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Identification of Soil Salinity Due to Seawater Intrusion on Rice Field in the Northern Coast of Indramayu, West Java

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ABSTRACT

The rice fields in Indramayu district is 55% of the district area. The average rainfall is 1590 mm per year. Most lands on the North Coast of Java (northern) were potentially affected by sea water intrusion. Extensive observations were 102.321 ha. Field observations were done by survey method. Observations had been conducted on rice fields Pantura, Indramayu, West Java. Soil salinity was measured by using the electromagnetic conductivity meter (EM-38). The results revealed that area had very high salinity which was 22.57%, closest to the beach Indramayu. In the South Region, soil salinity was lower, in accordance with the distance from the coastline. Some areas had a low, medium, and high salinity status in which 58.41%, 8.54% and 10.49%, respectively. Much of the research area had very high Sodium (Na) and ECe (0 - 30 cm) was between 1.37 to 16.38 dS m^{-1}, while the ECe (30 - 70 cm) was between 1.11 to 17.40 dS m^{-1}. This research was expected to assist in the agricultural development planning, especially in wetlands which have been affected by the intrusion of sea water (salinity). Planning for the implementation of the development of rice varieties that are sensitive to high and very high salinity. Planning and improvement of irrigation networks as sources of clean water for washing the salts or pushing salt water into the sea.

Keywords: Coast of Indramayu, rice field, seawater intrusion, soil salinity

INTRODUCTION

Indications of the earth global warming and climate change have an impact on increasing the frequency and intensity of extreme climate events. Increased incidence of extreme climatic phenomena was characterized by floods and drought. Besides that the increase in sea levels that caused flood frequently (rob) in coastal areas. In dry season, water discharge in the mainland was reduced , while the sea waters infiltrating through the canals, the furrows of the river and swamp. This resulted in agricultural land bordering the coast and even further to the agriculture land until the 20 km was contaminated with sea water through intrusion.

Indramayu is one of the northern regions of West Java which is the source of food and rice barns in Java with a rice field areas of 112,194 ha (55% of the area). It has technical and semi-technical irrigated area which are 72,347 ha and 13,013 ha, respectively (BPS 2008), but lately the productivity of Indramayu wetland area in the northern was decreased. One reason was caused by the growth and production of rice farmers during the second cropping season (gadu) was disturbed. This was due to the farmers delayed planting schedules lack of irrigation water, resulting in a lot of empty rice yield and spread of pest. Water for planting when needed was very difficult, because water was obtained from wells or other water sources such as canals and rivers which had been mixed by seawater.

Seawater contains a high salt (> 500 me l^{-1}), mainly in the form of NaCl, the combination between the bases cations (K, Ca, Mg) and sulfate, bicarbonate and chlorine (anion) (Gain *et al.* 2004; Amanullah 2008). While the salt content in the sea mud from the tsunami Aceh had EC of 19.8 - 84.2 dS m^{-1} (Rachman *et al.* 2007; Rachman *et al.* 2008). In contrast to the intrusion of sea water, salinity was resulting not only from marine mud but also from seepage or high tides. Impact of sea water intrusion and tsunami or other entry of salt water to the mainland will be felt at the drought time. Rice plants begin to dry and the impact on crop failure. Research shows that in the coastal areas, soil salinity (ECe) ranged from 2 dS m^{-1} to 18 dS m^{-1} in the dry

