium (Ca^{2+}), and magnesium (Mg^{2+}). Results of analysis showed weak correlation between soil potassium, sodium, and calcium levels and proximity to the swamp across periods of sampling from the start of the wet season to the end of the dry season. It indicates that there is no observed difference in the levels that can be attributed to proximity to the swamp (Table 5). Magnesium levels, however, were higher in the fields farther from the swamp during EWS until EDS.

Soil exchangeable K levels, however, were observed to be very high, with means ranging from 1.68 to 3.08 $cmol_c$ kg^{-1}, across all sampling sites, with no significant difference in values across sampling periods (Table 6). The lack of a more definite trend may be attributed to similarities in farmers' management practices which result in increased soil K levels with fertilizer application.

Although a weak correlation was observed between soil Na levels and distance from the swamp, raw data showed the highest Na content in Fields 1 and 2, at 8.04 and 5.92 cmolc kg^{-1}, respectively (data not presented), during the three periods of sampling with the highest levels measured at EDS at mean= 7.11 cmolc kg^{-1} across all sites (Table 6). The trend remained until EWS although at lower levels, depicting potential dilution effect of rainwater on highly soluble Na salts. This result validates the observations for ESP as detailed above. Analysis of water samples showed very high Na and chloride contents (Table 7), especially in the WS when the swamp can be swollen and affect areas for long periods of time but especially during high tide.

Calcium was the dominant cation in all sampling sites with soil analysis showing no significant difference in soil levels due to sampling period (Table 6). In all, Ca levels in the soil were very high (mean= 13.64 to 17.5 $cmol_c$ kg^{-1}). Observations were similar with magnesium, with high soil test values over all three sampling periods covering dry to wet seasons (Table 6). The exchange complex of most salt-affected soils is dominated by Ca^{2+} and Mg^{2+} with little exchangeable Na^+ (Weil and Brady 2017), unless other sources will increase the sodium levels with intrusion in coastal areas. Dauphin et al. (2010) and Mindari et al. (2015) observed high amounts of Ca in saline soil.

Zinc and Chlorine Levels in the Soil

Zinc levels were low, further decreasing with distance from the swamp as confirmed by a high negative correlation value (Table 5). The lowest level was observed at the start of the wet season and continued until the end of wet season. High levels of phosphorus may induce Zn deficiency, and this is especially true in high P fertilizer applications and when soil Zn is already low, which is typical in lowland rice areas. In the sampling areas, soil P test values ranged from high to very high (Table 2). Alloway (2009) found that low total Zn content, high pH, high calcite and organic matter contents and high

Table 5. Correlation coefficients between ionic concentration in soil and distance from swamp, measured in three sampling periods.

Ion in Soil	Sampling Period			
	Start of Wet Season	End of Wet Season	End of Dry Season	Average
Na^+	0.06	0.06	0	0.05
K^+	-0.18	-0.35	0.01	-0.21**
Ca^{++}	0.4	0.53	-0.35	0.29*
Mg^{++}	0.04	0.6	0.66	0.52***
Cl^-	0.69	-0.59	0.3	-0.04
Zn^{+++}	-0.59	-0.73	-0.81	-0.79****

**** strong, negative correlation
*** strong, positive correlation
** weak, negative correlation
* weak, positive correlation

Table 6. Mean values of concentration of non-acidic cations and other ions in the soil measured across sampling sites during three sampling periods.

Ion in Soil	Sampling Period[1]		
	Start of Wet Season	End of Wet Season	End of Dry Season
		($cmol_c$ kg^{-1})	
K^+	3.08[ns]	1.68[ns]	2.29[ns]
Na^+	5.19[b]	2.59[c]	7.11[a]
Ca^{++}	17.36[ns]	17.5[ns]	13.64[ns]
Mg^{++}	9.98[ns]	7.47[ns]	9.59[ns]
Zn^{+++}	2.31[b]	3.43[ab]	3.71[a]
Cl^-	388[ns]	608.13[ns]	527[ns]

[1]Means followed by a common letter in a row with the same superscript letters are not significantly different at 5% LSD.

Table 7. The pH, electrical conductivity (EC), and chemical composition of water samples during wet season (WS) 2014 and dry season (DS) 2014/15 in Barangay Navotas, Balayan, Batangas, Philippines.

