IMPROVEMENT OF RICE CROPPING IN SALINE SOILS IN THE NORTH CENTRAL COASTAL REGION OF VIETNAM

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CHAPTER 1

INTRODUCTION

1.1 Backgrounds

Vietnam is a humid tropical country with long coastline and large coastal area in Southeast Asia. Main land stretches from N08^{o}10’ to N23^{o}24’ and widens from E102^{o}09’ to E109^{o}30’. Vietnam has two fertile deltas of rivers Red and Mekong (Fig. 1.1). The total saline soils area of the country is about 971,356 hectares covering about 14 % of the total agricultural land (Vietnam Soil Science Society, 1996).

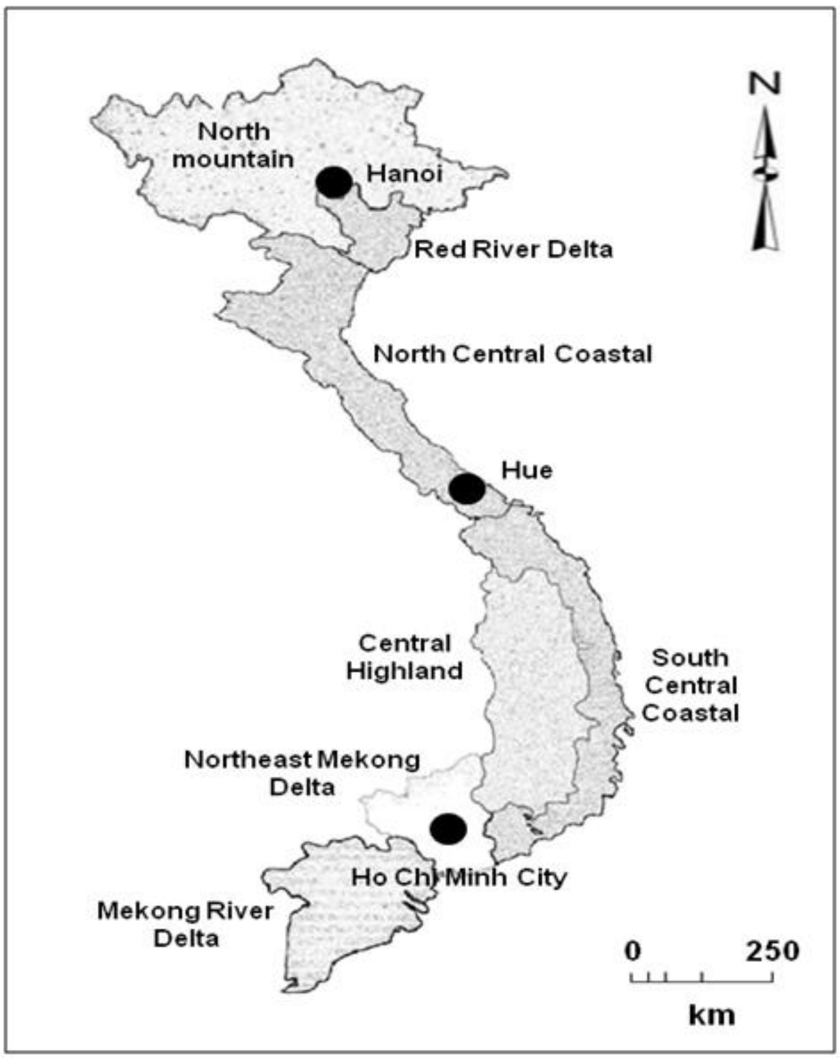


Fig. 1.1: Seven agro-economic zones of Vietnam

At present, salinization is one of the most widespread soil problem in rice–growing countries and is considered to be a serious constraint on rice production worldwide (Ghafoor et al., 2004). In Vietnam, particularly in the north central coastal regions of the country (Fig. 1.1), soil salinization is considered to be one of the most serious problems affecting rice (crop) production. The causes of salinity are mainly due to the inundation of seawater during high tidal action and ingress through creeks, especially in the dry season (Lang et al., 2010). As a result of serious salinization, rice growing is difficult in the north central coastal region. The average yield of rice on saline soils in the north central coastal regions is low, about 1.2 tons ha^{-1}, and that of maize is about 1.5 tons ha^{-1} (Lang et al., 2010), while the country average yield of rice and maize in 2010 was 5.3 and 4.1 tons ha^{-1}, respectively (Fig. 1.2) (General statistics office of Vietnam, 2014a).

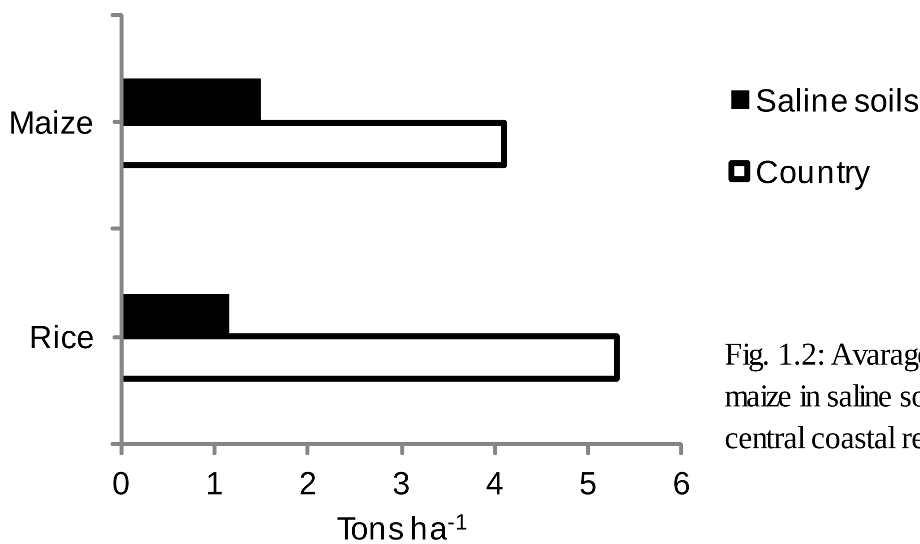


Fig. 1.2: Avarage yield of rice and maize in saline soils in the north central coastal region and country.

In recent years, the rapid increase of population has created a growing demand for food and put high pressure on food security. From 2000 to 2012, the population of Vietnam increased from 77.0 to 88.8 million people (Fig. 1.3), while rice cultivation areas just slightly increased from 7.7 to 7.8 million ha (General statistics office of Vietnam, 2014b). Hence, reclamation of saline soils and the potential of it to aid socioeconomic development in the north central coastal zones are gaining attention.

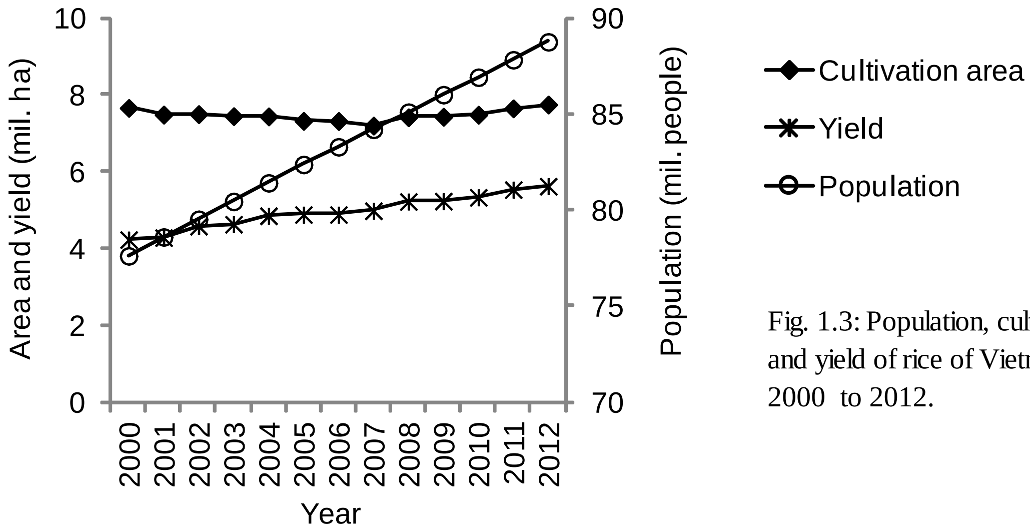


Fig. 1.3: Population, cultivation, and yield of rice of Vietnam from 2000 to 2012.

In the north central coastal region of Vietnam, agricultural land in the province of Thua Thien Hue is seriously affected by soil salinization. In this province, about 2,500 ha of agricultural soils adjacent to the Tam Giang lagoon (the biggest lagoon in Southeast Asia, about 22,000 ha) are saline. Because farmers here are cultivating the low–yielding local rice variety of Khang Dan (KD), their income on saline soils in this province is very low (Dan et al., 2006).

The main income of farmers in the region of Thua Thien Hue is from agricultural production on saline soils. Thus, in order to increase income of farmers in this region, the improvement of rice cropping in saline soils is a crucial and effective solution. To achieve this target, first of all, we have to clarify the current status, variability and mechanisms of salinity in this region; because this information can be used to select the appropriate site–specific methods for amelioration of saline soils. In addition, we have to elucidate how rice production is affected by saline soils. To solve these needs, I conducted a study entitled (the first study) *spatiotemporal variability of salinity and its effects on rice production in the central coastal region of Vietnam*. To increase the income of farmers, high–yielding rice varieties can be cultivated instead of low–yielding local rice varieties. However, it is time–consuming and expensive to breed new high–yielding salt–tolerant rice varieties for specific regions. The most effective strategy, therefore, is to introduce high–yielding, salt–tolerant rice varieties that have been bred and/or cultivated in other regions to the Thua Thien Hue Province. Therefore, I also carried out a second study entitled *assessment of performance of newly introduced salt–tolerant rice cultivars on saline soils in the north central coastal region of Vietnam*.

1.2 Objectives

The objective of the first study is to clarify the spatiotemporal variability of soil salinity and its effects on rice yield in paddy fields.

The second study has two objectives: to find higher–yielding rice varieties than the local variety of KD, and to identify the best yield indicators and quantify their contributions to yield, which can optimize selection of rice breeding lines for the north central coastal region of Vietnam.

The results of two studies will help to mitigate the unfavorable effects of soil salinity and improve rice cropping.

1.3 Frame of dissertation

The dissertation is comprised of the following chapters. Chapter 2 outlines the general information of the research site, and also describes climatic conditions, water table levels on the surface of rice fields, rice cropping calendar and general soil properties. Chapter 3 clarifies the spatiotemporal variability of salinity and its effects on rice production. Chapter 4 examines the performance of some newly introduced salt–tolerant rice varieties for 10 main agronomic traits and yield. Finally, Chapter 5 combines the results of the two studies and suggests the solutions to mitigate the unfavorable effects of soil salinization and improve rice cropping.

CHAPTER 2

GENERAL INFORMATION OF RESEARCH SITE

2.1 Research site

The research site was located in the Quang Phuoc commune (N16°35' and E107°32'), which is located in the Quang Dien district, Thua Thien Hue province, in the north central coastal region of Vietnam (Fig. 2.1). The commune is 14 km northeast of the city of Hue, stretching about 5 km along the Tam Giang lagoon, and has a flat landscape. People in this commune started to cultivate rice and other crops for living from 16 century (Dan et al., 2006). The total area is 1,048 ha, of which 509 ha is agricultural land, 161 ha is shrimp farming, 367 ha is non–agricultural land, and 10 ha is unused land (Dan et al., 2006). There are two main irrigation rivers (Dien Hong and Bao Kho) that supply fresh water for the cultivation of rice and other crops. The dike stretching along the lagoon was constructed from 1994 to 1995 to prevent seawater intrusion from the lagoon onto land. However, there are some sections of the dike that haven't been constructed, because of the financial constraints (Fig. 2.1).

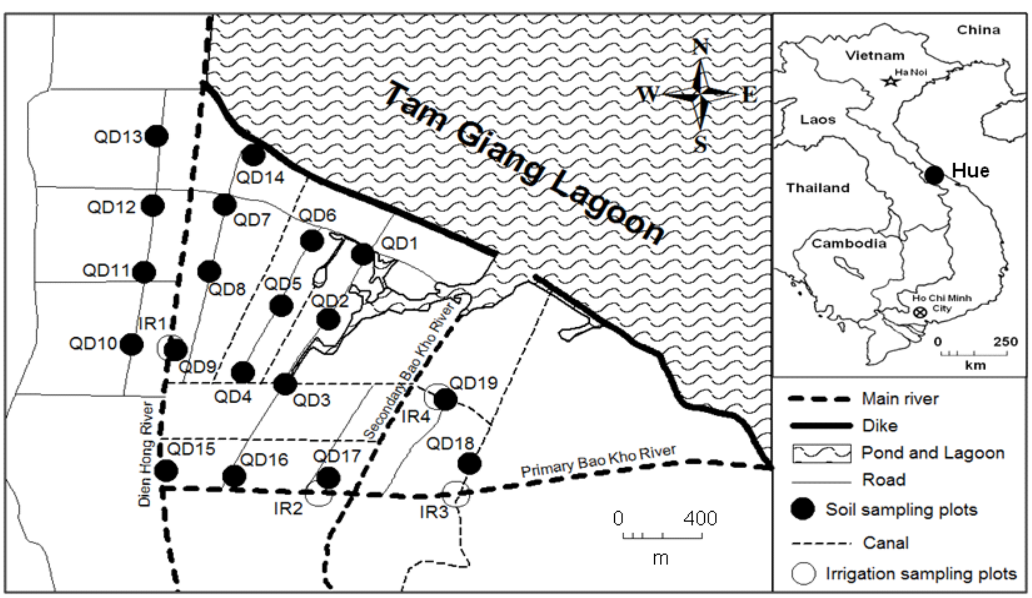


Fig. 2.1: Location of 19 research plots in the Quang Phuoc commune, Quang Dien district, Thua Thien Hue province, in the north central coastal region of Vietnam.

2.2 Climatic condition

The average air temperature and monthly precipitation of the studied site in three years of 2011 to 2013 is shown in Fig. 2.2. The climate of this region is tropical monsoon climate with two distinct dry (from April to August) and rainy (September to December) seasons. Annually, this region receives a big amount of precipitation; the total precipitation amount in 2011, 2012, and 2013 were 4540, 2190, and 2730 mm, respectively. Because precipitation unevenly distributes for the months and mainly focuses on the period of September to December, this area is flooded annually during this period. The air temperature increases gradually from January to May, then keeps stable around 28 to 29 ^{o}C during May to August (the hottest period in year), and then decreases until the end of year.

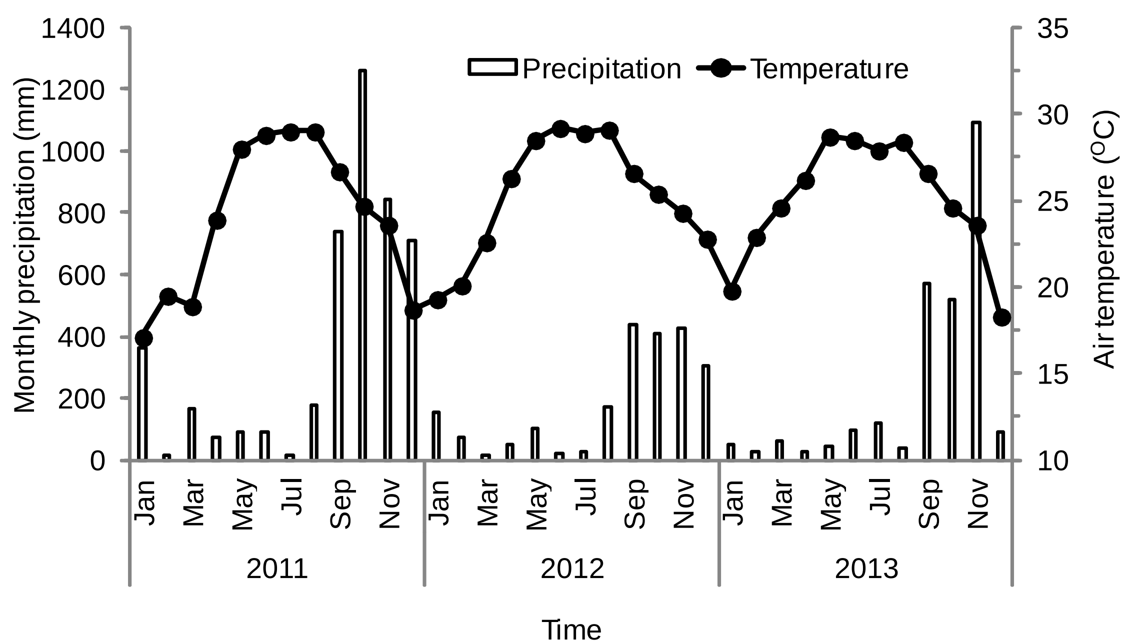


Fig. 2.2: Monthly precipitation and air temperature of research site from 2011 to 2013

Source: Meteorological Station of Thua Thien Hue Province, 2011 to 2013

2.3 Water table levels on the rice fields

The location map of the research plots is given in Fig. 2.1. Research plots in central part (QD2, 3, 4, and 5), those along the lagoon (QD1, 6, and 14) and those along secondary Bao Kho river (QD17 and 19) always have water on the surface. Water table levels are about 10 to 60 cm during January to August and about 60 to 200 cm during September to December (flooding time). In the areas along two main irrigation rivers of IR1 and IR2 (QD7, 8, 9, 10, 11, 12, 13, 15, 16, and 18) in Fig. 2.1, there is no water on the surface of the fields from late–April to the middle of May and from the middle of July to late–August. Water table levels are about 40 to 60 cm from September to December and about 20 to 30 cm during the rest of the time.