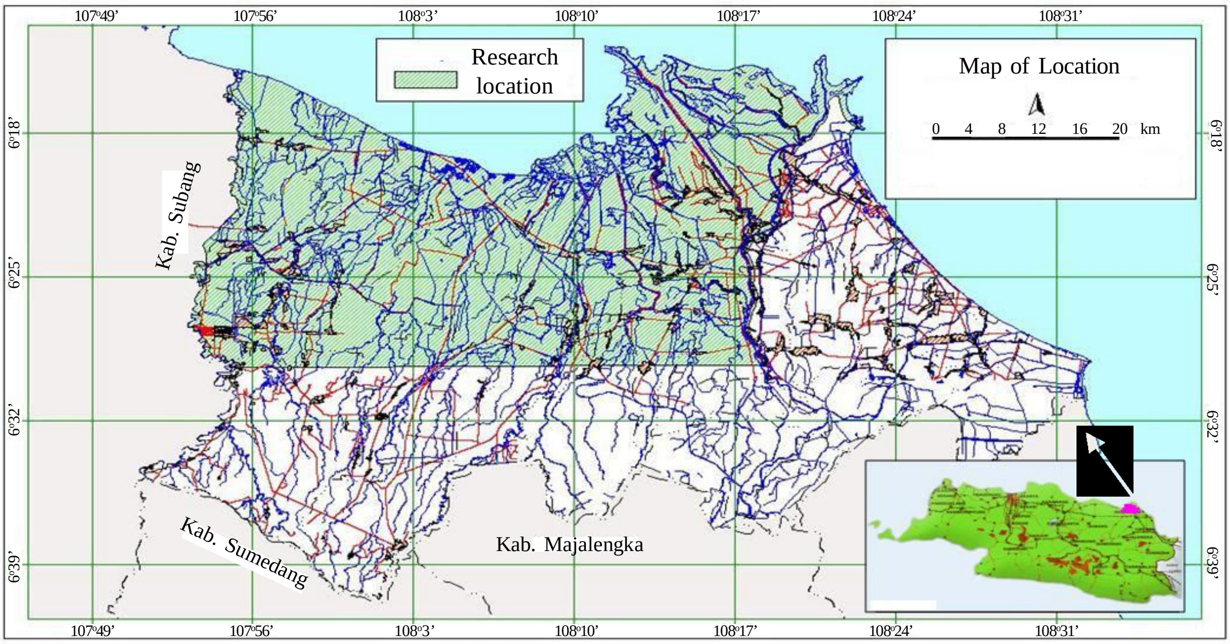

Figure 1. The location of the salinity soil in the northern coast of West Java, Indramayu.

season (Gain *et al.* 2004). While the tolerance limit of the ideal rice plant at transplanting is ECe values less than 4 dS m^{-1} (FAO 2005).

This paper aimed to identify soil salinity due to seawater intrusion, to obtain information about the spread of soil salinity in wetlands of northern Indramayu. This information was expected to assist Local Government to increase the productivity of paddy fields and irrigation network in the Indramayu Region.

MATERIALS AND METHODS

Site Description

The area of paddy fields were observed and it was located in the northern region of Java, Indramayu, West Java. The area which was 100,000 ha with the observation coordinate limits 107°53'09"; 108°19'02" East Longitude and 60°13'45"; 60°29'19" South Latitude (Figure 1). Research area was in the technical and semi-technical irrigation area.

The average rainfall was 1590 mm $year^{-1}$ with the number of rainy days 81 days and the highest rainfall in January-March (0 - 23 days of rain) and the lowest in August (0-7 days of rain). Rainfall data from the northern region of West Java, Indramayu was presented in Figure 2.

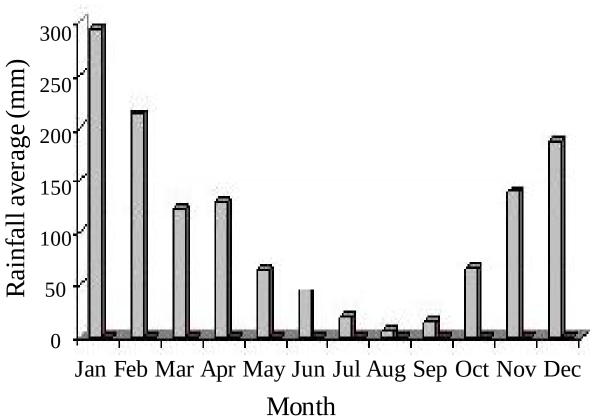

Figure 2. Average rainfall in Indramayu at the year of 1990-2007.

There are 4 types of soil in the observation area, namely Aeric Halaquepts, Sodic Endoaquents, Aeric Endoaquepts and Sodic Psammaquents (Soil Survey Division Staff 1993; FAO 1990). There were several types of soil that developed from fluvio-marine deposits such as Aeric Halaquepts, and Sodic Endoaquents.

Method for Field Observation

Field research was conducted in July 2009. Field observations carried out with a survey by a transect method from north to south to describe the extent of soil salinity status. Identification of soil salinity was based on taking into account the relationship between soil and landscape (King *et al*. 1983; Steers and Hajeek 1979; White 1966; Soil Survey Staff 2006).

EM-38 was used for observation the soil salinity. It is an electromagnetic conductivity meter, which can measure the salinity (EC) up to a depth of 60 cm. The use of EM-38 is suitable for mapping the soil salinity, because it can measure rapidly and actual (Slavich 2001). EM-38 can measure the soil

Table 1. Status indication of soil salinity (ECa) with differences in soil texture.