Parameter	WS (ppm)	DS (ppm)
pH	7.6	7.3
EC (dS m^{-1})	11.98	2.5
Calcium (ppm)	221	44.25
Magnesium (ppm)	525	525
Sodium (ppm)	5070	370
Sulfate (ppm)	22.84	2.13
Chloride (ppm)	31.80	380.2
Bicarbonate (ppm)	2560	3469
Nitrogen (ppm)	5.27	5.65
Phosphorus (ppm)	0.62	0.92
Potassium (ppm)	217	23.9
Zinc (ppm)	0.0088	0.0179
Iron (ppm)	Not detected	Not detected

concentrations of Na, Ca, Mg, bicarbonate and phosphate in the soil solution or in labile forms are factors affecting Zn availability. Some of these conditions are present in the sampling areas.

There was no observable trend in soil chloride levels attributable to distance from the swamp (Table 5). However, at EWS, conditions led to higher levels maintained until EDS, although the values were not significantly different statistically. Since application of muriate of potash (KCl) is uncommon in the area, levels of Cl in the soil may be attributed to proximity to the coast where chloride in ocean water gets into the atmosphere as ocean spray. Schulte (1999) stated that soils close to coastlines can receive more than 112 kg ha^{-1} of Cl in rainwater, with amounts decreasing with distance from the coast. All fields were within 400–500 m distance from the coast (Table 1).

Chemical Characteristics that are Indicators of Salinity and Sodicity

Certain soil properties such as soil pH, electrical conductivity (EC), and exchangeable sodium percentage (ESP) are indicators of salinity or sodicity in salt-affected soils where limits are established for their specific soil classification. Soil pH is characteristically high in salt-affected soils, the EC of soil solution gives an indirect measurement of salt content, while ESP characterizes the sodium status of soils.

Soil pH. There was good correlation between soil pH and distance from the swamp mainly due to the conditions at the start and end of the wet season (SWS and EWS), thus soil pH tended to be higher in fields farther from the swamp (Table 8). However, the pH values did not differ among the sampling periods with mean range at pH 7.4–7.7 (Table 9), classified as mildly alkaline. It must be noted that this pH value was measured potentiometrically in the laboratory. Soil pH in lowland rice areas are characteristically described as neutral (Ponnamperuma 1972) under field conditions.

The presence in the soil solution and exchange complex of non-acid cations Ca^{2+} , Mg^{2+}, K^{+} and Na^{+} results in soil pH that is around neutral, while the presence of carbonates and other anions causes alkalinity in soils (Weil and Bradey 2017). The cations Ca^{2+} and Na^{+} are particularly associated with carbonate and bicarbonate anions that produce higher soil pH. Soil analyses showed high levels of these non-acid cations throughout the sampling period resulting in a high pH (Table 6).

Electrical conductivity (EC). The strong negative correlation observed only at EWS shows that electrical conductivity of the soil was higher in fields that are closer to the swamp (Table 8). Further, EC value at EWS was highest among the sampling periods (Table 9). Analysis of water samples taken from the swamp showed slightly alkaline pH and higher EC during the WS but, more significantly, it also revealed highly elevated levels of sodium and chloride (Table 7). Bicarbonates are also high during the WS and DS. Inundation of saltwater with this composition during the wet season when the swamp is swollen, especially during high tides, may cause the high EC (Chhabra 1996). However, the presence of high amounts of sodium salt did not translate to correspondingly higher soil exchangeable sodium percentage (ESP) at EWS (Table 9) because the presence of high amounts of calcium ions enhances the preference for Ca to occupy the exchange sites in the soil colloids more

Table 8. Correlation coefficients between salinity indicator soil properties and distance from swamp measured in three sampling periods.

Soil Property	Sampling Period			
	Start of Wet Season	End of Wet Season	End of Dry Season	Average
pH	0.68	0.57	-0.22	0.56***
Electrical conductivity (EC, dS m^{-1})	-0.07	-0.54	-0.31	-0.47**
Exchangeable sodium percentage (ESP, %)	-0.15	-0.35	-0.01	-0.21**

*** strong, positive correlation
** weak, negative correlation

Table 9. Mean values of salinity indicator soil properties across sampling sites, measured in three sampling periods.

Soil Property	Sampling Period[1]		
	Start of Wet Season	End of Wet Season	End of Dry Season
pH	7.7[ns]	7.4[ns]	7.6[ns]
Electrical conductivity (EC, dS m^{-1})	1.02[b]	1.76[a]	1.24[ab]
Exchangeable sodium percentage (ESP, %)	12.11[b]	6.3[c]	17.68[a]

[1]Means followed by a common letter in a row with the same superscript letters are not significantly different at 5% LSD.

than the Na ions, according to the principle of cation selectivity (Weil and Brady 2017). Results of soil analyses for exchangeable cations showed the dominance of the Ca^{2+} ion (Table 6).