2.4 Rice cropping calendar

There are two rice cropping seasons: winter–spring cropping lasts from January to May and summer–autumn cropping from May to September. Because Quang Phuoc commune is usually flooded in the rainy season (from the end of September to the end of December), there is no rice cultivation during this period because of water submergence (Dan et al., 2006).

2.5 General soil properties

The physicochemical properties of soils at 19 representative plots (Table 2.1) showed that fertility of these soils in this region was very low, indicating that these soils were not suitable for rice growth. Most the soils were high in sand and low in silt and clay; and most the soils were classified as sandy loam. Most of the soils had pH (H_2O) from 5.3 to 6.6 and pH (KCl) from 4.3 to 5.8. CEC, total C, and total N were very low, from 2.0 to 6.4 $cmol_c$ kg^{-1}, 7.8 to 15.2 g kg^{-1}, and 0.8 to 1.6 g kg^{-1}, respectively. In soils at the plots in the central part (QD2, 3, 4, and 5), those along the lagoon (QD1, 6, and 14) and those along secondary Bao Kho river (QD17 and 19) (Fig. 2.1), the dominant exchangeable cation was Na^+, Mg^{2+} and Ca^{2+}. In soils at the plots along two main irrigation rivers of IR1 and IR2 (QD7, 8, 9, 10, 11, 12, 13, 15, 16, and 18), the dominant exchangeable cation was Ca^{2+}, followed by Mg^{2+} and Na^+. Exchangeable cation K^+ of all soils was small.

Table 2.1: General properties of soils

Plots	Sand	Silt	Clay	pH		CEC	Exchangeable cations				Total C	Total N
							Na^{+}	K^{+}	Mg^{2+}	Ca^{2+}		
		(%)		(H_20)	(KCl)	($cmol_c$ kg^{-1})		($cmol_c$ kg^{-1})			(g kg^{-1})	
QD3	54	28	18	6.1	5.3	4.5	1.8	0.1	1.4	1.3	12.7	1.2
QD5	77	11	13	6.0	5.2	3.7	0.7	0.1	1.0	0.9	9.9	0.8
QD2	67	19	14	6.2	5.4	4.7	1.6	0.2	1.4	1.1	12.5	1.1
QD4	74	15	10	6.1	5.8	4.0	2.1	0.2	1.4	0.5	9.1	0.8
QD6	82	7	11	5.8	5.1	3.6	1.1	0.1	1.1	1.0	10.5	0.9
QD14	67	18	15	6.4	5.6	3.9	1.2	0.1	1.4	1.2	9.7	1.0
QD19	80	13	8	5.9	4.9	2.5	0.3	0.1	0.4	0.4	8.7	0.8
QD1	68	17	15	6.0	5.4	3.9	2.1	0.2	1.8	1.2	10.1	1.0
QD17	61	28	12	6.6	5.2	3.7	0.5	0.1	0.7	0.6	10.8	1.0
QD16	44	42	14	5.3	4.3	5.5	0.2	0.1	0.5	0.8	10.9	1.0
QD18	44	40	16	5.7	4.6	4.0	0.2	0.1	0.4	0.7	15.2	1.6
QD15	45	39	15	5.4	4.3	6.4	0.2	0.1	0.1	0.4	13.5	1.4
QD7	34	40	26	5.4	4.4	4.9	0.2	0.1	0.2	0.8	12.7	1.4
QD8	58	26	17	5.6	4.4	3.0	0.1	0.1	0.1	0.4	11.1	1.2
QD9	27	57	16	5.3	4.3	6.4	0.2	0.1	0.2	0.6	10.3	1.0
QD10	69	19	12	6.0	4.7	2.9	0.1	0.1	0.1	0.8	12.0	1.3
QD11	69	20	12	6.1	4.9	3.6	0.2	0.1	0.1	1.1	12.1	1.3
QD13	70	21	9	5.8	4.5	2.0	0.1	0.1	0.0	0.4	8.1	0.8
QD12	73	18	9	5.9	4.6	2.2	0.1	0.1	0.0	0.4	7.8	0.8

Soil samples at the 19 plots were collected in January 2012, from a depth of approximately 0 – 20 cm.

CHAPTER 3

SPATIOTEMPORAL VARIABILITY IN SOIL SALINITY AND ITS EFFECTS ON RICE PRODUCTION

3.1 Backgrounds

At present, salinization is one of the most widespread soil problems in rice–growing countries and is considered to be a serious constraint on rice production worldwide (Ghafoor et al. 2004). In Vietnam, in particular the north central coastal regions of the country, soil salinization is considered to be one of the most serious problems affecting rice and other crops such as bean, onion, and maize production. Salinization is mainly due to the inundation of seawater during high tidal action and ingress through creeks (Lang et al., 2010). As a result of the effects of salinization, the average yield of rice and maize in the north central coastal regions is low, about 0.8 to 1.5 tons ha^{-1} and 1.0 to 2.0 tons ha^{-1}, respectively (Lang et al., 2010). The national average yield of rice and maize in 2010 was 5.3 and 4.1 tons ha^{-1}, respectively (General statistics office of Vietnam, 2014a).

In the past, problems associated with saline soils were not given much attention by the Vietnamese government because of the small population of the country. However, in recent years, the rapid increase in population has created a growing demand for food and put high pressure on food security. From 2000 to 2012, the population of Vietnam increased from 77.0 to 88.8 million peoples, while rice cultivation areas just slightly increased from 7.7 to 7.8 million ha (General statistics office of Vietnam, 2014b). Hence, reclamation of saline soils and the potential for it to aid socioeconomic development in the north central coastal region is gaining attention.

In the north central coastal region of Vietnam, agricultural land in the region of Thua Thien Hue province is seriously affected by soil salinization. In this region, about 2,500 ha of agricultural soils adjacent to the Tam Giang lagoon (the biggest lagoon in Southeast Asia, about 22,000 ha) are saline (Dan et al., 2006). It is therefore urgent to develop practical solutions to alleviate the adverse effects of soil salinization on agricultural production in the region of Thua Thien Hue province.

To address this need, spatial and temporal variability in soil salinity and its effects on rice production needs to be investigated; because information on spatial and temporal variability in soil salinity can be used to select the appropriate site–specific methods for the amelioration of saline soils (Qadir et al., 2000 and Zheng et al., 2009). Li et al., (2007) suggested that there is both spatial and temporal variation in soil salinity and both types of variability need to be considered to achieve the ultimate goal of sustainable cropping systems.

The important roles of elevation on salt accumulation in soils has been reported by many authors, including Sugimori et al., (2008), Funakawa and Kosaki (2007), Funakawa et al., (2000), Zheng et al., (2009), Li et al., (2007), Haruyama et al., (2006), and Moral et al., (2010). However, there is limited information on the influence of minor differences in elevation (on the scale of centimeters to decimeters) on soil salinization, especially for saline soils adjacent to lagoons, such as those in the Thua Thien Hue region.

To develop solutions to mitigate the unfavorable effects of soil salinization and promote rice cropping, I examined the spatial distribution and temporal variability of soil salinity in paddy fields; in which there are small differences in elevation, and evaluated the influence of elevation, electrical conductivity of soil saturation paste (ECe), electrical conductivity of soil solution on the fields (ECw) and soil properties on rice yield.

3.2 Materials and analytical methods

3.2.1 Experimental design

Experiments were conducted on 19 plots (QD1 – QD19) that were distributed widely in the Quang Phuoc commune (Fig. 2.1). The distance between plots was approximately 400 m. To evaluate the influence of elevation on salinity distribution, the elevation of each point was measured by the static surveying technique with a handheld global navigation satellite system (GNSS) receiver and field controller (GRS–1 GG, TOPCON, Tokyo, Japan) and computer software (GNSS–Pro, TOPCON, Tokyo, Japan) (one of sampling plots was designated elevation as 0 m and the elevations of the 18 remaining plots were measured relative to this). To investigate the spatiotemporal variability of soil salinity, soil samples at the 19 plots were collected three times a year in both 2012 and 2013, from a depth of approximately 0 – 20 cm using an auger. Soil sampling was conducted in January (after flooding, and at the beginning of winter–spring cropping), in the middle of May (the transitional period between the winter–spring harvest and the beginning of sowing/transplanting time of the summer–autumn cropping), and in September (at the end of summer–autumn cropping and prior to flooding). To measure EC of the soil solution in the paddy fields (ECw), 19 porous cups (DIK–8390–11, Daiki, Japan) were installed in the 19 plots to collect soil solution samples at an interval of about 10 days (from February 2012 to September 2013) at a depth of approximately 20 cm from the soil surface. We did not measure ECw from the end of September to the end of December, because all research plots were flooded during this period.

Irrigation water sampling was conducted three times in 2013 at almost the same time as soil sampling. The sample collection points were the same as the pump setting stations of farmers. There were four sample collection points (sites IR1 through IR4); these were located at the Dien Hong River, the primary Bao Kho river section adjacent to QD17, the primary Bao Kho river section near QD18, and the canal adjacent to QD19, respectively (Fig. 2.1).

Rice yield of five representative square meters near each plot in the winter–spring and summer–autumn cropping season of 2013 was measured, and then averaged to examine the influences of elevation, salinity, and major soil properties on rice production, including pH, cation exchangeable capacity (CEC), clay content, total C, and total N content.

3.2.2 Analytical methods

Soil samples were air–dried, then crushed and passed through a 2–mm mesh sieve before analysis.

One hundred grams of air–dried soil was mixed with 43 ml of deionized water (ratio 1:0.43) to prepare the saturation paste, which was used for the measurement of pH (pHe), ECe, and concentrations of water–soluble cations and anions. The soil:water ratio of 1:0.43 was predetermined to satisfy the saturation paste criteria; these include the requirements that the soil paste should glisten, should flow slightly when the container is tipped, and that there is no free water accumulation on the surface after standing for at least 4 hours (Miller and Curtin 2006). To compare the soil parameter values over time, the ratio of soil and water was fixed for all samples and for all soil collection times. ECe were measured by a conductivity meter (CM–30S, TOA Electronics Ltd, Tokyo, Japan). Water–soluble cations Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, and NH_4^{+} and water–soluble anions Cl^{-}, SO_4^{2-}, and NO_3^{-} in the extracts were measured by high–performance liquid chromatography (LC–20AT, Shimadzu, Japan) equipped with shim–pack IC–C3 for cations, shim–pack IC–A1 for anions, and a conductivity detector CDD–10A.

To evaluate the hazards of sodium in solution, sodium adsorption ratio (SAR) was calculated by the formula: $SAR = [Na^{+}]/([Ca^{2+}]+[Mg^{2+}])^{0.5}$ and the concentrations of Na^{+}, Ca^{2+}, and Mg^{2+} were presented in mmol L^{-1} (Miller and Curtin 2006). ECw were measured by the conductivity meter.

The correlations between rice yield and elevation, ECe, pH, CEC, clay content, and total C and N concentrations were analyzed by Sigma Plots 11 statistics software (SSI, San Jose, USA). Because data of ECe was not normally distributed, the Spearman Rank Order Correlation was applied for analyzing correlations between yield and this parameter. Data of pH, CEC, clay content, total C, and N was normally distributed, thus Pearson Product Moment Correlation was used for analyzing correlations between yield and these parameters.

3.3 Results

3.3.1 Chemical compositions of irrigation water

The chemical composition of irrigation water at the study sites are given in Table 3.1. pH was between 7.01 and 7.35. Although the irrigation water samples were collected at different times, the fluctuation in pH was small. EC of IR4 in January and September and of IR3 in January was higher than that of the other locations, 0.38, 0.45, and 0.27 dS m^{-1}, respectively. Meanwhile, EC of IR1 and IR2 were low in all seasons, ranging from 0.06 to 0.11 dS m^{-1}. Concentrations of major cations and anions occurred in the following order: Na^{+}, Mg^{2+}, Ca^{2+}, and Cl^{-}. Concentrations of NH_4^{+} and NO_3^{-} were negligible.

According to the criteria used to evaluate the quality of irrigation water based on EC and SAR (United States Salinity Laboratory Staff, 1954), irrigation water at IR4 in

January and September, and IR3 in January, were classified as C2−S1 (EC from 0.25 to 0.75 dS m^{-1} at 25 ^{o}C and SAR from 0 to 10). Classification for the two main irrigation rivers of IR1 and IR2 was C1−S1 (EC from 0.10 to 0.25 dS m^{-1} at 25 ^{o}C and SAR from 0 to 10) in all seasons.

Table 3.1: Cation concentrations, sodium adsorption ratios, pH, and EC of water from four different irrigation rivers in the study area

Collection date	Location	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}	SAR†	pH	EC	Irrigation water class††	
		(mmol$_c$ L^{-1})								(mmol L^{-1})$^{0.5}$		(dS m^{-1})		
Jan. 2013	IR1	0.19	0.09	0.09	0.14	0.02	0.22	0.08	0.04	0.55	7.22	0.07	C1-S1	Low salinity
	IR2	0.21	0.08	0.11	0.18	0.02	0.16	0.07	0.08	0.55	7.09	0.06	C1-S1	Low salinity
	IR3	1.40	0.09	0.41	0.38	0.05	1.61	0.02	0.16	2.22	7.35	0.27	C2-S1	Medium salinity
	IR4	2.25	0.09	0.54	0.25	0.06	2.71	0.02	0.28	3.58	7.19	0.38	C2-S1	Medium salinity
Jun. 2013	IR1	0.13	0.04	0.10	0.15	0.00	0.24	0.02	0.04	0.37	7.31	0.09	C1-S1	Low salinity
	IR2	0.19	0.04	0.11	0.15	0.00	0.13	0.02	0.05	0.54	7.01	0.06	C1-S1	Low salinity
	IR3	0.20	0.05	0.12	0.16	0.00	0.28	0.02	0.07	0.53	7.32	0.09	C1-S1	Low salinity
	IR4	0.17	0.04	0.10	0.15	0.00	0.17	0.02	0.05	0.47	7.16	0.07	C1-S1	Low salinity
Sep. 2013	IR1	0.41	0.15	0.16	0.25	0.03	0.52	0.00	0.10	0.89	7.24	0.11	C1-S1	Low salinity
	IR2	0.48	0.12	0.16	0.19	0.01	0.55	0.00	0.10	1.16	7.20	0.11	C1-S1	Low salinity
	IR3	0.32	0.21	0.10	0.17	0.04	0.37	0.00	0.13	0.86	7.14	0.10	C1-S1	Low salinity
	IR4	2.54	0.19	0.60	0.32	0.08	3.17	0.00	0.32	3.74	7.15	0.45	C2-S1	Medium salinity

IR1, IR2, IR3 and IR4 located at Dien Hong river, primary Bao Kho river section adjacent plot of QD17, primary Bao Kho river section near plot of QD18, and canal adjacent plot of QD19, respectively.