Soil Texture	ECa dS m^{-1}			
	Low*	Medium*	High*	Very High*
Sandy loams	< 0.4	0.4 – 0.7	0.7 – 1.3	> 1.3
Loams	< 0.7	0.7 – 1.1	1.1 – 1.9	> 1.9
Clay loam-light clay	< 1.0	1.0 – 1.5	1.5 – 2.5	> 2.5
Medium-heavy clays	< 1.25	1.25 – 1.9	1.9 – 3.0	> 3.0

*: Low - ECe = <2 ; Medium - ECe = 2 – 4; High - ECe = 4 – 8; Very high - ECe = >8.
Source : Rhoades *et al.* (1989).

EC vertically and horizontally. Sensitivity level of the vertical (EMv) can detect the depth of 1.5 meters; while for the horizontal (EMh) can detect the depth of 0.5 meters. The reading rate is affected by the properties condition of soil moisture levels and iron oxide (Norman 1990). An integration approach, based on an exponential decay profile model, was proposed and the model was fitted to all the calibration sites. The obtained model can then be used to predict EC1.5 at a certain depth from electromagnetic measurements made using the EM38 device positioned in horizontal and vertical positions at the soil surface (Yao *et al.* 2007).

In calculating the average apparent electrical conductivity (ECa) of the EM-38 tools few equations were used. Slavich developed the equation: if the EMh<EMv, the ECa (0-60 cm) = 1.24 * EMh - 0.05 * EMv, and if the EMh> EMv, the ECa (0-60 cm) = 1.87 * EMH – 1.87 * EMV. Table 1 presented indication of soil salinity status (ECa) under different soil texture. Conversion of EC 1:5 into ECe value was calculated based on Slavisch and Peterson (1993).

To calibrate the status of soil salinity, soil samples were taken based on the composite land unit and the alleged land affected by salinity. Soil sample taken at the upper layer (0-30 cm) and bottom layer (30-70 cm) for analysis of soil pH, EC, salinity, CEC, base saturation, sodium chloride and soil texture.

RESULTS AND DISCUSSION

Status of Soil Salinity

Indramayu region, especially in the northern part was influenced by the formation of marine soil from marine sediments, thus forming the delta. This caused the field having high salinity. Besides, high salinity in paddy fields affected by the surrounding land uses such as land for salt production and fish ponds (pond). Observations of salinity and its status are presented in Table 2.

Water is absorbed by plant roots through a process called osmosis, which involves movement of water from places with concentrations of salt (Ca, Na, Mg, Cl and SO_4) in low (ground) to a place that has a high salt concentration (the inside of cells roots). If the concentration of salt in the soil is high, the movement of water from the soil into the roots is slow. If the salt concentration in soil is higher than in the root cells, the soil will absorb water from the roots, and the plant will be wilted and died (Maruyama and Tanji 1997).

The destructive influences of salt on plants were not only caused by the power of osmosis, but also by the sodium (Na^+) and chlorine (Cl^-) at a concentration of poison plants (Cornillon and Palloix 1997; Gunes *et al.* 1996). This happens on the field, the plants look dead drought, and susceptible to pests and diseases. The research areas had texture which contained most of the clay and Na ranged from moderate to very high.

The rice fields that had a high salinity generally found in the north near the coast or in the areas which affected by the pond. High salinity caused by seawater intrusion from the river and canals. This intrusion was shallow because the white color seen on the surface of the soil with a pH ranging from 6.5 to 8.0. This can be seen during the dry season. Brondong village had a very high of soil salinity status and Na, it was evident from field observations and soil analysis (Table 3).

In the rice field with low and medium salinity, such as Sub district of Lelea; Widasari; Sukra; Patrol South, the salinity processes could occur because of leaching. In these regions, irrigation was very good, so the salty water could be driven and leached into the inner lining. During the dry season soil salts did not appear above the ground surface, thus it was safe for the rice crop. The pH distribution in this area was ranged from 5.5 to 6.0. Table 4 shows Bangkaloa Village, Widasari Sub district had low salinity status and low Na. This area was good for the growth and production of rice.

Table 2. Observations results of salinity and salinity status.