All sites, however, had EC lower than 4 dS m^{-1}, or the limit for saline soils (Weil and Brady 2017), in all three sampling periods (Table 9), but the soils in the sampled areas can be classified as slightly saline based on soil salinity classes proposed by Dahnke and Whitney (1998). At the end of DS 2014, EC values decreased in most of the sampling sites, appearing to be affected by frequency of irrigation. During the dry season, farmers irrigate their fields continuously or more frequently, with some farmers irrigating with fresh water as frequently as seven to eight times, or every 15 d, during the rice growing season, especially those whose farms are nearer the swamp. This practice helps in diluting, while flooded, and flushing the soluble salts out of the soil with drainage and leaching, so that the EC is maintained below the limit for salt-affected soils (Mindari et al. 2015; Abrol et al. 1988). According to Bohn et al. (2001), periodic irrigation for crops is a proper management practice to leach accumulated salts in the plant root zone.

Exchangeable sodium percentage (ESP). Results of analysis showed weak correlation between ESP and distance from the swamp (Table 8), indicating that the presence of a high proportion of the sodium ion in the soil may be observed in all fields regardless of distance from the saltwater source. What is a significant observation, however, is the high ESP values especially at EDS which, at 17.68%, is higher than the limit set for sodic soil (15% ESP) (Table 9). The high levels appear consistent with the increase in exchangeable sodium level in the soil, as shown in Table 6. A relatively high mean ESP of 12.11% on all sampling sites was also observed at SWS, or coming from a dry period. This indicates a period of accumulation and precipitation during the dry season, where dissolved sodium in the soil solution may have been flushed out with irrigation but a considerable portion of the exchange sites in soil colloids remained occupied by Na^{+} ions. White salt deposits on the surface of the soil near the swamp were also highly visible during the dry months (Fig. 2). By the end of the wet season, these ions may have been sufficiently flushed out to cause lower ESP. Sodium in the soil can be easily removed by washing thru irrigation or heavy precipitation as Na^{+} ion has weak soil-colloid bond (Mindari et al. 2015).

Plant Uptake of Potassium as Affected by Sodium

In addition to the toxic effects that ions like Na^{+} and Cl^{-} cause in plants, high levels of Na^{+} can cause imbalances in the uptake and utilization of other essential nutrient cations like K^{+}, competing in the process of transport across the cell membrane during uptake (Weil and Brady 2017).

For this study, during the wet and dry seasons, plant uptake of both Na and K was measured from tissue concentrations in rice grain and straw, and presented as Na/K ratio (Fig. 3). Results of analysis showed the ratio greater than 1 in the grain during WS cropping in all of the sites, indicating greater Na uptake than K. This trend was not similarly reflected in the straw which means that with a Na/K ratio lower than 1, K content in straw tissues, thus uptake, was higher than Na. In the DS crop, greater Na uptake than K was observed also in the grain samples in the sites nearer the swamp (Fields 1 to 3) where soil Na level was also higher as discussed above. However, if this finding was compared with yield data, a potential effect may be observed only in Field 1 (Table 10).

Rice Yield in the Study Area

All fields in the area where this study was conducted were planted to rice from August 2014 to November 2014 for WS, and December 2014 to April 2015 for DS. The different varieties used by farmers and their

Table 10. Grain yield of rice varieties grown during WS 2014 and DS 2014/15 in Barangay Navotas, Balayan, Batangas.

Field	Wet Season (WS)		Dry Season (DS)	
	Variety	Yield (t ha^{-1})	Variety	Yield (t ha^{-1})
1	NSIC Rc226 (Tubigan 20)	5.0	NSIC Rc216 (Tubigan 17)	4.2
2	NSIC Rc326 (Salinas 11)	5.4	NSIC Rc326 (Salinas 11)	4.0
3	NSIC Rc226 (Tubigan 20)	7.0	NSIC Rc216 (Tubigan 17)	8.0
4	NSIC Rc226 (Tubigan 20)	8.2	NSIC Rc216 (Tubigan 17)	8.0
5	NSIC Rc216 (Tubigan 17)	6.6	NSIC Rc160 (Tubigan 14)	5.4
6	NSIC Rc216 (Tubigan 17)	6.4	NSIC Rc160 (Tubigan 14)	6.4
7	NSIC Rc216 (Tubigan 17)	8.8	NSIC Rc160 (Tubigan 14)	8.0
8	NSIC Rc216 (Tubigan 17)	6.0	NSIC Rc160 (Tubigan 14)	3.6