† SAR: Sodium adsorption ratio

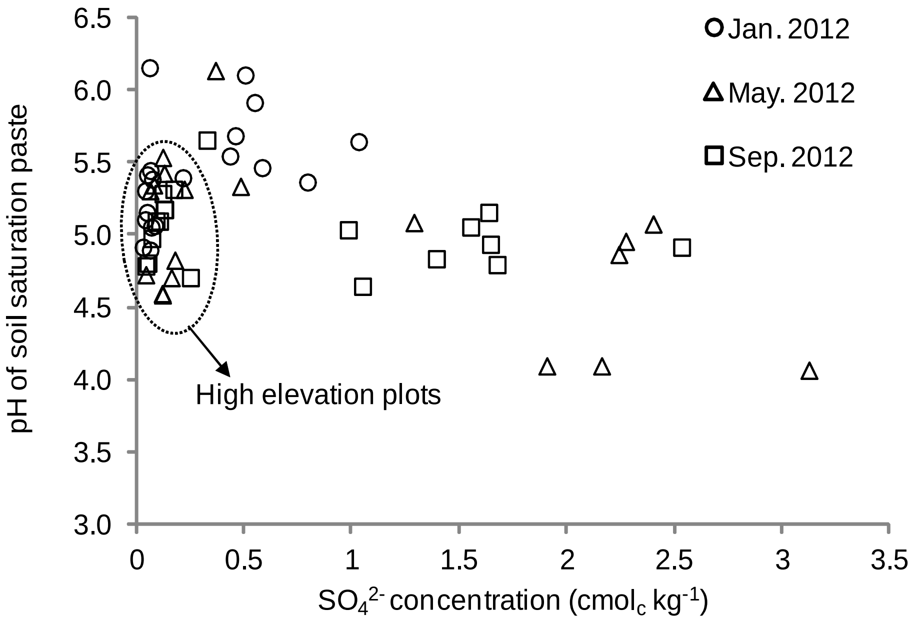
†† United States Salinity Laboratory Staff (1954)

3.3.2 Topography

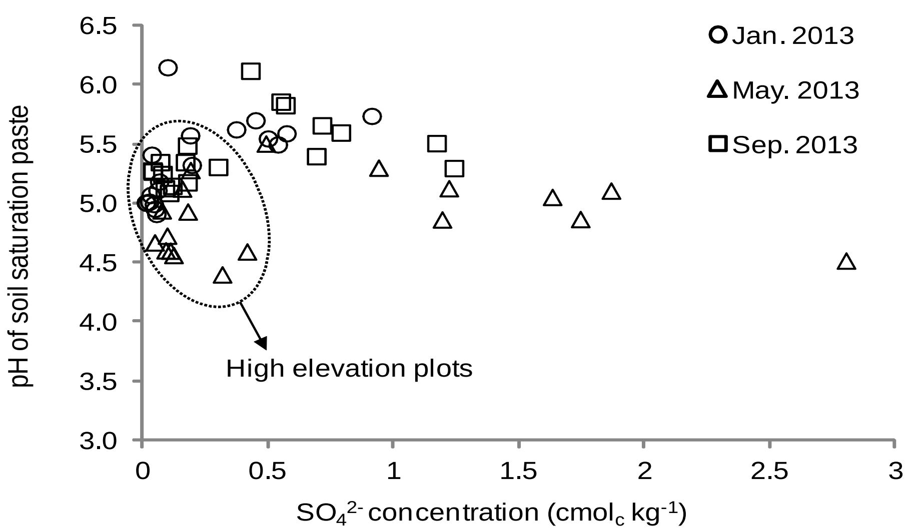
Based on the values of relative elevations and ECe of 19 representative plots (Table 3.2), the research site can be divided into low and high–elevation plots. Soils that have ECe larger than 1.9 dS m^{-1} in at least one of the samples were in the low–elevation plots. In contrast, soils that have ECe smaller than 1.9 dS m^{-1} in all the samples were in the high–elevation plots. ECe of 1.9 dS m^{-1} was used for the division, because rice growth starts to be influenced when ECe is larger than 1.9 dS m^{-1} (Grattan et al., 2002). The low–elevation plots were the central part of the research site (QD2, 3, 4, and 5), along the lagoon (QD1, 6 and 14) and along secondary Bao Kho river (QD17 and 19), while the other surrounds the two main irrigation rivers of IR1 and IR2 (QD7, 8, 9, 10, 11, 12, 13, 15, 16, and 18) (Fig. 2.1). However, the difference between the high and low–elevation plots was not large; relative elevation in the low–elevation plots was between –0.52 and 0.07 m, and that in the high–elevation plots was between 0.26 and 0.86 m.

3.3.3 Physicochemical properties of soils

The physicochemical properties of soils (Tables 2.1 and 3.2 to 3.4 and Figs. 3.1 to 3.3) showed that fertility of these soils was very low, indicating that they were not suitable for rice growth. In the low–elevation plots, pHe in May and September were much lower than in January; that may be because SO_4^{2-} concentration in the May and September was higher than that of January (Fig. 3.1). While in the high–elevation plots, pHe was stable throughout the seasons; that may be because of SO_4^{2-} concentration was small and stable from January to September (Fig. 3.1). The dominant water–soluble cation was Na^{+}, followed by Ca^{2+} and Mg^{2+} (Table 3.4). Water–soluble cations of K^{+} and NH_4^{+} were present in negligible concentrations (Table 3.4). The dominant water–soluble anion was Cl^{-}, followed by SO_4^{2-} (Table 3.4), while NO_3^{-} was present in negligible concentrations (Table 3.4). Because an increase in ECe and total soluble cations coincided with an increase in SAR (Fig. 3.2), Na^{+} was considered to be mainly responsible for salt accumulation in the surface paddy soils (Funakawa and Kosaki 2007 and Funakawa et al., 2000). Moreover, a high significant positive correlation between Na^{+} and Cl^{-} (Fig. 3.3) indicated the influence of NaCl from seawater on EC and total salt content (Haruyama et al., 2006). There were no correlations between ECe and pH, clay content, CEC, total C, and total N.

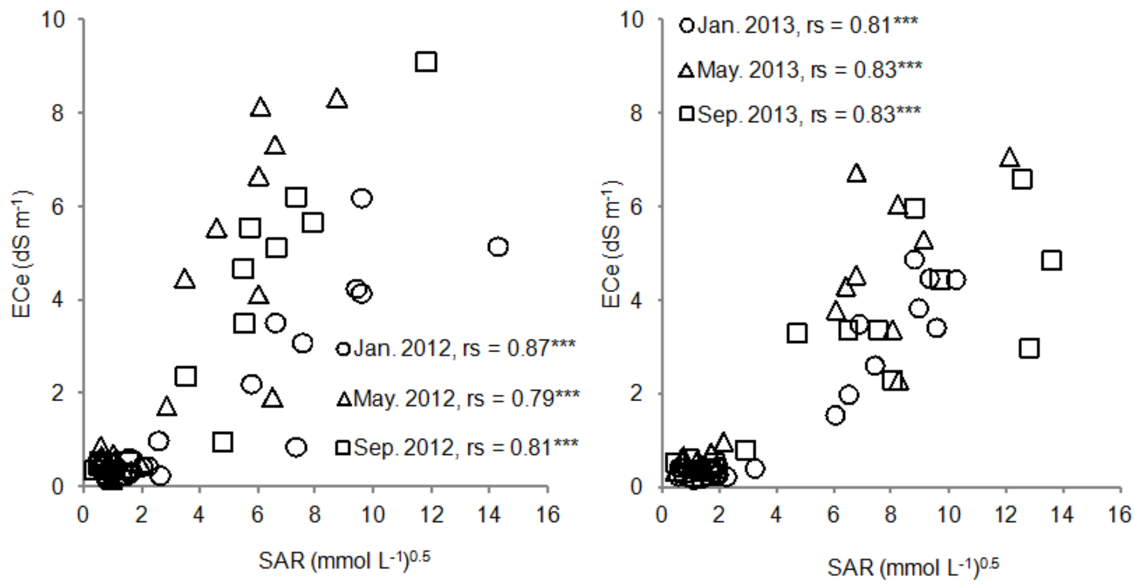


(a)



(b)

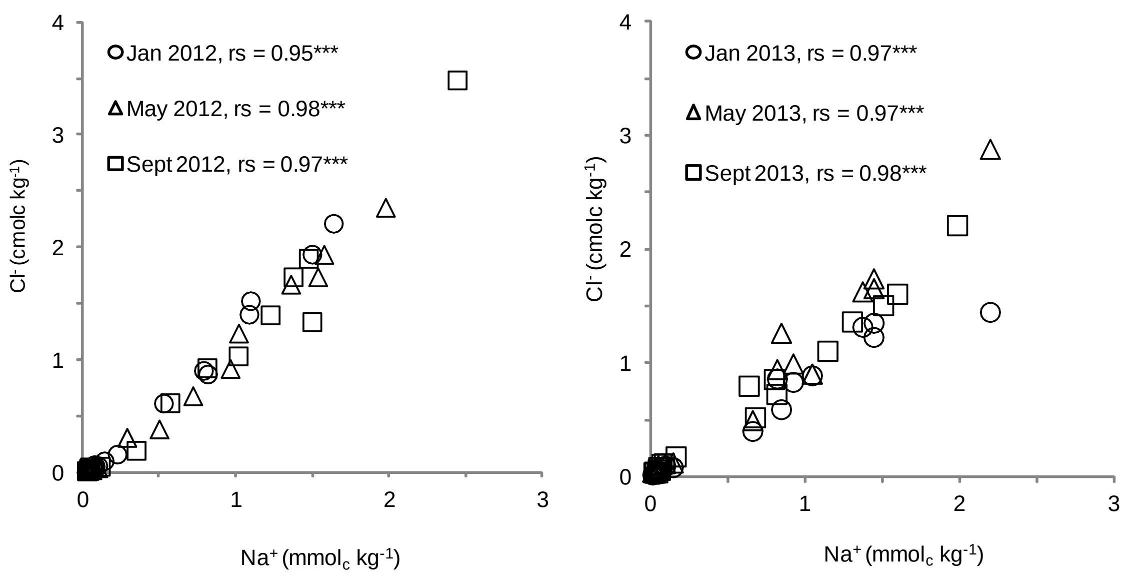
Fig. 3.1: Relationship between pH of soil saturation paste and SO_4^{2-} concentration in (a) 2012 and (b) 2013



(a) (b)

Fig, 3.2: Relationship between electrical conductivity of soil saturation paste and sodium adsorption ratio in (a) 2012 and (b) 2013

*** means the significant level at 0.001



(a) (b)

Fig, 3.3: Relationship between water soluble cation of Na^{+} and anion of Cl^{-} in (a) 2012 and (b) 2013

*** means the significant level at 0.001

Table 3.2: Relative elevation to QD1, electrical conductivity of saturation paste and sodium adsorption ratio of surface soils (0 – 20 cm) from the 19 plots in the study area

Plots		Relative elevation to QD1	ECe (dS m^{-1})						SAR[†] (mmol $L^{-1})^{0.5}$					
			Jan	May	Sep	Jan	May	Sep	Jan	May	Sep	Jan	May	Sep
		(m)	2012			2013			2012			2013		
Low elevation plots	QD3	-0.52	4.26	4.14	4.69	4.48	7.08	6.60	9.41	6.03	5.50	9.30	12.11	12.53
	QD5	-0.44	2.22	4.49	3.51	2.62	3.81	3.38	5.78	3.48	5.52	7.39	6.02	6.45
	QD2	-0.41	4.16	6.68	5.13	3.84	6.06	4.45	9.58	6.03	6.63	8.92	8.19	9.68
	QD4	-0.41	5.16	8.35	9.11	4.45	5.31	4.86	14.31	8.74	11.81	10.23	9.09	13.57
	QD6	-0.35	3.53	5.57	5.68	3.50	4.32	3.39	6.62	4.58	7.89	6.84	6.37	7.48
	QD14	-0.14	3.10	7.34	5.57	3.43	4.56	3.31	7.55	6.60	5.72	9.54	6.73	4.66
	QD19	-0.02	1.01	1.75	2.39	2.00	3.39	2.31	2.57	2.86	3.52	6.47	8.00	7.98
	QD1	0.00	6.20	8.16	6.23	4.89	6.74	5.99	9.59	6.10	7.31	8.77	6.74	8.77
	QD17	0.07	0.87	1.94	0.98	1.56	2.32	2.99	7.32	6.51	4.79	6.00	8.23	12.79
High elevation plots	QD16	0.26	0.46	0.54	0.58	0.42	1.00	0.82	2.20	1.93	1.53	3.18	2.09	2.85
	QD18	0.26	0.45	0.72	0.37	0.46	0.76	0.56	2.02	1.02	1.05	1.88	1.64	1.75
	QD15	0.28	0.26	0.40	0.53	0.32	0.52	0.43	2.63	1.34	0.76	1.89	1.28	1.57
	QD7	0.37	0.27	0.57	0.24	0.18	0.56	0.40	1.43	1.04	0.85	1.05	1.13	1.30
	QD8	0.42	0.25	0.49	0.30	0.20	0.42	0.24	0.75	0.53	0.80	1.29	0.99	1.04
	QD9	0.73	0.31	0.18	0.26	0.25	0.37	0.26	1.57	0.96	1.27	2.20	1.42	1.64
	QD10	0.75	0.34	0.89	0.47	0.45	0.69	0.62	0.90	0.57	0.52	0.75	0.67	0.90
	QD11	0.81	0.64	0.68	0.56	0.44	0.63	0.55	1.57	0.60	0.55	0.52	0.62	0.40
	QD13	0.84	0.36	0.39	0.37	0.28	0.44	0.42	0.77	0.74	0.71	1.90	1.34	1.83
	QD12	0.86	0.35	0.41	0.38	0.25	0.37	0.33	1.64	0.68	0.36	0.49	0.39	0.71

[†] SAR is sodium adsorption ratio

Table 3.3: pH of surface soils (0 – 20 cm) from the 19 plots in the study area

Plots		H_2O						KCl						Saturation paste					
		Jan	May	Sep	Jan	May	Sep	Jan	May	Sep	Jan	May	Sep	Jan	May	Sep	Jan	May	Sep
		2012			2013			2012			2013			2012			2013		
Low	QD3	6.1	5.5	5.2	6.3	5.5	5.8	5.3	4.6	4.4	5.3	4.9	5.0	5.5	5.1	4.8	5.5	5.1	5.6
elevation	QD5	6.0	4.6	5.4	6.3	5.3	5.6	5.2	3.8	4.5	5.3	4.6	4.6	5.6	4.1	5.0	5.6	5.3	5.4
plots	QD2	6.2	5.1	5.3	6.2	5.1	5.9	5.4	4.5	4.4	5.2	4.6	5.0	5.7	4.9	4.9	5.6	4.9	5.7
	QD4	6.1	5.2	5.3	6.4	5.5	6.1	5.8	4.4	4.6	5.4	4.8	5.2	6.1	5.0	5.1	5.6	5.1	5.9
	QD6	5.8	4.5	5.2	6.4	5.2	5.7	5.1	3.8	4.4	5.5	4.6	4.8	5.4	4.1	4.8	5.5	4.9	5.5
	QD14	6.4	5.3	5.1	6.5	5.4	5.3	5.6	4.6	4.4	5.4	4.8	4.5	5.9	5.1	4.9	5.7	5.1	5.3
	QD19	5.9	5.7	5.1	6.2	4.8	5.5	4.9	4.6	4.2	4.7	4.2	4.5	5.4	5.3	4.7	5.3	4.6	5.3
	QD1	6.0	4.3	5.3	6.6	4.7	6.0	5.4	4.0	4.7	5.7	4.3	5.3	5.7	4.1	5.2	5.7	4.5	5.8
	QD17	6.6	6.4	6.1	7.3	5.9	6.4	5.2	5.0	5.0	5.7	4.9	5.0	6.2	6.1	5.7	6.1	5.5	6.1
High	QD16	5.3	5.3	5.1	6.0	4.6	5.1	4.3	4.1	4.0	4.5	3.9	4.1	5.1	4.8	4.7	5.1	4.4	5.2
elevation	QD18	5.7	5.6	5.6	5.8	5.2	5.1	4.6	4.4	4.3	4.5	4.3	4.1	5.1	5.4	5.2	5.0	4.9	5.1
plots	QD15	5.4	5.1	5.3	5.6	4.8	5.1	4.3	4.0	3.9	4.3	4.0	4.1	4.9	4.6	4.8	4.9	4.6	5.1
	QD7	5.4	5.1	5.5	5.7	4.9	5.2	4.4	4.0	4.0	4.4	4.1	4.1	5.2	4.7	5.0	5.0	4.6	5.2
	QD8	5.6	5.2	5.5	5.7	5.0	5.3	4.4	4.0	4.2	4.3	4.1	4.1	4.9	4.6	5.1	5.0	4.7	5.3
	QD9	5.3	5.0	5.1	5.6	4.9	5.1	4.3	3.8	3.9	4.3	4.0	4.0	5.1	4.7	4.8	5.0	4.7	5.3
	QD10	6.0	5.5	5.1	6.1	5.4	5.4	4.7	4.3	4.3	4.8	4.4	4.3	5.3	5.3	5.3	5.4	5.3	5.5
	QD11	6.1	5.9	5.5	6.0	5.3	5.3	4.9	4.4	4.2	4.6	4.3	4.1	5.4	5.5	5.3	5.2	5.1	5.3
	QD13	5.8	5.6	5.4	5.6	4.9	5.1	4.5	4.1	4.1	4.2	4.0	4.1	5.5	5.4	5.1	5.0	4.6	5.1
	QD12	5.9	5.6	5.6	5.8	5.1	5.3	4.6	4.2	4.3	4.3	4.1	4.0	5.4	5.3	5.2	5.1	4.9	5.3