Observation code	Village/Subdistrict	ECa (dS m^{-1})	Soil texture	Status
A1/2	Brondong. Pasekan	10.54	Clay	Very high
A3	Brondong	2.09	Silty clay	high
A4	Karanganyar. Kandang haur	4.87	Silty clay	Very high
A5	Karanganyar	4.46	Clay	Very high
A6	Santing. Losarang	4.04	Clay	Very high
A7	Petean. Patrol	2.76	Clay	High
A9	Cantigi Kulon. cantigi	4.47	Clay loam	Very high
A9a	Cantigi Kulon	5.51	Clay	Very high
A10	Penyingkiran	1.63	Silty clay	Medium
A11	Arahan Lor. Arahan	0.83	Silty clay	Low
A12	Bangkaloa. Widasari	0.73	Clay	Low
A12a	Bangkaloa	0.86	Clay	Low
A13	Pendok	0.20	Clay	Low
A14	Tamansari. Lelea	0.27	Clay	Low
A15	Pamayahan. Lohbener	0.61	Clay	Low
A16	Dermayu. Sindang	2.45	Silty clay	High
A17	Pabean Ilir. Pasekan	4.73	Clay	Very high
A17a	Pabean Ilir	7.19	Clay	Very high
A18	Pabean Ilir	3.45	Silty clay	Very high
A20	Karanganyar	5.94	Silty clay	Very high
A21	Langut. Lohbener	1.93	Silty clay	Low
A22	Kiajaran Kulon	1.37	Clay	Low
A23	Kertajadi. Losarang	4.27	Silty clay	Very high
A23a	Kertajadi	5.19	Clay	Very high
A24	Pegagan. Losarang	0.88	Silty clay	Low
A24a	Pegagan	0.57	Silty clay	Low
A25	Wirakanan. Kandanghaur	0.94	Silty clay	low
A26	Bulak. Kandanghaur	3.09	Clay	High
A29	Ujung Gebang. Sukra	2.56	Clay	High
A30	Mekarsari. Patrol	1.36	Silty clay loam	Medium
A31	Soge. Kandanghaur	3.64	Clay	Very high
A32	Losarang. Losarang	6.35	Clay	Very high
A32a	Losarang	4.13	Silty clay	Very high
A33	Losarang	4.12	Silty clay	Very high
A35	Muntur. Losarang	0.95	Silty clay	Low
A36	Muntur	2.66	Clay loam	Very high
A37	Karangsinom. Kandanghaur	2.64	Clay	High
A39	Bugel. Patrol	1.02	Silty clay	Low

Rice fields in Kandanghaur Sub District had a lot of technical irrigation (BPS 2008). But this area was trouble with the discharge of water to irrigate the fields, so that sea water intrusion occured through seepage irrigation. In the northern part of the Karanganyar Village there were areas with a very high salinity and the salinity was reduced in accordance to the distance from the shoreline and near water sources such as Bulak and Wirakanan Village (Table 5).

Irrigation is an important factor in dealing with salinity. Indramayu region has two irrigation network (IN) that is managed Salamdarma Jatiluhur Authority Project (OJP) and Jati Tujuh irrigation through a watershed Cimanuk. However, due to lack of water resources and poor infrastructure, salt water infiltrated the rivers, canals and swamps. Kandanghaur Sub district is an example of the problematic areas with salinity in rice fields. This was a result of irrigation discharge was reduced, so that water did not flow evenly, and even less to irrigate the fields. Due to lack of water during a bad drought on rice plants, roots were disturbed, the plants were

Table 3. Soil salinity on Brondong Village, Pasekan Sub district.

Depth (cm)	Eca (dS m^{-1})	pH (H_2O)	Ece (dS m^{-1})	Na (cmol+Kg^{-1})
0-30	8.89	7.0	16.38	17.07
30-70	9.57	6.8	17.40	24.95

Table 4. Soil salinity on Bangkaloa Village, Widasari Sub district.

Depth (cm)	ECa (dS m^{-1})	pH (H_2O)	ECe (dS m^{-1})	Na cmol+Kg^{-1})
0-30	0.75	5.4	1.37	0.54
30-70	1.06	5.7	1.11	0.91

dried and were susceptible to local pests and diseases.

Sharma and Minhas (2005) argued that there were some alternatives: 1) The management of crops including cropping patterns, the use of tolerant varieties. 2) irrigation water management, including improving irrigation and drainage channels, such as intensifying the use of traditional irrigation tertiary canals, and channels between plots of rice field. Irrigation water was needed to push the sea water or salt water entering through the channel. In the second plot of rice fields, irrigation water as the washer contained salt levels in soil. 3) Use of amelioration, such as gypsum ($CaSO_4$. $2H_2O$) and organic materials as needed. 4) Learn the habits of farmers, on the management of wetland salinity. From the integration of these alternatives, it can provide the necessary approach to the sustainability of paddy fields productivity. Reclamation of saline lands seems difficult for climatic and economic reasons, but cultivation of salt tolerant plants is an approach to increasing productivity and improvement of salt-affected wastelands (Akhter *et al.* 2003).