Fig. 2. Appearance of soil surface with salt precipitates on lowland rice field near the swamp (in the background) during dry season.

corresponding yields during WS 2014 and DS 2014 are presented in Table 10. Varieties used were not the same in all fields sampled within season and between seasons so that an analysis of variance on yield data cannot be done. Correlation analysis was done, however, between the season's yield and soil salinity indicators that are highly variable across fields and will most likely affect the yield, such as EC, ESP, and Na level. This can help in further analyzing which of these soil properties limit yield during the wet and the dry season. Therefore, WS yield was correlated with measured soil parameters at EWS, and DS yield was correlated with the same parameters at EDS.

NSIC Rc160 (Tubigan 14), NSIC Rc226 (Tubigan 20) and NSIC Rc216 (Tubigan 17) are varieties recommended for irrigated lowland production. Tubigan 14 has an average yield of 5.6 tha^{-1} and a maximum yield of 8.2 t ha^{-1}, while Tubigan 20 has an average yield of 5.4 t ha^{-1} and a maximum yield of 8.5 t ha^{-1} and NSIC Rc216 (Tubigan 17) has an average yield of 5.7 t ha^{-1} and a maximum yield of 9.3 t ha^{-1} (Philippine Seedboard 2011). NSIC Rc326 (Salinas 11) is a variety for salinity-prone irrigated lowland areas and can yield 2.2 t ha^{-1} for WS and 2.6 t ha^{-1} for DS (National Seed Industry Council 2013).

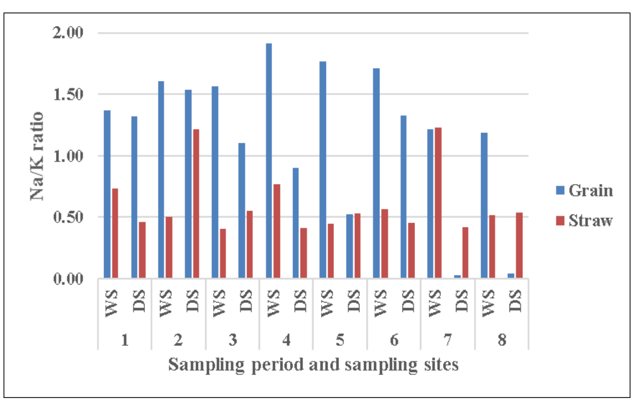

Fig. 3. Ratio of Na/K in rice grain and straw from samples taken during wet season (WS) and dry season (DS) in eight sampling sites.

Table 10 further shows that, except for the field nearest the swamp (Field 1), rice yields were generally within the range of potential yield for each of the varieties used, usually higher than the established averages. In Field 2 where the salinity-tolerant variety Salinas was planted, the yields were considerably higher than the average potential. Based on the presented chemical characteristics of soils in the entire study area, it can be observed that soil fertility of the rice fields is generally adequate, and farmers were using good management practices to maintain good yields.

Other factors may then be limiting yield in the rice field near the swamp. The observed lower WS and DS yields in Field 1 (11.4 m away from the swamp), compared with the varietal yield potential as well as the actual yields in Fields 3 and 4 planted to the same variety, may be attributed to salinity affecting the field. Results of correlation analyses (Table 11) indicated that in the WS, yields tended to be lower in fields where ESP and exchangeable sodium levels were high. Results previously discussed showed high ESP and Na levels in the soil in fields closest to the possible source of saline water intrusion. In the DS, however, yields were more affected by high EC.

SUMMARY AND CONCLUSION

This research has provided current and specific information on the physical and chemical characteristics of soils in a salt-affected lowland rice ecosystem located in a coastal area in Balayan, Batangas, Philippines. Particular focus was also given to characteristics that are indicators of soil salinity. The effects of environmental factors, such as rainfall, season, and distance from saltwater source, and production practice, such as irrigation and fertilizer management, were assessed in relation to the observed soil characteristics.

Eight rice fields in Barangay Navotas, Balayan, Batangas, Philippines with varying distances from the coast and swamp were selected for this study. For the three sampling periods, soil samples were collected and analyzed for physicochemical properties, namely: soil texture, pH, electrical conductivity, cation exchange capacity, organic matter content, total nitrogen, available phosphorus, and exchangeable cations of Na, Ca, Mg, and K. Plant and water samples were also collected and analyzed. Key informant-farmer interviews were conducted to collect specific data on cropping systems,

Table 11. Correlation coefficients between wet season (WS) and dry season (DS) yields and selected soil parameters.