Table 3.4: Water soluble cations and anions of surface soils (0 – 20 cm) from the 19 plots in the study area

Plots		Water soluble cations ($cmol_c\ kg^{-1}$)											
		Na^+						K^+					
		Jan	May	Sep	Jan	May	Sep	Jan	May	Sep	Jan	May	Sep
		2012			2013			2012			2013		
Low elevation plots	QD3	1.08	0.96	1.01	1.18	2.20	1.99	0.03	0.03	0.02	0.03	0.06	0.04
	QD5	0.52	0.72	0.81	0.70	0.82	0.80	0.02	0.01	0.02	0.02	0.05	0.02
	QD2	1.09	1.35	1.22	0.97	1.45	1.31	0.03	0.04	0.04	0.03	0.07	0.08
	QD4	1.63	1.97	2.44	1.20	1.37	1.60	0.08	0.05	0.05	0.03	0.06	0.05
	QD6	0.78	1.01	1.47	0.75	0.93	1.15	0.02	0.01	0.03	0.02	0.03	0.04
	QD14	0.81	1.53	1.49	0.98	1.05	0.68	0.03	0.03	0.03	0.03	0.03	0.03
	QD19	0.14	0.28	0.57	0.43	0.85	0.64	0.01	0.01	0.02	0.01	0.02	0.01
	QD1	1.49	1.57	1.37	1.21	1.45	1.51	0.05	0.05	0.04	0.06	0.07	0.07
	QD17	0.22	0.50	0.35	0.27	0.66	0.82	0.01	0.01	0.01	0.01	0.02	0.01
High elevation plots	QD16	0.08	0.10	0.11	0.09	0.15	0.17	0.00	0.00	0.00	0.00	0.01	0.01
	QD18	0.07	0.07	0.06	0.08	0.10	0.09	0.00	0.01	0.00	0.01	0.01	0.01
	QD15	0.07	0.06	0.02	0.05	0.06	0.06	0.02	0.00	0.01	0.01	0.01	0.01
	QD7	0.04	0.06	0.03	0.03	0.05	0.05	0.00	0.01	0.00	0.00	0.01	0.01
	QD8	0.02	0.03	0.03	0.04	0.04	0.03	0.00	0.00	0.00	0.00	0.01	0.00
	QD9	0.05	0.03	0.05	0.05	0.04	0.05	0.00	0.01	0.00	0.00	0.01	0.00
	QD10	0.04	0.05	0.04	0.04	0.04	0.05	0.00	0.01	0.00	0.01	0.01	0.01
	QD11	0.10	0.04	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.00
	QD13	0.03	0.03	0.04	0.06	0.05	0.08	0.01	0.01	0.00	0.00	0.01	0.01
	QD12	0.06	0.03	0.02	0.02	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.4: Continued

Plots		Water soluble cations ($cmol_c\ kg^{-1}$)											
		Mg^{2+}						Ca^{2+}					
		Jan	May	Sep	Jan	May	Sep	Jan	May	Sep	Jan	May	Sep
		2012			2013			2012			2013		
Low elevation plots	QD3	0.31	0.52	0.60	0.39	0.85	0.60	0.25	0.56	0.77	0.34	0.61	0.49
	QD5	0.21	0.78	0.45	0.19	0.46	0.37	0.16	1.01	0.38	0.22	0.40	0.32
	QD2	0.32	0.98	0.76	0.32	0.77	0.47	0.26	1.12	0.64	0.22	0.65	0.32
	QD4	0.43	1.11	1.00	0.38	0.57	0.40	0.16	1.01	0.69	0.24	0.45	0.22
	QD6	0.35	1.00	0.78	0.31	0.53	0.57	0.27	1.09	0.55	0.24	0.43	0.48
	QD14	0.28	1.03	0.96	0.24	0.50	0.46	0.23	1.26	1.31	0.25	0.60	0.48
	QD19	0.05	0.15	0.33	0.10	0.26	0.14	0.08	0.29	0.48	0.11	0.24	0.15
	QD1	0.62	1.41	0.81	0.53	0.97	0.71	0.44	1.43	0.68	0.36	1.05	0.61
	QD17	0.02	0.13	0.08	0.06	0.17	0.12	0.02	0.11	0.08	0.04	0.11	0.06
High elevation plots	QD16	0.02	0.05	0.07	0.02	0.09	0.06	0.04	0.06	0.10	0.02	0.13	0.08
	QD18	0.02	0.08	0.04	0.03	0.05	0.04	0.04	0.12	0.06	0.05	0.11	0.07
	QD15	0.01	0.02	0.01	0.01	0.03	0.02	0.02	0.05	0.02	0.02	0.07	0.05
	QD7	0.01	0.04	0.01	0.01	0.03	0.02	0.03	0.09	0.04	0.02	0.07	0.05
	QD8	0.01	0.03	0.02	0.01	0.02	0.01	0.03	0.08	0.04	0.03	0.05	0.03
	QD9	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.03	0.02	0.03	0.02
	QD10	0.02	0.05	0.03	0.02	0.03	0.03	0.06	0.24	0.14	0.10	0.15	0.14
	QD11	0.03	0.03	0.04	0.02	0.03	0.03	0.13	0.19	0.17	0.09	0.10	0.13
	QD13	0.01	0.02	0.02	0.01	0.01	0.02	0.04	0.06	0.07	0.03	0.05	0.06
	QD12	0.01	0.02	0.02	0.01	0.01	0.01	0.05	0.08	0.11	0.05	0.06	0.06

Table 3.4: Continued

Plots		Water soluble cations (cmol$_c$ kg^{-1})						Water soluble anions (cmol$_c$ kg^{-1})					
		NH_4^+						NO_3^-					
		Jan	May	Sep	Jan	May	Sep	Jan	May	Sep	Jan	May	Sep
		2012			2013			2012			2013		
Low elevation plots	QD3	0.06	0.05	0.03	0.06	0.06	0.05	0.01	0.00	0.00	0.01	0.01	0.00
	QD5	0.04	0.05	0.03	0.04	0.04	0.02	0.04	0.00	0.00	0.01	0.01	0.00
	QD2	0.05	0.03	0.02	0.05	0.05	0.04	0.02	0.00	0.00	0.01	0.01	0.00
	QD4	0.05	0.17	0.03	0.06	0.04	0.04	0.01	0.00	0.00	0.01	0.01	0.00
	QD6	0.04	0.03	0.02	0.04	0.03	0.04	0.01	0.00	0.00	0.01	0.01	0.00
	QD14	0.07	0.03	0.03	0.08	0.04	0.03	0.03	0.00	0.00	0.00	0.00	0.00
	QD19	0.01	0.02	0.02	0.04	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00
	QD1	0.05	0.03	0.01	0.06	0.04	0.05	0.02	0.00	0.00	0.01	0.01	0.00
	QD17	0.01	0.02	0.02	0.03	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.00
High elevation plots	QD16	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.00	0.00	0.00	0.00	0.00
	QD18	0.02	0.02	0.01	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00
	QD15	0.03	0.01	0.00	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	QD7	0.02	0.01	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
	QD8	0.02	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.01	0.00	0.00
	QD9	0.01	0.01	0.01	0.02	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.01
	QD10	0.01	0.03	0.03	0.04	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.00
	QD11	0.03	0.03	0.02	0.03	0.07	0.02	0.00	0.00	0.01	0.00	0.00	0.00
	QD13	0.03	0.03	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	QD12	0.02	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.4: Continued

Plots		Water soluble anions ($cmol_c\ kg^{-1}$)											
		Cl^-						SO_4^{2-}					
		Jan	May	Sep	Jan	May	Sep	Jan	May	Sep	Jan	May	Sep
			2012			2013			2012			2013	
Low	QD3	1.41	0.92	1.04	1.44	2.88	2.20	0.58	1.29	1.68	0.54	1.87	0.79
elevation	QD5	0.62	0.68	0.93	0.86	0.94	0.85	0.43	1.91	0.98	0.19	0.94	0.69
plots	QD2	1.53	1.67	1.40	1.22	1.74	1.36	0.46	2.24	1.64	0.37	1.75	0.72
	QD4	2.21	2.36	3.49	1.31	1.62	1.60	0.51	2.27	1.55	0.58	1.22	0.55
	QD6	0.91	1.24	1.90	0.83	0.99	1.10	0.79	2.16	1.39	0.50	1.20	1.17
	QD14	0.88	1.74	1.34	0.89	0.90	0.52	0.55	2.40	2.53	0.45	1.63	1.24
	QD19	0.10	0.31	0.62	0.59	1.26	0.79	0.22	0.48	1.05	0.20	0.42	0.30
	QD1	1.94	1.94	1.74	1.35	1.65	1.50	1.03	3.12	1.64	0.91	2.80	0.57
	QD17	0.16	0.39	0.20	0.40	0.49	0.72	0.06	0.37	0.33	0.10	0.49	0.43
High	QD16	0.06	0.04	0.06	0.08	0.12	0.17	0.09	0.18	0.25	0.06	0.32	0.18
elevation	QD18	0.07	0.05	0.05	0.09	0.12	0.11	0.04	0.13	0.13	0.03	0.18	0.12
plots	QD15	0.04	0.02	0.01	0.04	0.08	0.06	0.06	0.12	0.04	0.06	0.13	0.11
	QD7	0.03	0.04	0.02	0.02	0.10	0.06	0.05	0.16	0.07	0.02	0.11	0.08
	QD8	0.05	0.02	0.02	0.04	0.06	0.03	0.03	0.12	0.09	0.02	0.10	0.04
	QD9	0.03	0.02	0.03	0.02	0.08	0.03	0.07	0.04	0.05	0.05	0.05	0.04
	QD10	0.04	0.06	0.02	0.03	0.07	0.08	0.04	0.22	0.17	0.04	0.19	0.18
	QD11	0.06	0.03	0.05	0.02	0.05	0.03	0.07	0.12	0.12	0.07	0.16	0.17
	QD13	0.03	0.02	0.04	0.03	0.06	0.11	0.06	0.08	0.11	0.05	0.09	0.09
	QD12	0.06	0.03	0.02	0.01	0.04	0.04	0.05	0.06	0.13	0.03	0.08	0.07

Table 3.4: Continued

Plots		Total cations ($cmol_c\ kg^{-1}$)						Total anions ($cmol_c\ kg^{-1}$)					
		Jan	May	Sep	Jan	May	Sep	Jan	May	Sep	Jan	May	Sep
			2012			2013			2012			2013	
Low	QD3	1.73	2.12	2.43	2.00	3.86	3.18	2.00	2.22	2.71	2.00	4.01	3.00
elevation	QD5	0.95	2.57	1.69	1.16	1.76	1.54	1.09	2.59	1.92	1.05	1.89	1.55
plots	QD2	1.74	3.53	2.69	1.60	2.99	2.22	2.01	3.92	3.05	1.61	3.49	2.08
	QD4	2.34	4.31	4.21	1.91	2.49	2.31	2.73	4.63	5.04	1.90	2.85	2.16
	QD6	1.48	3.14	2.86	1.36	1.95	2.28	1.72	3.40	3.30	1.34	2.19	2.27
	QD14	1.42	3.88	3.82	1.58	2.21	1.68	1.46	4.14	3.87	1.34	2.54	1.76
	QD19	0.29	0.75	1.41	0.69	1.40	0.96	0.32	0.80	1.67	0.79	1.54	1.10
	QD1	2.66	4.50	2.91	2.22	3.57	2.94	2.99	5.06	3.38	2.27	3.92	2.07
	QD17	0.28	0.77	0.54	0.41	0.99	1.05	0.23	0.75	0.53	0.50	0.99	1.15
High	QD16	0.15	0.21	0.29	0.15	0.39	0.33	0.18	0.22	0.31	0.14	0.44	0.35
elevation	QD18	0.15	0.31	0.18	0.19	0.29	0.23	0.12	0.18	0.18	0.12	0.30	0.23
plots	QD15	0.14	0.15	0.07	0.12	0.18	0.16	0.11	0.15	0.06	0.10	0.20	0.16
	QD7	0.10	0.21	0.10	0.08	0.17	0.14	0.08	0.20	0.09	0.04	0.21	0.14
	QD8	0.09	0.16	0.12	0.09	0.13	0.08	0.08	0.14	0.12	0.06	0.16	0.07
	QD9	0.11	0.08	0.11	0.09	0.12	0.10	0.10	0.06	0.09	0.07	0.13	0.08
	QD10	0.13	0.37	0.24	0.20	0.26	0.26	0.09	0.28	0.19	0.07	0.27	0.26
	QD11	0.30	0.30	0.27	0.18	0.23	0.20	0.14	0.16	0.19	0.09	0.22	0.20
	QD13	0.11	0.15	0.15	0.11	0.14	0.17	0.09	0.11	0.15	0.08	0.16	0.20
	QD12	0.14	0.16	0.16	0.10	0.10	0.11	0.11	0.09	0.15	0.05	0.12	0.11

3.3.4 Spatiotemporal variability of salinity

The spatial variability in ECe in the surface soils is shown in Table 3.2, Figs. 3.4 and 3.5, and temporal variability are shown in Table 3.2, Figs. 3.4 to 3.6. ECe and total soluble cation concentrations were high at low–elevation plots (Tables 3.2 and 3.4 and Fig. 3.4). Compared with the high–elevation plots, ECe and ECw in the low–elevation plots were much higher. At the high–elevation plots, ECe was less than 1.0 dS m^{-1}. At the low–elevation plots (except for soils at QD17 in January 2012 and 2013 and September 2012, QD19 in January and May 2012), ECe was larger than the threshold for rice growth of 1.9 dS m^{-1} (Grattan et al., 2002). ECw in high and low–elevation plots increased gradually from January to September, though the increase was slight in the high–elevation plots (Fig. 3.6).