The spread of Soil Salinity

Areal distributions of soil salinity are presented in the form of soil salinity maps with a scale Indramayu District 1: 50,000 (Figure 3). Area covered by the observation is 102.321 ha. Areas with low, moderate, high, and very high salinity status were including 58.41%, 8.54%, 10.49% and 22.57% of the total observations, respectively. High salinity is generally spread in an area near the beach until the average of 5 km. Mekarsari Village, Patrol Sub district, a distance of 500 meters from the coastline has a medium salinity. This area is used by farmers to plant some vegetables like onion, red pepper, eggplant, tomatoes and paria. The supply of irrigation in this area is quite well, so that salt water seeping into the channel can be overcomed. In general, the distribution pattern of soil salinity in the region was in accordance with land units. While some components of land units provide a unique indication of salinity in region.

Soil that has a high to very high salinity is generally characterized by inclined close to the sea that allowing seawater intrusion occurred intensively; it have a material derived from marine sediments that have a strong marine influence; and it is an area of the delta coast and shoals that are still exposed to the influence of marine activity . However, criteria in a soil salinity zone there are variations of the specific differences in soil characteristics. It is possible that the existence of drainage and irrigation patterns were varied, giving the effect of fluctuations in concentration and depth of the salt intrusion in the soil layer. On soil units which are potentially high salinity, but because of the influence of a fairly intensive irrigation, it resulted in soil salinity is low. This is because irrigation water serves as a washer and controlling the salt water entering through the channel.

Relation to soil characteristics are: (1) on soils that have potential for high salinity due to its pattern of intensive irrigation, the high salt levels found

Table 5. Soil salinity in some villages in the Kandanghaur Sub district.

Village	Depth (cm)	Eca (dS m^{-1})	pH (H_2O)	ECe (dS m^{-1})	Na (cmol+Kg^{-1})	Salinity status
Karanganyar	0-30	4.13	6.9	6.17	5.71	Very high
	30-70	4.97	7.0	11.66	7.80	
Bulak	0-30	2.62	5.3	4.90	4.17	High
	30-70	3.11	4.8	5.93	4.61	
Wirakanan	0-30	0.81	6.8	3.05	4.09	Medium
	30-70	1.19	7.0	2.95	4.32	