Parameter	WS	DS
Electrical conductivity (EC)	-0.17[nc]	-0.48**
Exchangeable sodium percentage (ESP)	-0.47**	0.11
Soil exchangeable Na^+	-0.61***	-0.06[nc]

*** strong, positive correlation
** weak, negative correlation
[nc] no correlation

management practices, and relevant socioeconomic data.

The soils in the lowland rice area where our research was done are relatively fertile as shown by results of analyses of soil organic matter, nitrogen, and phosphorus levels during three sampling periods across the wet and dry seasons. Soil OM level increased by the wet season and was maintained until the end of dry season, indicating build up with slower decomposition during wet conditions. This condition will be beneficial in the long term if farmers continue with good residue management. Levels of soil nitrogen and phosphorus were high at the end of the wet and dry seasons or after the rice cropping and can be attributed to the fertilizer management by farmers. Levels were also higher in the fields closer to the swamp, so that it may be the practice of the farmer to compensate for anticipated fertility problems by applying higher rates of fertilizer in these fields. The CEC of the soils in all sampling sites were high, with the exchange sites adequately occupied by macronutrient cations of Ca^{2+}, Mg^{2+}, and K^+ as shown by the base saturation percentage. Zinc levels were low and may be induced by the high soil phosphorus in the area.

While in its current condition, this coastal lowland rice agroecosystem can be classified as productive and the soil relatively fertile, it is also a concern that salinity may be developing primarily through saltwater intrusion from nearby tributaries or swamps. Thus, certain soil properties such as soil pH, EC and ESP, which are indicators of that condition, were measured. Our findings showed soil pH in the study site was higher than what is commonly measured in lowland rice soils, which is around neutral. At mean values of 7.4–7.7 across seasons, the soils are mildly alkaline. Electrical conductivity of the soil was higher in fields that are closer to the swamp and was highest at the end of the wet season. Analysis of water samples taken from the swamp revealed highly elevated levels of sodium, chloride, and bicarbonates during the WS. Intrusion through the nearby swamp of saltwater with high salt content during the wet season and flushing out and leaching of excess salts with frequent irrigation during the dry season can explain these observations. The values obtained for ESP indicate the presence of a high proportion of the sodium ion in the soil in all fields regardless of distance from the saltwater source. It is also a significant observation that ESP values were high especially at EDS which, at 17.68%, is higher than the limit set for sodic soil (15% ESP), consistent with the significantly higher levels of the exchangeable Na ion in the soil in the same sampling period.

At the start of the wet season, or coming in from a dry period, the ESP was still high in all sampling sites, suggesting a period of accumulation and precipitation in drier months. Due to the evident high presence of the Na+ ion, a potential effect on plant uptake of K+ was investigated and results showed greater uptake of sodium than potassium in the WS rice crop as seen in the grains. However, a potential effect on yield was only observed in the field closest to the swamp.

Yield data showed that, except for the field nearest the swamp (Field 1), rice yields were generally within the range of potential yield for each of the varieties used, including the salinity tolerant variety Salinas. However, in Field 1, yields were lower during wet and dry seasons and were found to be related to the high ESP and exchangeable sodium levels in the soil more than the other soil properties.

With these findings, it can be concluded that the lowland rice area in Barangay Navotas, Balayan, Batangas, which is in a coastal environment, is prone to soil salinity and sodicity from intrusion of saline seawater. In its current state, the area is still a productive agro-environment with good soil fertility and with proper management, it can continue to sustain the livelihood of farmers. However, it is important that this lowland rice area be continuously monitored because indicators such as soil pH, EC, ESP and levels of exchangeable cations, especially sodium, showed that the soil is salt-affected at certain times in the wet and dry seasons and negative effects were mitigated only with irrigation and fertilizer management.

Management Alternatives for Sustained Productivity in Coastal Lowland Rice Areas

Specific soil constraints to rice growth and productivity due to salinity include osmotic effects or water stress, toxic ion effects of excess sodium and chloride uptake, and a reduction in nutrient uptake because of antagonistic effects. Rice can tolerate salinity at certain growth stages but becomes sensitive at others. Findings from this study are important inputs to evaluate management alternatives for sustained productivity in salinity-threatened lowland rice areas and mitigation measures for salt-affected areas. Farmers can be advised on options that include water and irrigation management, nutrient management, organic matter management, use of tolerant varieties, modification in cropping system, and, in worse-case scenarios, use of salt free irrigation water and gypsum application.

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