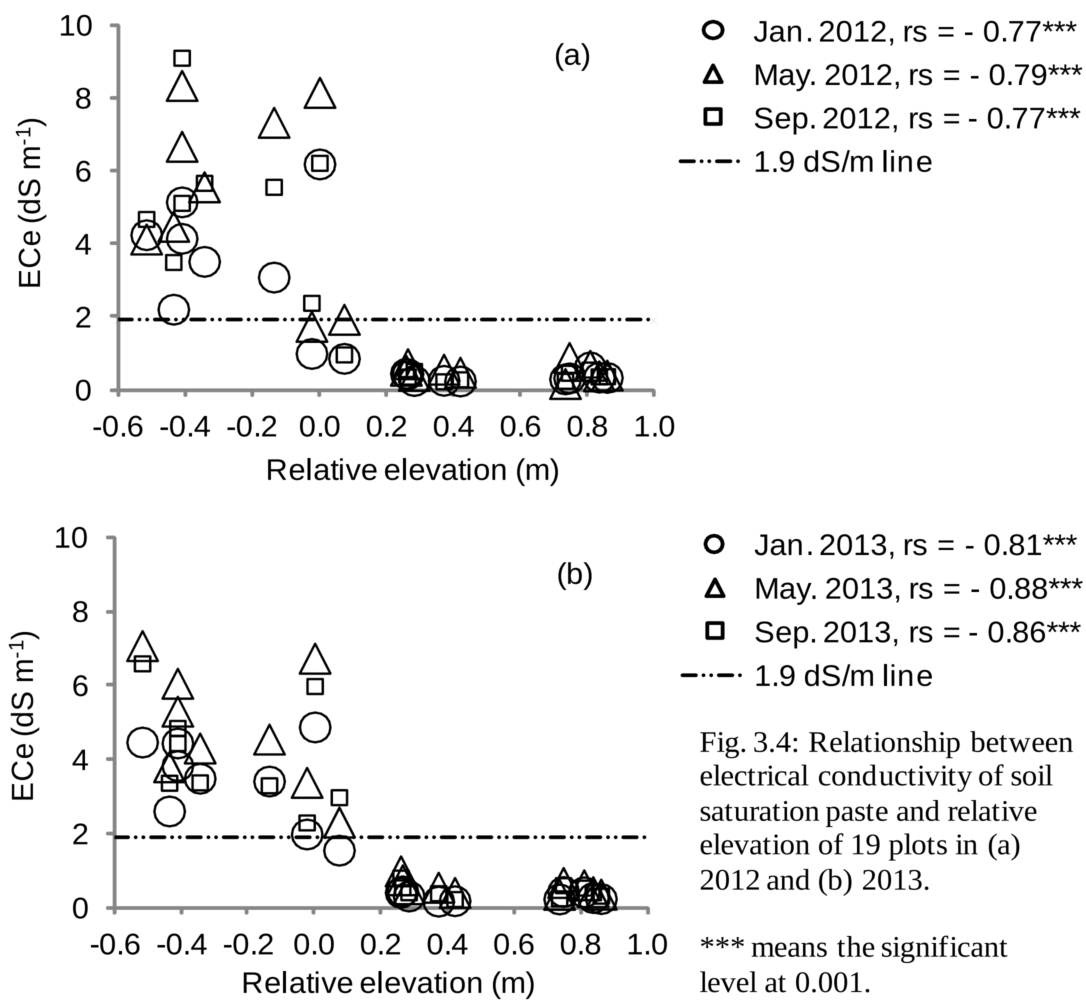
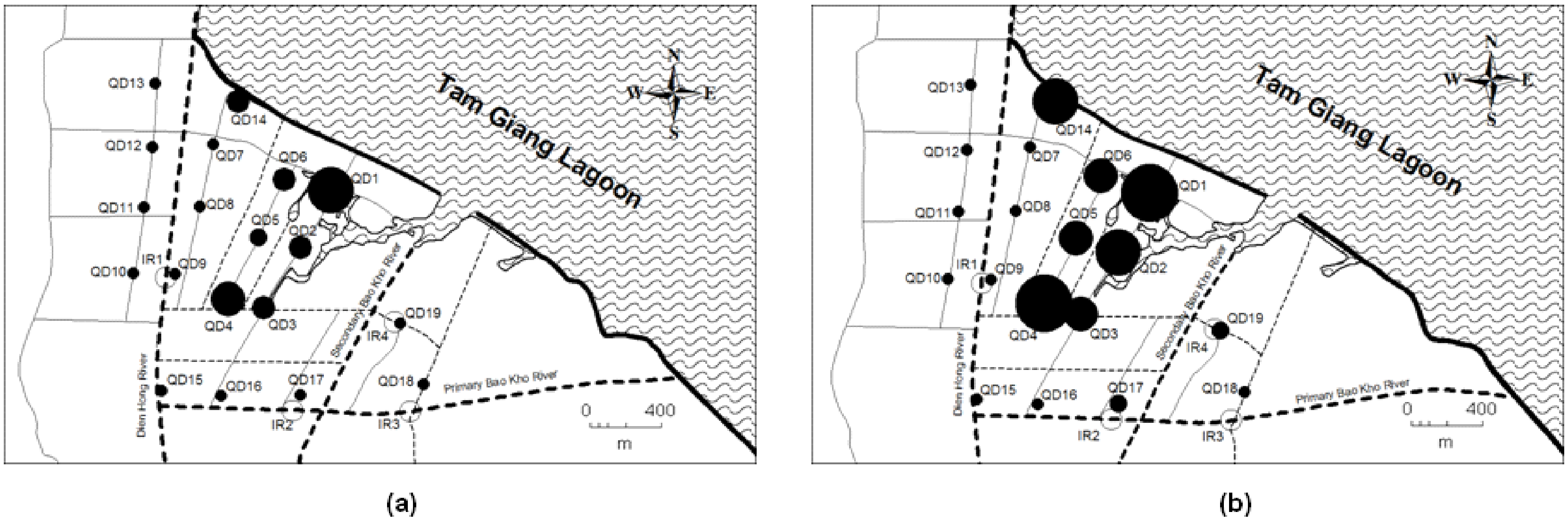


Fig. 3.4: Relationship between electrical conductivity of soil saturation paste and relative elevation of 19 plots in (a) 2012 and (b) 2013.

*** means the significant level at 0.001.



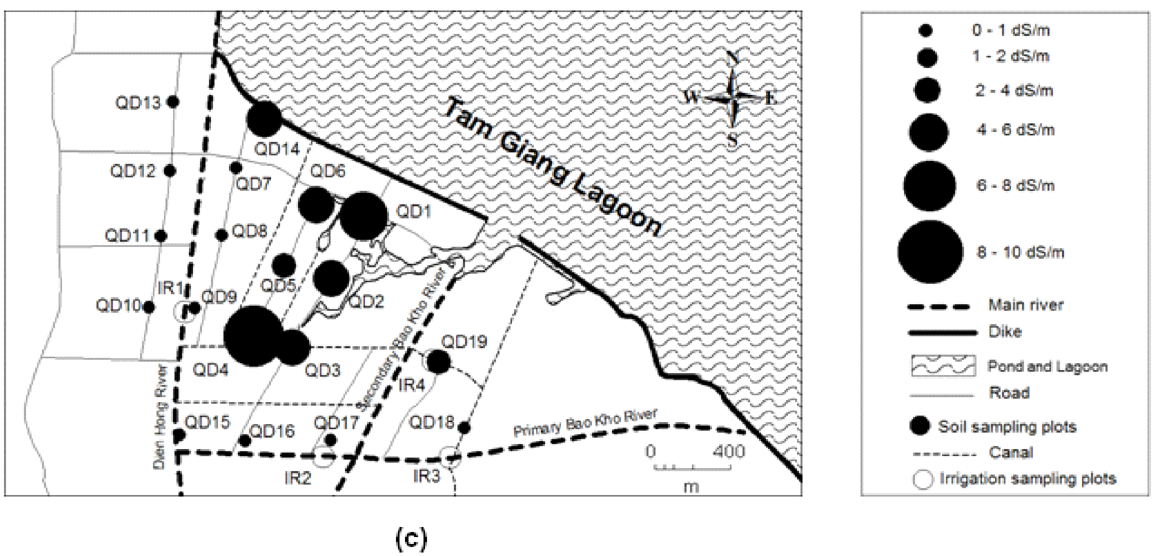


Fig. 3.5: Distribution of electrical conductivity of soil saturation paste in (a) January, (b) May, and (c) September in 2012.

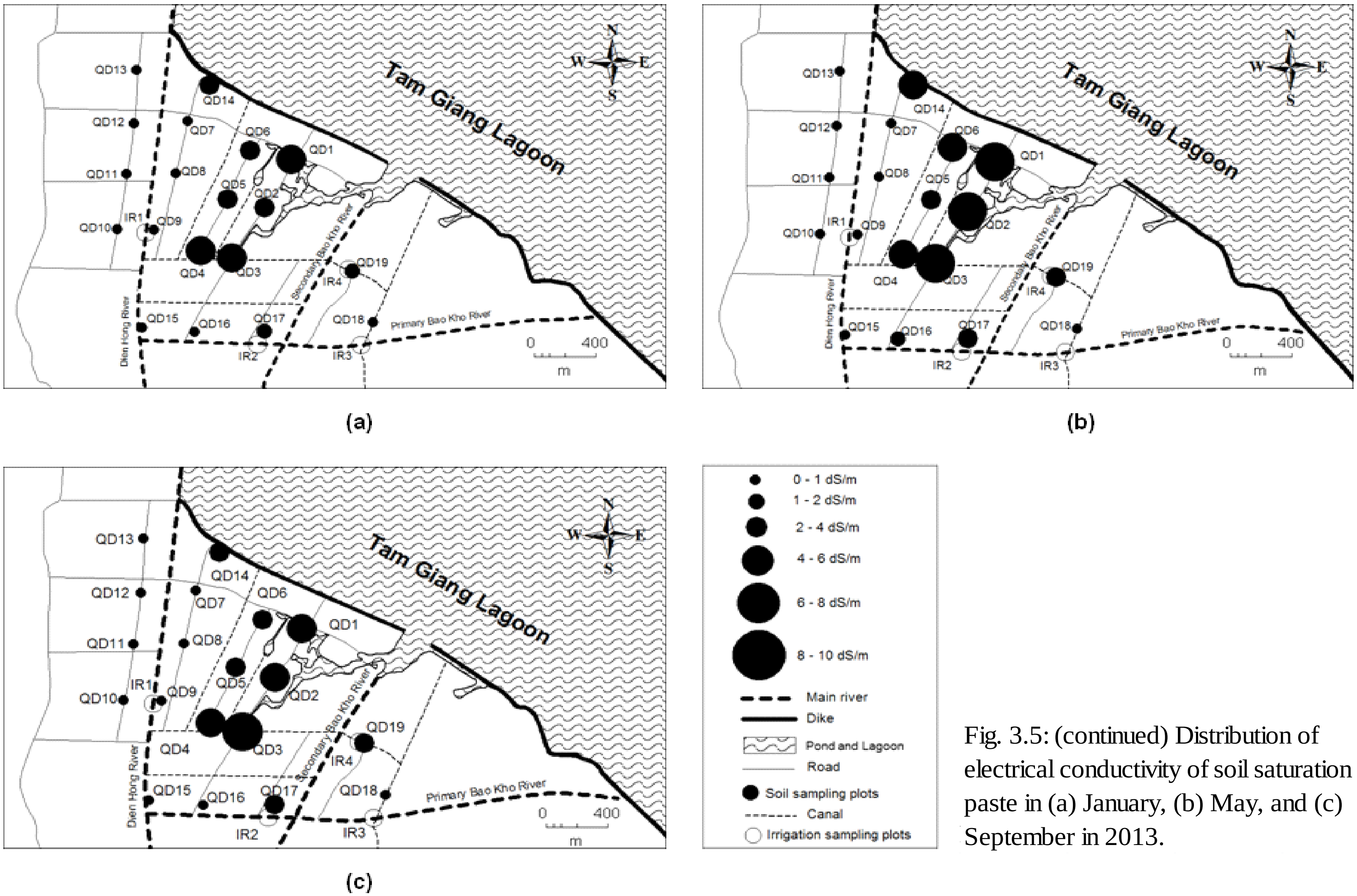


Fig. 3.5: (continued) Distribution of electrical conductivity of soil saturation paste in (a) January, (b) May, and (c) September in 2013.

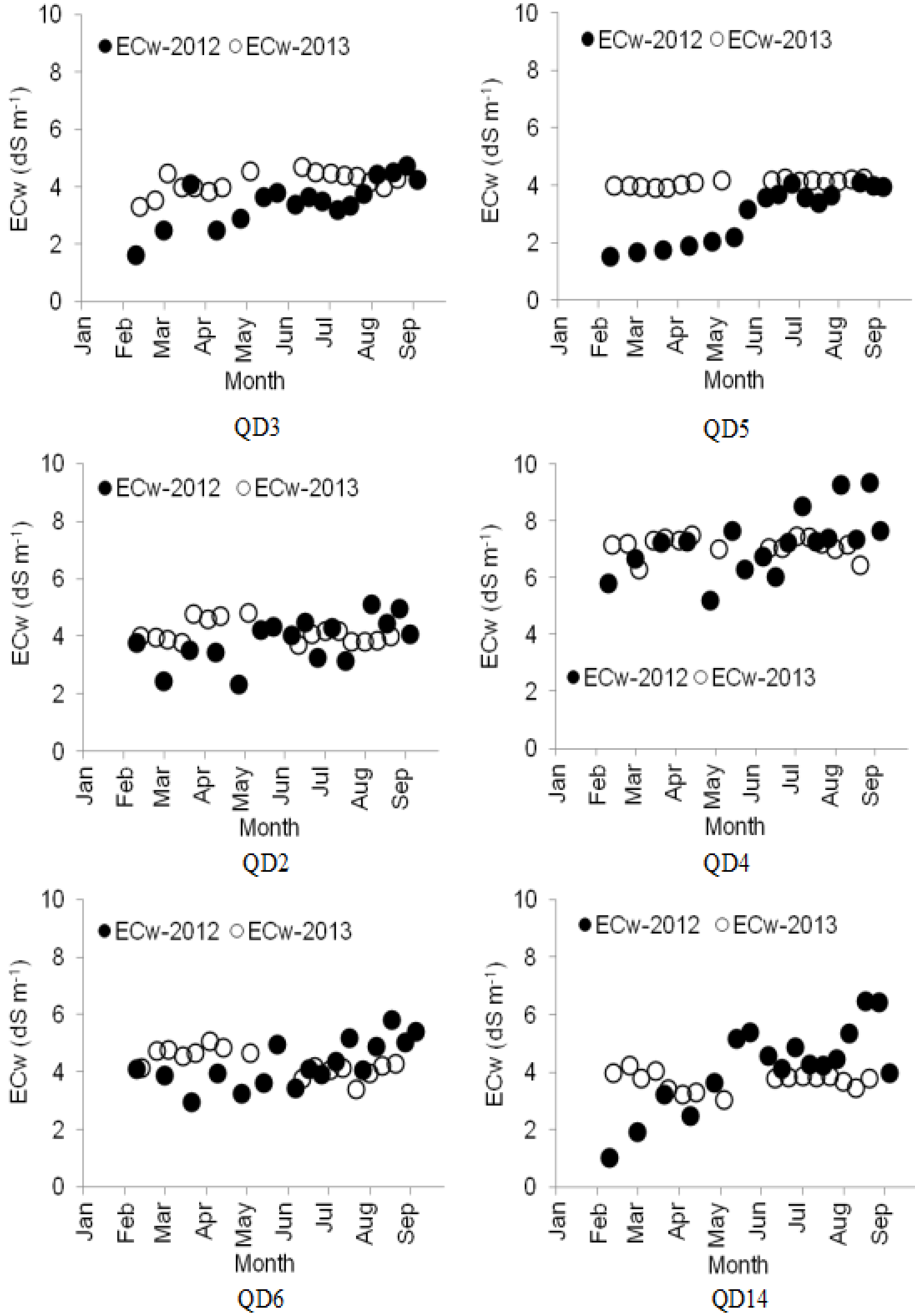
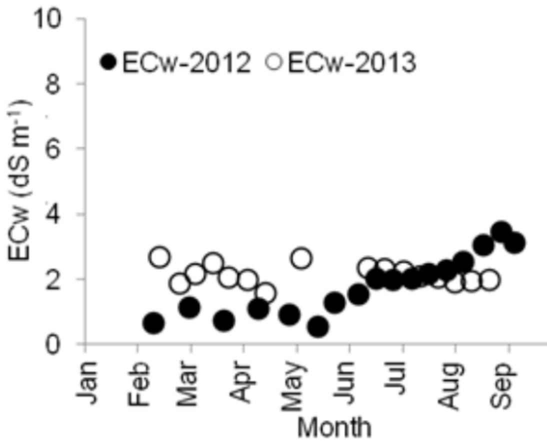
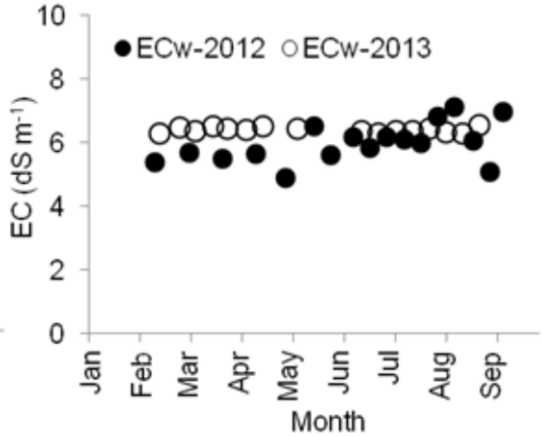


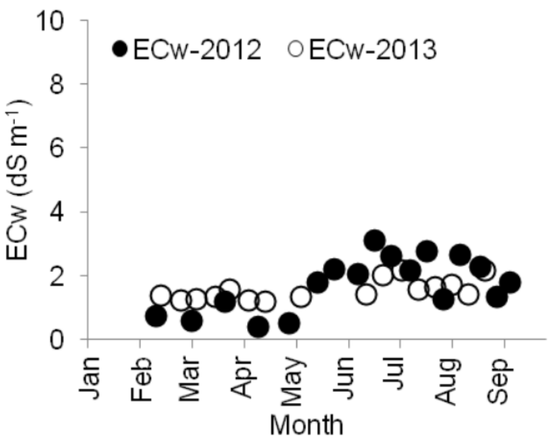
Fig. 3.6: Temporal variability of electrical conductivity of soil solution throughout the year at the low elevation plots