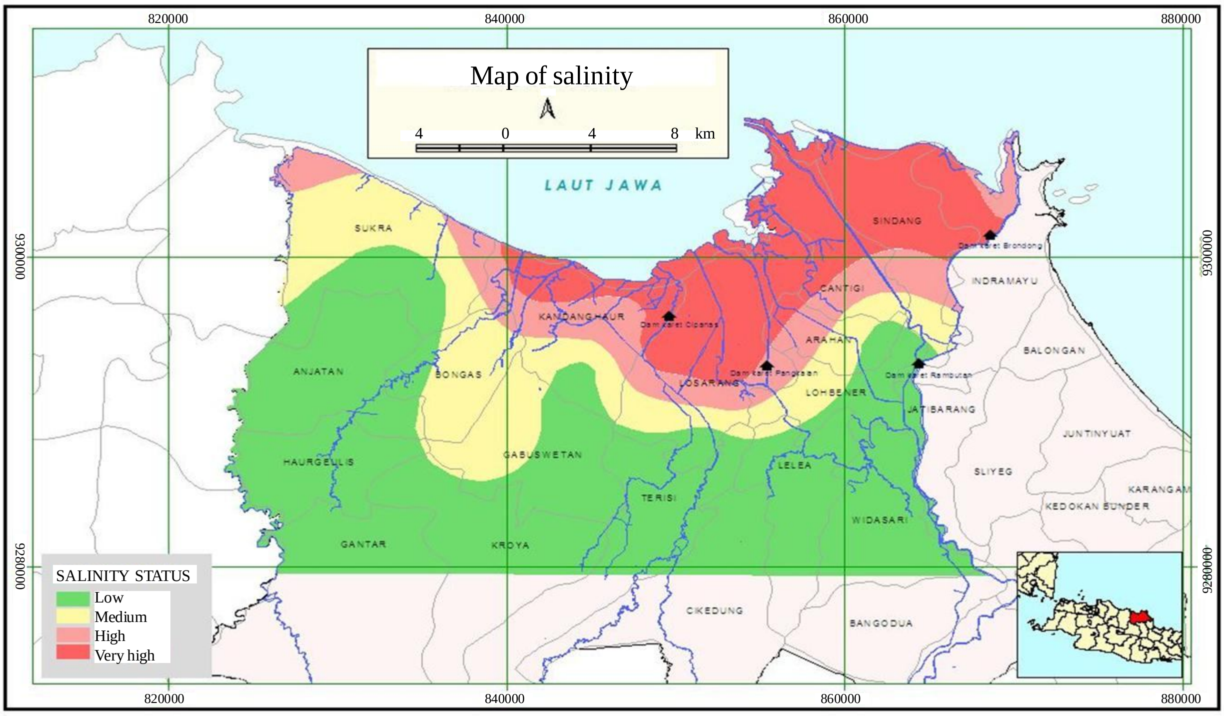

Figure 3. Map of soil salinity in the Indramayu District.

only in the layer below it. Soil that had a high potential for seawater intrusion but intensive irrigation, had a tendency of high levels of salts in the below until the middle layer. This occurs in Sukra and part eastern Sub district and Lelea Sub district although Lohbener Sub district had great potential for intrusion of intensive irrigation was included in the medium salinity; (2) on soils that had potential for high salinity water with a strong marine influence, without the neutralizing effect of intensive irrigation channels so that the characteristics of the soil showed high salinity from the soil surface to the bottom layer. This situation was found in the sub district of northern Kandanghaur and Losarang. Its soil was classified as an area with very high salinity levels. Whereas in other parts of land which had characteristics similar to a better irrigation conditions, soil characteristics that showed a better effect of salinity was classified as land with high salinity levels.

From this condition, it was known that on soil, which actually had the characteristic with the potential for high salinity was naturally going to show the characteristics of the soil with high salt levels ranging from surface soil until the bottom layer. Soil with such characteristics were classified as Aeric Halaquepts and Sodic Endoaquents. This happens especially when the dry season and following evaporation of groundwater from beneath the upper layer so as to bring the salt solution was deposited in the layers above it, or salt water which brought the sea and deposited on the upper layer. From field observations, it indicated that soil pH from top to bottom layer ranged > 7.0, and from laboratory analysis it showed that the EC 1-2 dS m^{-1}. While on the same soil with more intensive irrigation conditions, the soil characteristics indicated that generally salt content was only found on the bottom layer, or if in the upper layer but it had low levels. Soil with such characteristics was classified as Sodic Endoaquents and the texture was classified as a Sodic Psammaquents sand. Field observations indicated that the top layer had a pH between 5 to 6.5, while the laboratory analysis showed an average value of EC < 1 dS m^{-1}.

In some natural soil, the soil had medium to low salinity levels. This shows the effect of soil characteristics that was not a small or nonexistent. The soil characteristics in this region generally shows a low level of salt content or very low, only in some parts of the soil were rather high in the lower layers. Soil with such characteristics was classified as Aeric Endoaquepts. From field observations indicated the top layer of soil pH to a depth of 1 meter was between 5 to 6.5, even lower in some soil layers. While the laboratory analysis showed an average EC value of < 0.5 dS m^{-1}, only some parts of the soil EC > 0.5 dS m^{-1}. On the soil condition with such kind of soil characteristics, the function of irrigation on soil salinity level was less.

CONCLUSIONS

Most rice fields in the North Coast of Java, Indramayu was potentially affected by sea water intrusion. The area that had very high salinity was mostly located close to the beach. While getting into the lower south, sea water intrusion was depended on the distance from the coastline. Area with low, moderate, high and very high soil salinity status were as follows 58.41%, 8.54%, 10.49%, 22.57%, respectively. Soil that has a high to very high salinity was generally characterized by closed to the sea and having the material from marine sediments, so that, sea water intrusion was occured intensively. Survey area had moderate to very high sodium (Na) and ECe (0-30 cm) was between 1.37 to 16.38 dS m^{-1}, while the ECe (30-70 cm) was between 1.11 to 17.40 dS m^{-1}, so that, the wetland with high or very high salinity is recommended not only using rice varieties which tolerant of saline, but also using Gypsum. Improvement of drainage and irrigation channels is an absolute thing, because in addition to reducing water loss, it was also to wash the salt levels in the plot of rice fields.

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