QD19

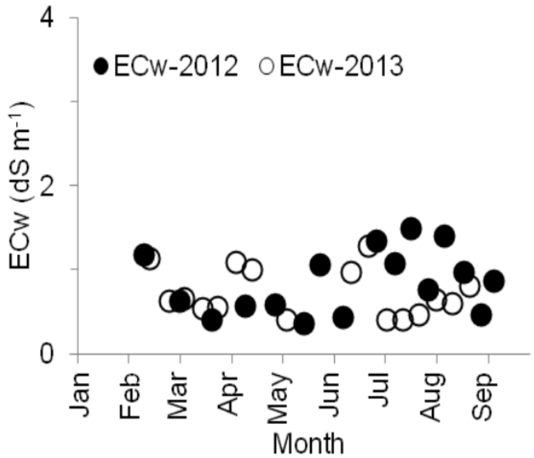


QD1

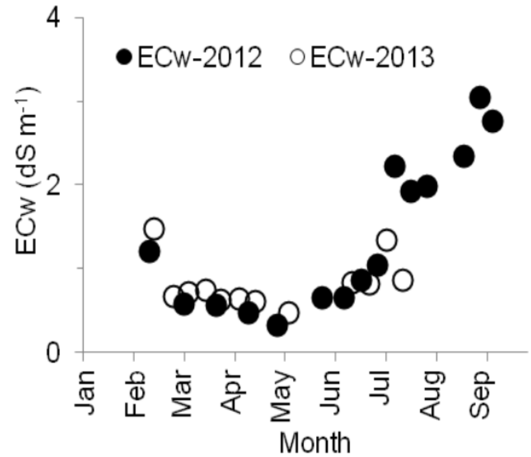


QD17

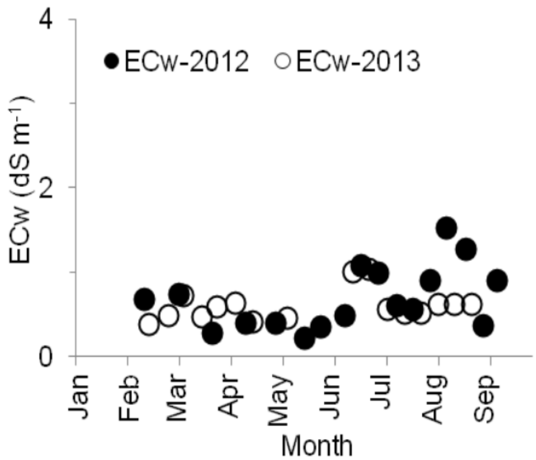
Fig. 3.6: Continued



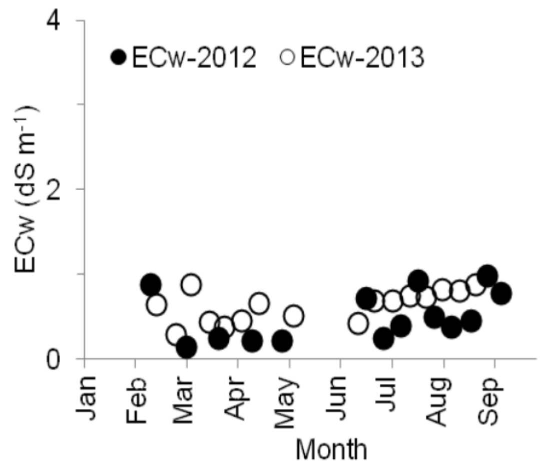
QD18



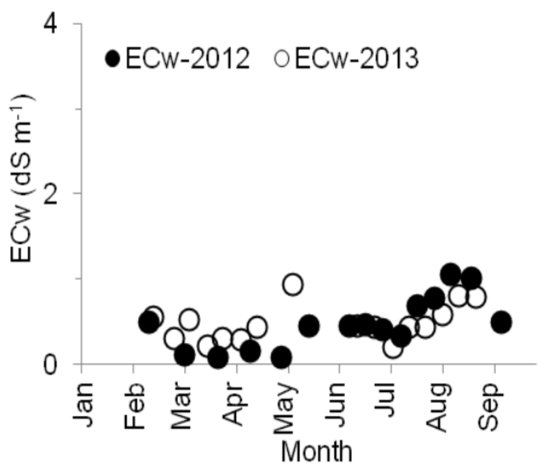
QD16



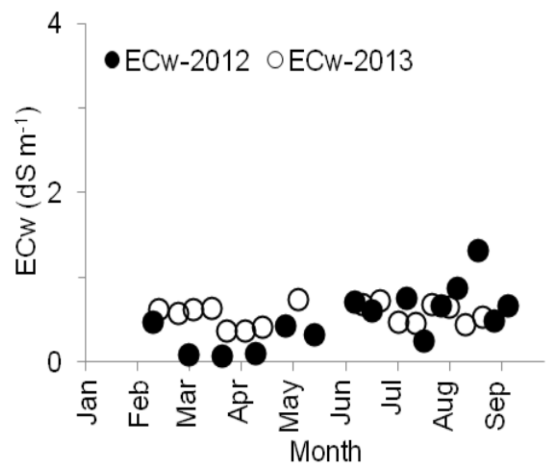
QD15



QD7



QD8



QD9

Fig. 3.7: Temporal variability of electrical conductivity of soil solution throughout the year at the high elevation plots

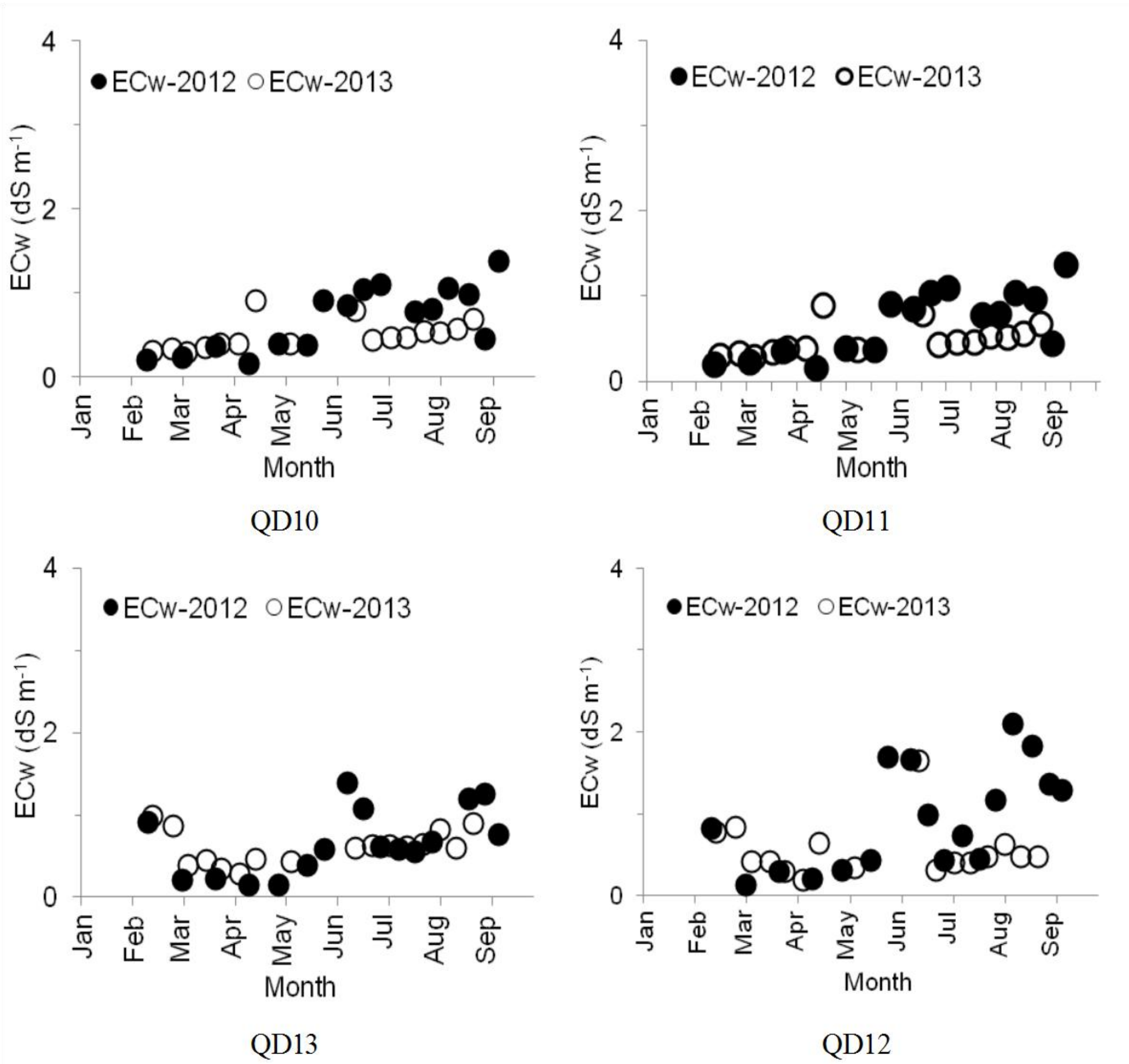


Fig. 3.7: Continued

3.3.5 Influences of soil salinity on rice yield

The relationship between rice yield m^{-2} and ECe is shown in Fig. 3.8. The results demonstrate that rice yield in summer–autumn cropping was significantly negatively correlated with ECe ($rs = -0.51$, $P < 0.05$), while a non–significant correlation was observed in winter–spring cropping. There was non–significant correlation between yield and elevation, pH, clay content, CEC, total C, and total N content. Fig. 3.8 also shows that rice yields in winter–spring cropping were much higher than in summer–autumn cropping.

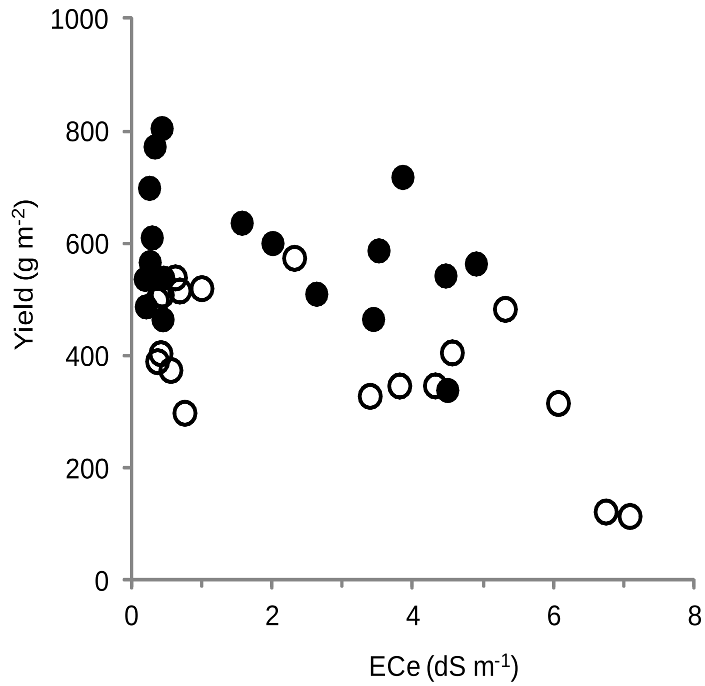


Fig. 3.8: Relationship between rice yield m^{-2} and electrical conductivity of soil saturation paste.

* means the significant level at 0.05.

3.4 Discussion

EC of the two main irrigation water sources (IR1 and IR2) were low and stable throughout the year, being less than 0.1 dS m^{-1} and classified as C1–S1 (United States Salinity Laboratory Staff, 1954) (Table 3.1). This implies that IR1 and IR2 are not influenced by the intrusion of seawater. Therefore, IR1 and IR2 water can be used for irrigation of most crops and soils with little risk of causing harmful levels of salinity and exchangeable sodium (United States Salinity Laboratory Staff, 1954). Because IR3 and

IR4 are located adjacent to the secondary Bao Kho river that connects directly to the lagoon (Fig. 2.1), seawater from the lagoon easily seeps into these two irrigation sources. As a result, EC of IR3 (in January) and IR4 (in January and September) were medium level (0.27, 0.38, and 0.45 dS m^{-1}, respectively) and classified as C2–S1 (United States Salinity Laboratory Staff, 1954). However, EC of IR3 and IR4 was low (less than 0.1 dS m^{-1}) in the beginning of June; because beginning of June is the beginning of second rice cropping season, farmers take extra care to ensure the sluice gates are closed to prevent seawater intrusion during periods. Irrigation water sources IR3 (in January) and IR4 (in January and September) are classified as C2–S1, thus they can also be used for irrigation of crops and soils with a moderate amount of leaching occur (United States Salinity Laboratory Staff, 1954).

ECe and total soluble cation concentrations were high at low–elevation plots (Fig. 3.4). This indicates that there is insufficient leaching of salts or salt re–accumulation in the low–elevation plots. Compared with ECe and ECw at the high–elevation plots, ECe and ECw at the low–elevation plots were much higher. In the low–elevation plots, ECe and ECw were higher than 1.9 dS m^{-1} in all seasons (except for ECe at QD17 in January 2012 and 2013 and September 2012, QD19 in January and May 2012) (Table 3.3, Figs. 3.4 to 3.6), indicating the intrusion of seawater from the lagoon into these plots. There are dense canals and ponds that connect directly to the lagoon (Fig. 2.1) and are flooded annually from September to December in the depression region; seawater therefore easily inundates the inland area via the canals and ponds at the rising time of tide or during flooding. In the high–elevation plots, ECe were low and less than 1.0 dS m^{-1} (Table 3.2 and Fig. 3.4), indicating that soils in these plots were not invaded by seawater. The high–elevation plots are located along the two main irrigation rivers of IR1 and IR2; therefore these plots are supplied frequently by freshwater with low salinity (Table 3.1). Though the relative elevation measurements (Table 3.2) indicate that the differences in elevation between the 19 plots were very small (centimeter to decimeter), they still led to large differences in soil salinity levels (Figs. 3.4 to 3.6). Thus, salt accumulation and distribution was strongly influenced by elevation. The influences of elevation on salinity accumulation have also been reported by Sugimori et al., (2008), Funakawa and Kosaki (2007), and Moral et al., (2010). Grattan et al., (2002) suggested that if ECe of soil is greater than 1.9 dS m^{-1}, rice starts to be adversely affected. Thus, soils and rice growth (production) in the low–elevation plots (except for soils at QD17 in January 2012 and 2013 and September 2012, QD19 in January and May 2012) were adversely affected by salinity, because ECe and ECw at these plots were much higher than 1.9 dS m^{-1} (Table 3.2, Figs. 3.4 to 3.6). In contrast, soils and rice growth (production) in the high–elevation plots were not affected by salinity, because ECe and ECw were much lower than the threshold of 1.9 dS m^{-1} (Table 3.2, Figs. 3.4, 3.5, and 3.7).

Besides being influenced by elevation, soil salinity also varied seasonally. ECe and ECw from May to September were much higher than in January (Table 3.2, Figs. 3.4 to 3.6) and the differences in ECe and ECw between May and September were small. Because the flood or rainy season ends at the beginning of January, and the hot season with higher temperature and surface water evaporation occurs from May to September, salt concentrations in soils were diluted by high amounts of freshwater supplied by flooding in January, and became more condensed from May to September.

Rice yield in the summer–autumn cropping season tended to be lower than in the winter–spring cropping season (Fig. 3.8). These results may be caused by high ECe and ECw in the summer–autumn cropping season (May 2013) (Figs. 3.4 to 3.6). Rowell (1994) and Ghafoor et al., (2004) suggested that soil salinity directly affects rice growth through osmotic stress and ionic toxicity caused by Na^+, Cl^-, and SO_4^{2-}, which may also promote imbalances in rice nutrient metabolism. The negative correlations between yield and ECe have also been reported by Sugimori et al., (2008).

3.5 Conclusions

Though the differences in relative elevations between the 19 plots were very small (centimeter to decimeter), they can lead to large differences in soil salinity. Elevation and ECe measurements show that the research site could be divided into low and high–elevation plots. The low–elevation plots were located in the central part of the research site, along the lagoon, and along secondary Bao Kho river, and the high–elevation plots surrounded the two main irrigation rivers. ECe and ECw in the low–elevation plots were much higher than in the high–elevation plots. In the high–elevation plots, soils were irrigated by freshwater with low EC, and not subject to seawater intrusion, thus ECe and

ECw of soils were low throughout the year. Because ECe levels were much lower than the threshold for rice growth of 1.9 dS m^{-1}, rice growth (production) was not influenced by salinity. However, soils had poor fertility, as indicated by the low pH, CEC, total C, and total N; soil fertility is therefore also considered one of the main factors limiting rice production in the high–elevation plots. In the low–elevation plots, soils were subject to seawater intrusion, thus its ECe was much higher than the threshold for rice growth of 1.9 dS m^{-1}. Moreover, soils also were poor fertility; hence, rice yield (production) at the low–elevation plots was not only influenced by high salinity but also by low soil fertility. Salinity level from May to September was the highest in a year.

CHAPTER 4

PERFORMANCE OF NEWLY INTRODUCED SALT–TOLERANT RICE CULTIVARS ON SALINE SOILS

4.1 Backgrounds

Salinity is the major environmental factor limiting plant growth and productivity (Allakhverdiev *et al.*, 2000). At present, salinity is the second most widespread soil problem in rice–growing countries after drought, and it is considered as a serious constraint to increased rice production worldwide (Gregorio, 1997). Rice (*Oryza sativa* L.), one of the major food crops of the world, is extremely salt–sensitive (Maas and Hoffman, 1977). Rice plants are more sensitive during the emergence and early seedling growth stages than during the germination and later growth stages, including the grain development stage (Bresler *et al.*, 1982). For many rice varieties, the grain yield is reduced by half when they are grown in soil with an electrical conductivity (EC) of 6.0 dS m^{-1} (Yoshida, 1981).

In the north central coastal region of Vietnam, agricultural lands in the Thua Thien Hue Province are seriously affected by intrusion of saline water from the Tam Giang Lagoon, the biggest lagoon in Southeast Asia (approx. 22,000 ha) (Dan *et al.*, 2006). At present, famers in this province cultivate the local rice variety KD on saline soils. This variety has a weak–to–medium tillering ability and a low 1,000–grain weight (19.5 – 20.5 g). Therefore, it has a low yield of approximately 3.5 – 5.0 tons per hectare (Dan *et al.*, 2006). As a result, the income of farmers cultivating rice on saline soils in Thua Thien Hue Province is very low.

To increase the income of rice farmers, high–yielding varieties can be cultivated instead of low–yielding local rice varieties. However, it is time–consuming and expensive to breed new high–yielding salt–tolerant varieties for specific regions. The most effective strategy, therefore, is to introduce high–yielding, salt–tolerant varieties that have been bred and/or cultivated in other regions to the Thua Thien Hue Province.

Recently, farmers in regions of the Mekong River Delta and the south–central coastal area of Vietnam started cultivating some new high–yielding, salt–tolerant rice varieties including AS996, OM4900, OM5900, MNR3, and CM2 on the saline soils in these regions. These varieties were bred by the Cuu Long Delta Rice Institute (Can Tho Province) and the Southern Central Coastal Agricultural Science Institute (Binh Dinh Province). However, because they are new varieties, there is no information on their growth and yield when cultivated on the low–fertility, low–pH, saline soils in the north central coastal region of Vietnam.

Analyzing the relationships between yield and various yield components can reveal the best indicators for yield, and size of their contributions to yield. However, because the correlations between agronomic traits of rice and yield are strongly affected by the environmental conditions and rice genotypes (Senanayake and Wijerathen, 1988), correlation analyses should be conducted for each specific variety in field experiments in the region in which it will be cultivated. Although the correlations between rice agronomic traits and yield have been intensively studied, there have been no reports on these relationships for the new rice varieties cultivated in the north central coastal region of Vietnam. Therefore, it is important to analyze the relationships between various rice traits and yield to identify the best yield indicators and their contributions to yield. This information can be used to select the best breeding lines to cultivate in the north central coastal region of Vietnam.

This study had two objectives: to evaluate the performance of 13 newly introduced salt–tolerant rice varieties cultivated in the north central coastal region of Vietnam, and to identify the best yield indicators and quantify their contributions to yield. To achieve these objectives, the 13 highest–yielding new salt–tolerant rice varieties that are widely cultivated on saline soils in the Mekong River Delta and south central coastal regions of Vietnam (Table 4.1) were cultivated at three sites in the north central coastal region of Vietnam, in the winter–spring and summer–autumn cropping seasons of 2012 and 2013.

4.2 Materials and study methods

4.2.1 Rice cultivars

Fourteen rice varieties (including one local variety, KD) were used in this research. Twelve varieties were bred by the Cuu Long Delta Rice Institute, located in Can Tho Province, South Vietnam, and one variety was bred by the South Central Coastal

Agricultural Science Institute, located in Binh Dinh Province, south–central Vietnam). The local variety KD was used as the control. The names and major characteristics of the 14 rice varieties are shown in Table 4.1.

Table 4.1: Details of 14 rice varieties used in this study

Designation	Growth duration (days)	Plant height (cm)	1,000-grain weight (g)	Parentage	Origin
MNR3	100–105	100–105	27–28	OM6073/DS20//DS20	Cuu Long Delta Rice Institute
OM5629	95–100	95–100	28–29	C27/IR64/C27	Cuu Long Delta Rice Institute
OM2395	95–100	90–100	27–28	IR63356-6B/TN1	Cuu Long Delta Rice Institute
MNR4	100–105	100–105	25–26	AS996/JASMINE85	Cuu Long Delta Rice Institute
AS996	90–95	95–100	26–27	IR64 /ORYZA RUFIPOGON	Cuu Long Delta Rice Institute
CM2	100–105	90–100	27–28	-[††]	Southern Central Coastal Agricultural Science Institute
OM6L	90–95	95–100	27–28	OM1490/HOALAI/HOALAI	Cuu Long Delta Rice Institute
OM5900	90–95	95–100	27–28	AS996/IR50404	Cuu Long Delta Rice Institute
OM4900	95–105	100–110	28–29	C53/JASMINE85//JAPONICA	Cuu Long Delta Rice Institute
OM2718	90–100	100–105	22–25	OM1738/MCRDB	Cuu Long Delta Rice Institute
OM8104	92–95	100–110	27–28	OM2718/OM2717	Cuu Long Delta Rice Institute
OM9922	90–95	95–100	27–28	IR68523-61-1-1-2-2/OM1570	Cuu Long Delta Rice Institute
OMCS2000	90–95	95–110	27–28	OM1723/MRC19399	Cuu Long Delta Rice Institute
KD[†]	100–105	90–105	22–25	KD18 mutation	Thua Thien Hue Seed Company

[†] KD = Khang Dan, the local variety.

[††] Information about parentage of CM2 was not available from the Southern Central Coastal Agricultural Science Institute.

4.2.2 Experimental design

The field experiments were conducted at the Quang Phuoc commune (16°35'N, 107°32'E) in Quang Dien District, Thua Thien Hue Province, in the north–central coastal region of Vietnam (Fig. 4.1).

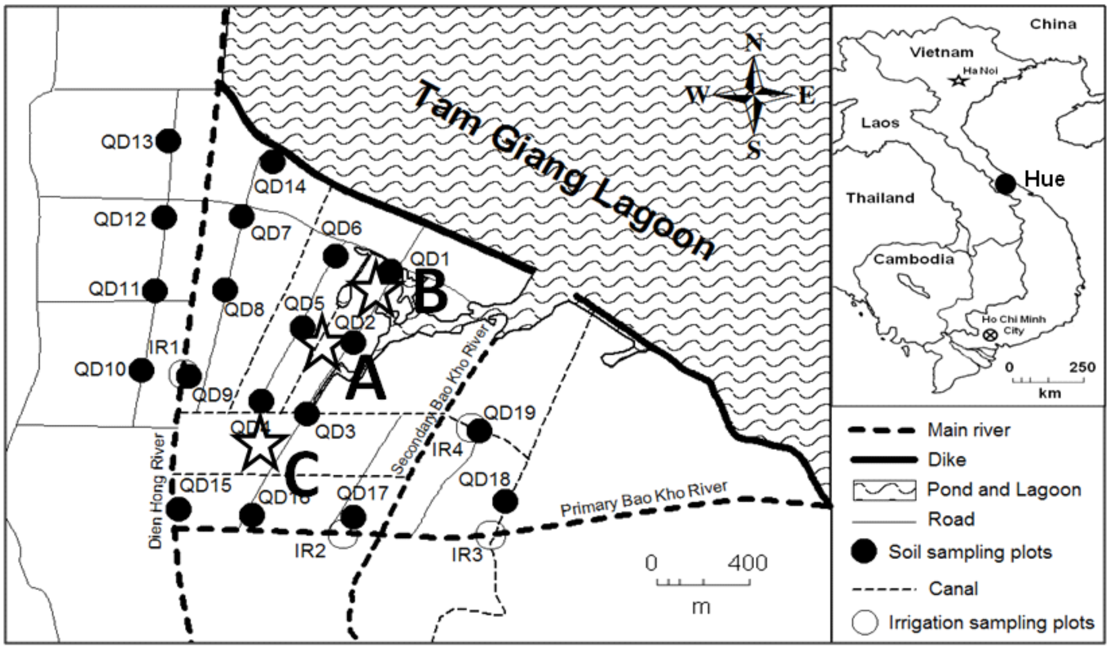


Fig. 4.1: Locations of experimental plots of A, B, and C (star symbols)

The field experiments were conducted in three locations with varying degrees of soil salinity: low (plot A), medium (plot B), and high (plot C) (Fig. 4.1). In total, seven field experiments were conducted in 2012 and 2013: one in plot B, in which the EC of soil solution (ECw) was 6.6 before transplanting and 7.3 dS m^{-1} at harvest, in the 2012 winter–spring cropping season; three in plots A, B, and C with ECw ranges of 3.9 – 4.3, 6.3 – 6.5, and 8.3 – 9.6 dS m^{-1}, respectively, in the 2012 summer–autumn cropping season, and three in plots A, B, and C with ECw value ranges of 3.9 – 4.5, 6.2 – 6.5, and 9.1 – 10.7 dS m^{-1}, respectively, in the 2013 winter–spring cropping season (Table 4.3).

All of the field experiments had a randomized complete block design with three replicates. In the 2012 winter–spring cropping season, rice plants were planted in rows with 20 × 20 cm spacing and two plants per hill. In the other six experiments, rice plants were planted in rows with 10 × 20 cm spacing and one plant per hill. The area of each plot was 5.0 m^2 (2.5 m × 2.0 m). The fertilizer application rate for all experiments was the same as that used by local farmers (200 kg ha^{-1} lime, 100 kg ha^{-1} N as urea, 60 kg ha^{-1} P_2O_5 as superphosphate, and 60 kg ha^{-1} K_2O as potassium chloride). For basic application, 100% of P_2O_5 and 30% of N were applied. The remaining fertilizer was applied twice as a dressing. The first application was at 2 weeks after sowing (50% of K_2O and 40% of N), and the second application was at 20 days before flowering (50% of K_2O and 30% of N). The rice plots were weeded twice during the cultivation period, at the same time as top–dressing.

The climatic conditions during the experimental period are shown in Table 4.2.

Table 4.2: Climatic conditions from January 2012 to May 2013

Month	Year	Temperature			Humidity	Precipitation		Sunlight
		T_{ave}	T_{max}	T_{min}	(%)	(days)	(mm)	(h)
		(°C)						
January	2012	19.3	29.8	15.7	95.0	21.0	155.9	30.0
February		20.1	35.2	15.0	92.0	13.0	71.6	62.0
March		22.6	35.7	16.2	90.0	10.0	17.3	111.0
April		26.3	37.5	18.5	85.0	8.0	51.1	180.0
May		28.7	39.5	21.0	79.0	9.0	43.4	261.0
June		28.5	37.8	20.5	79.0	10.0	96.0	226.0
July		27.9	36.7	23.0	83.0	15.0	118.3	206.0
August		28.4	37.3	23.4	80.0	7.0	39.3	182.0
September		26.6	37.2	22.5	89.0	19.0	569.0	129.0
January	2013	19.8	28.0	14.5	91.0	15.0	47.3	90.0
February		22.9	32.0	16.5	90.0	6.0	27.0	144.0
March		24.6	35.0	16.8	88.0	10.0	64.0	159.0
April		26.2	39.7	20.4	86.0	13.0	25.5	159.0
May		28.0	37.0	22.0	80.0	13.0	87.5	205.0

T: Temperature; ave: average; max: maximum; min: minimum; h: hours.

Source: Meteorological Station of Thua Thien Hue Province, 2012 and 2013.

4.2.3 Electrical conductivity of soil solution on the fields

To measure electrical conductivity in the field (ECw) during the rice cultivation period, five porous cups (DIK–8390–11, Daiki, Japan) were installed at the center and the four corners of the experimental fields to collect soil water samples. The water samples were collected twice per month from approximately 20–cm depth during the rice cultivation period. ECw values were measured with a conductivity meter.

4.2.4 Soil samples and analytical methods

Soil samples were collected from cultivated horizon at before transplanting. Before analysis, soil samples were air–dried, crushed and passed through a 2–mm mesh sieve.

Particle size distribution was determined by a combination of pipette and sieving methods (Jackson et al., 1986). CEC and exchangeable cations were determined using the ammonium acetate (1 mol L^{-1} and pH 7.0) method (Miller and Curtin 2006). Exchangeable cations Na^+, K^+, Mg^{2+}, and Ca^{2+} were determined by atomic absorption spectrophotometry (AA–700, Shimadzu, Kyoto, Japan). For CEC determination, residual soil was washed with 80% ethanol following ammonium acetate extraction; the remaining NH_4^+ was extracted with 10% NaCl, and then determined by the Kjeldahl distillation method. Total C and N contents in soils were determined using a dry combustion method with a CN analyzer (VarioMax CHN, Elementar, Germany). pH(H_2O) and pH(KCl) (using a soil:solution water ratio of 1:5) was determined using a glass electrode meter (Blakemore et al., 1987).

The other analytical methods of soil parameters (Table 4.3) are described in the item of analytical methods, section of material and analytical methods, chapter 3.

4.2.5 Agronomic traits

Five plants in each plot were randomly selected to record agronomic traits. At 1 week before harvest, plant height was determined by measuring the distance from the soil surface to the end of the longest panicle. At harvest, five plants were pulled out, their roots were removed, and then the number of panicles per plant was counted. Five panicles from the five measured plants were randomly selected, and then bagged individually before measuring yield components. Panicle length, number of grains per panicle, number of filled grains per panicle, 1,000–grain weight, and panicle weight were measured. After removing unfilled seeds and drying the filled seeds, yield per hill was calculated from the weight of dried filled seeds. To determine the aboveground biomass (without roots) of each plant, the shoots were oven–dried at 70 °C for 1 week and then weighed. Grain fertility (%) was calculated by dividing the number of filled grains per panicle by the number of grains per panicle (Zeng and Shannon, 2000). Harvest index was calculated as the total dry grain weight divided by total aboveground biomass (Zeng and Shannon, 2000).

4.2.6 Statistical analysis

Data were analyzed using Statistix 9.0 (Analytical Software, Tallahassee, FL, USA). To compare the differences in agronomic traits and yield per plant among rice varieties at each EC level and at combinative three EC levels altogether, we conducted one–way ANOVA and Tukey's test. To evaluate the effects of different EC levels on agronomic traits and yield per plant in each cropping season, we used two–way ANOVA and Tukey's test. To test the effects of the two cropping seasons on agronomic traits and yield per plant at each EC level, we conducted ANOVA and Fisher's Least Significance Different test. In all cases, $P < 0.1$ was considered to be significant. The correlations between agronomic traits and yield were analyzed after evaluating the normality of the data by Pearson's test.

4.3 Results

4.3.1 Electrical conductivity of soil solution in experimental plots

The ECw values recorded during the growing period in the seven experiments are shown in Figure 4.2. The ECw was quite stable during the rice growing period in most of the field experiments. However, in experimental plot C in the winter–spring cropping season in 2013, ECw increased gradually from January until May.

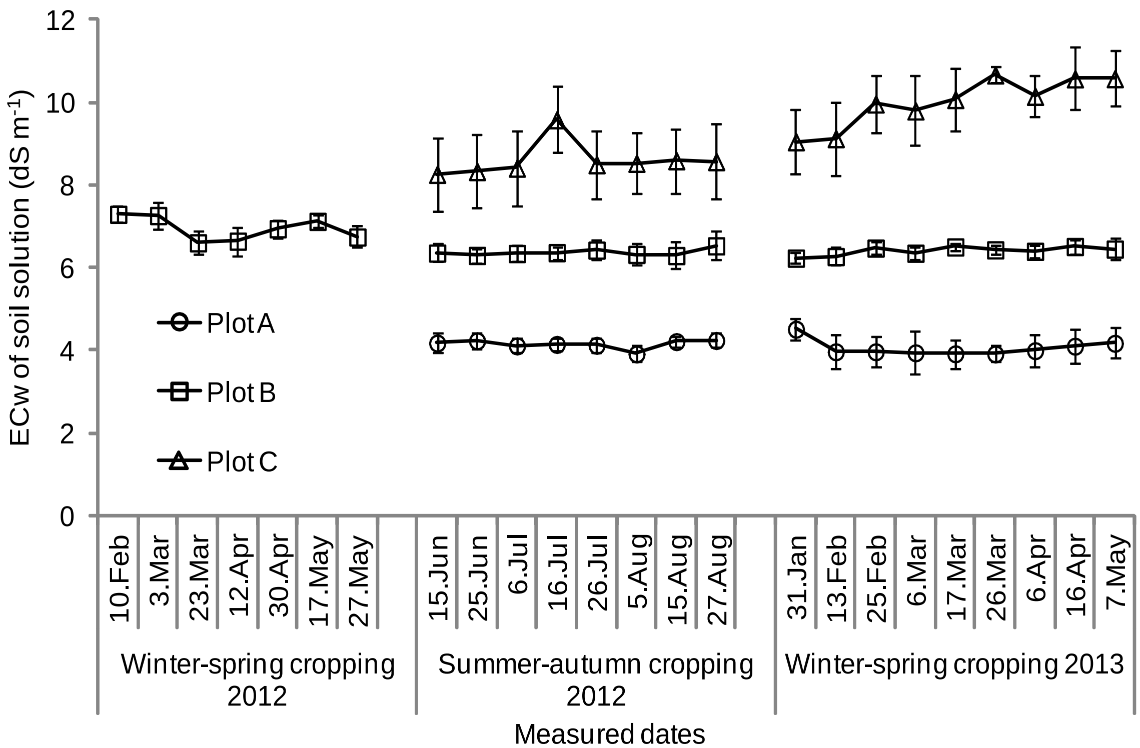


Fig. 4.2: Electrical conductivity of soil solution in experimental plots

4.3.2 Physicochemical properties of experimental soils

The physicochemical properties of soils indicated that they were not suitable for rice growth (Table 4.3). The soils in experimental plots A, B, and C were classified as sandy loam with a sand fraction of 45%, 68%, and 61%, respectively. The pH (H_2O) of soil in experimental plots A, B, and C was lower in the 2012 summer–autumn cropping season than in the 2013 winter–spring cropping season; that may be because of higher SO_4^{2-} concentration in the 2012 summer–autumn cropping season and lower in 2013 winter–spring cropping season. In all the soils, there were very low values for CEC (3.5 – 5.0 $cmol_c\ kg^{-1}$), total C (10 – 13 g kg^{-1}), and total N (0.9 – 1.3 g kg^{-1}). As shown in Table 3, the major water soluble cations were Na^+, Ca^{2+}, and Mg^{2+}, while the amounts of the water soluble cations K^+ and NH_4^+ were negligible. The major water soluble anions were SO_4^{2-} and Cl^-, while the amount of NO_3^- was negligible.

Table 4.3: Physicochemical properties of soils in experimental plots

Cropping	Winter–spring cropping season 2012	Summer–autumn cropping season 2012			Winter–spring cropping season 2013		
Experimental plot	B	A	B	C	A	B	C
ECw† (dSm^{-1})	6.6–7.3	3.9–4.3	6.3–6.5	8.3–9.6	3.9–4.5	6.2–6.5	9.1–10.7
Soil texture							
Sand (%)	68	45		61			
Silt (%)	17	31		26			
Clay (%)	15	24		14			
pH							
H_2O	6.0	5.3	4.7	5.2	6.3	6.6	6.2
KCl	5.4	4.6	4.3	4.7	5.3	5.6	5.8
ECe†† ($dS\ m^{-1}$)	6.2	4.0	6.7	9.6	3.9	5.9	7.9
CEC ($cmol_c\ kg^{-1}$)	5.0	3.7		3.5			
Total C ($g\ kg^{-1}$)	10.0	13.0		10.0			
Total N ($g\ kg^{-1}$)	1.0	1.3		0.9			
Exchangeable cations ($cmolc\ kg^{-1}$)							
Na^+	2.03	0.74		2.55			
K^+	0.24	0.10		0.38			
Ca^{2+}	1.20	0.88		1.63			
Mg^{2+}	1.72	1.01		2.37			
Water soluble cations ($cmolc\ kg^{-1}$)							
Na^+	1.40	0.82	1.45	2.76	0.70	1.21	2.00
K^+	0.05	0.05	0.07	0.07	0.02	0.06	0.04
Ca^{2+}	0.41	0.40	1.05	0.85	0.22	0.36	0.22
Mg^{2+}	0.58	0.46	0.97	1.13	0.19	0.53	0.47
NH_4^+	0.04	0.04	0.04	0.05	0.04	0.06	0.06
Sum of cations	2.50	1.76	3.57	4.86	1.16	2.22	2.78
Water soluble anions ($cmol_c\ kg^{-1}$)							
Cl^-	1.82	0.94	1.65	3.63	0.86	1.35	2.56
SO_4^{2-}	0.97	0.94	2.80	2.41	0.19	0.91	0.37
NO_3^-	0.02	0.01	0.01	0.01	0.01	0.01	0.00
Sum of cations	2.81	1.89	3.92	6.04	1.05	2.27	2.93

† ECw: Electrical conductivity of soil water solution in the field.

†† ECe: Electrical conductivity of saturation paste.

4.3.3 Performance of studied rice varieties in terms of agronomic traits and yield per plant

Tables 4.4 and 4.5 show the performance of the 14 rice varieties, in terms of ten main agronomic traits and yield per plant, in experimental plot A and in three experimental plots A, B, and C altogether in the 2013 winter–spring cropping season. Among the 14 studied rice varieties in the seven field experiments, only MNR3 and OM5629 in experimental plot A (2013 winter–spring cropping season; ECw from 3.9 to 4.5 dS m^{-1}) showed significantly higher yields per plant than that of the local variety KD (16.5 g and 15.3 g compared with 8.3 g, respectively). The other varieties showed low yields per plant (9.0 – 13.5 g). In the statistical analysis performed using all the values of three experimental plots in the winter–spring cropping season, the five newly introduced rice varieties of MNR3, MNR4, OM4900, AS996, and OM2395 recorded significantly higher yields per plant, that is, 16.9 g, 16.2 g, 15.6 g, 15.5 g, and 15.4 g, respectively, than that of the local variety KD, 10.9 g (Table 4.5). In contrast, the analysis including all the experimental plots did not give any statistically significant difference for yields per plant between thirteen newly introduced rice varieties and local variety KD in the summer–autumn cropping season (Table 4.6). The yield per plant of the 14 studied rice varieties in the other six experimental plots (experimental plot B in the winter–spring cropping 2012, three experimental plots A, B and C in the summer–autumn cropping 2012, and two experimental plots B and C in the winter–spring cropping 2013) was not significantly different from that of the local variety KD (Tables 4.7 to 4.16).

Table 4.4: Performance of rice varieties, in terms of agronomic traits and yield, in experimental plot A in winter–spring of 2013

Trait	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1,000-grain weight	Total biomass	Harvest index	Yield
Variety	(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)	(g $plant^{-1}$)
MNR3	93.9 abc	7.3 ab	24.7 a	2.8 a	120.7 a	101.9 a	84.8 ab	27.9 ab	30.4 ab	54.4 a	16.5 a
OM5629	100.8 a	8.0 ab	22.2 ab	2.3 ab	109.1 ab	86.2 a	78.3 abcd	26.3 ab	30.5 a	49.9 abc	15.3 ab
OM2395	90.9 abc	7.6 ab	23.3 ab	2.3 ab	94.8 ab	82.4 a	86.0 a	27.7 ab	24.8 ab	54.5 a	13.5 abc
AS996	87.9 bc	8.1 ab	22.6 ab	2.2 ab	94.5 ab	77.7 a	82.1 abcd	28.0 ab	24.9 ab	53.6 a	13.3 abc
MNR4	92.0 abc	6.5 ab	22.6 ab	2.3 ab	114.3 ab	92.1 a	78.4 abcd	27.7 ab	24.3 ab	54.2 a	13.3 abc
CM2	90.7 abc	8.5 ab	20.9 bc	2.0 ab	91.0 ab	65.2 a	73.1 bcd	31.1 a	25.4 ab	51.4 abc	13.0 abc
OM6L	84.6 c	8.7 ab	23.1 ab	2.2 ab	99.9 ab	87.9 a	87.4 a	25.8 b	24.4 ab	53.2 ab	12.9 abc
OM5900	87.5 bc	8.9 a	19.2 c	1.7 b	68.5 b	60.9 a	88.9 a	28.7 ab	24.1 ab	51.0 abc	12.4 abc
OM4900	94.7 abc	6.6 ab	22.6 ab	2.5 ab	119.1 a	100.8 a	83.6 abc	25.7 b	24.3 ab	50.4 abc	12.2 abc
OM2718	93.8 abc	7.4 ab	22.7 ab	2.3 ab	114.8 ab	83.9 a	71.7 d	27.1 ab	23.9 ab	49.4 abc	11.9 abc
OM8104	96.8 ab	6.9 ab	21.2 bc	2.2 ab	101.3 ab	80.7 a	79.1 abcd	27.7 ab	25.2 ab	43.9 abc	11.1 abc
OM9922	96.7 ab	6.1 ab	21.8 bc	2.0 ab	88.7 ab	71.7 a	80.4 abcd	28.1 ab	23.9 ab	42.2 c	10.1 bc
OMCS2000	92.1 abc	6.8 ab	22.0 abc	1.6 b	93.9 ab	65.8 a	71.8 cd	24.0 b	20.9 ab	42.4 bc	9.0 c
KD	93.1 abc	5.9 b	21.3 bc	1.9 ab	94.2 ab	76.5 a	80.6 abcd	25.4 b	20.1 b	41.2 c	8.3 c
Mean	92.5	7.4	22.1	2.2	100.3	81.0	80.4	27.2	24.8	49.4	12.3
SD†	4.2	1.0	1.3	0.3	14.2	12.5	5.5	1.7	2.8	4.9	2.2
CV†† (%)	4.5	12.9	5.9	14.1	14.1	15.5	6.9	6.3	11.4	9.9	18.0

Values followed by different letters are significantly different (Tukey's test, $P < 0.1$).

† SD: Standard deviation; †† CV: Coefficient of variation.

Table 4.5: Performance of rice varieties, in terms of agronomic traits and yield, combinative values of three experimental plots A, B and C in winter–spring 2013

Variety	Plan height (cm)	Number of productive tillers plant^{-1}	Panicle length (cm)	Panicle weight (g)	Number of grains (panicle^{-1})	Number of filled grains (panicle^{-1})	Grain fertility (%)	1,000–grain weight (g)	Total biomass (g)	Harvest index (%)	Yield (g plant^{-1})
MNR3	93.3 bc	7.8 bcd	25.5 a	2.6 a	120.5 ab	98.6 ab	81.8 abcd	26.1 bcd	32.9 a	51.3 ab	16.9 a
OM5629	99.4 a	7.9 bcd	21.7 bc	2.3 abcd	105.7 abcd	81.5 bcd	76.3 cd	26.6 bcd	31.4 ab	46.5 bcd	14.7 abcd
OM2395	89.1 cde	9.1 ab	22.1 bc	2.2 abcd	92.4 cde	78.5 bcd	84.4 abc	27.1 bc	29.3 abc	52.8 ab	15.4 abc
AS996	88.7 de	8.7 abc	22.4 b	2.3 abcd	103.5 abcde	81.7 bcd	79.1 bcd	26.9 bc	31.1 ab	50.0 abc	15.5 abc
MNR4	93.6 bc	7.4 cd	22.2 b	2.4 abc	115.9 abc	91.6 abc	78.3 bcd	26.8 bc	31.2 ab	52.2 ab	16.2 ab
CM2	91.6 bcd	8.6 abcd	20.8 bc	2.2 abcd	93.9 cde	71.0 cd	75.9 d	30.1 a	27.9 abc	53.1 a	14.9 abcd
OM6L	86.8 e	8.7 abc	21.6 bc	2.1 bcd	97.4 bcde	83.4 abcd	85.1 ab	23.9 de	26.1 bc	52.0 ab	13.5 abcd
OM5900	88.2 de	9.7 a	19.9 c	1.8 d	80.3 e	70.4 cd	87.7 a	25.2 bcde	26.7 abc	52.6 ab	14.1 abcd
OM4900	94.8 b	7.5 bcd	22.1 bc	2.5 ab	126.3 a	103.1 a	80.6 abcd	24.5 cde	30.9 ab	50.6 abc	15.6 ab
OM2718	92.4 bcd	7.6 bcd	22.0 bc	2.2 abcd	113.1 abc	87.0 abcd	75.6 d	25.3 bcde	27.2 abc	47.1 abcd	12.7 bcd
OM8104	93.5 bc	7.6 bcd	20.5 bc	1.9 cd	85.3 de	68.6 d	80.0 abcd	27.4 b	26.6 abc	42.6 de	11.4 cd
OM9922	94.8 b	7.1 cd	22.3 b	2.1 bcd	107.4 abcd	82.3 abcd	76.5 cd	25.4 bcde	28.4 abc	39.9 e	11.1 d
OMCS2000	90.9 bcd	8.5 abcd	21.7 bc	1.9 d	92.4 cde	72.1 cd	78.8 bcd	24.8 bcde	27.1 abc	46.7 abcd	12.8 abcd
KD	90.8 bcd	7.0 d	20.8 bc	2.0 cd	108.6 abcd	89.6 abcd	81.9 abcd	23.1 e	23.8 c	44.5 cde	10.9 d
Mean	92.0	8.1	21.8	2.2	103.0	82.8	80.1	25.9	28.6	48.7	14.0
SD†	3.3	0.8	1.3	0.2	13.4	10.5	3.7	1.8	2.6	4.2	1.9
CV†† (%)	3.6	10.0	5.9	11.0	13.0	12.7	4.6	6.8	9.0	8.6	13.8

Values followed by different letters are significantly different (Turkey's test, $P < 0.1$).

† SD: Standard deviation; †† CV: Coefficient of variation.

Table 4.6: Performance of rice varieties, in terms of agronomic traits and yield, combinative values of three experimental plots A, B and C in summer-autumn 2013

Variety	Plan height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1,000–grain weight	Total biomass	Harvest index	Yield
	(cm)	$plant^{-1}$	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)	(g $plant^{-1}$)
MNR3	89.1 a	8.4 cde	23.8 abcd	1.8 ab	121.5 cd	75.5 bc	62.7 cdef	24.3 ab	28.3 a	37.2 b	10.5 ab
MNR4	96.1 a	8.6 bcde	24.5 ab	2.1 ab	169.9 ab	97.0 ab	56.7 ef	21.8 cde	35.9 a	35.5 bc	12.8 ab
OM4900	95.3 a	8.2 de	23.9 abc	2.3 a	178.2 a	108.0 a	59.9 cdef	20.9 de	35.9 a	35.7 bc	13.0 ab
AS996	89.5 a	9.6 bcde	23.5 abcde	1.8 ab	121.1 cd	81.5 abc	68.4 abcde	22.5 bcd	30.6 a	42.5 ab	13.1 ab
OM2395	90.6 a	13.5 a	22.8 bcdef	1.7 ab	95.5 d	74.7 bc	77.0 ab	22.6 bcd	37.8 a	41.5 ab	15.5 a
CM2	89.3 a	11.7 ab	21.8 ef	1.7 ab	110.0 cd	67.4 c	60.7 cdef	25.9 a	35.6 a	39.1 ab	14.0 ab
OM5629	97.1 a	8.4 cde	23.8 abcd	2.1 ab	140.8 bc	88.8 abc	63.3 cdef	23.6 bc	35.4 a	34.8 bc	12.4 ab
OM5900	90.7 a	11.5 abc	21.6 f	1.9 ab	111.4 cd	89.4 abc	80.9 a	21.5 cde	31.8 a	45.4 a	14.4 ab
OM6L	92.4 a	10.7 abcd	22.3 cdef	1.7 ab	108.2 cd	73.9 bc	67.2 bcdef	22.6 bcd	31.1 a	41.7 ab	13.2 ab
OMCS2000	94.7 a	9.9 bcde	23.4 abcde	1.8 ab	111.1 cd	79.0 bc	70.4 abcd	23.0 bcd	30.9 a	37.9 ab	11.7 ab
0M2718	92.5 a	9.8 bcde	23.3 abcde	1.9 ab	136.2 bc	80.6 abc	58.9 def	23.5 bc	34.7 a	38.1 ab	13.2 ab
OM8104	90.5 a	11.3 abcd	22.1 def	1.6 b	96.2 d	69.0 bc	72.3 abc	23.2 bc	31.9 a	39.6 ab	12.5 ab
OM9922	95.8 a	7.0 e	24.6 a	1.9 ab	142.3 bc	79.3 bc	54.8 f	23.8 abc	31.0 a	29.5 c	9.2 b
KD	90.1 a	11.7 ab	23.1 abcdef	1.9 ab	142.0 bc	97.0 ab	68.8 abcde	19.8 e	36.5 a	38.4 ab	13.9 ab
Mean	92.4	10.0	23.2	1.9	127.4	82.9	65.9	22.8	33.4	38.4	12.8
SD†	2.8	1.8	1.0	0.2	25.3	11.7	7.7	1.5	2.9	3.9	1.6
CV†† (%)	3.1	17.8	4.1	9.8	19.9	14.1	11.6	6.6	8.6	10.1	12.3

Values followed by different letters are significantly different (Turkey's test, $P < 0.1$).

† SD: Standard deviation; †† CV: Coefficient of variation.

Table 4.7: Performance of rice varieties, in terms of agronomic traits and yield, in experimental plot B in winter–spring of 2013

Trait	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1,000-grain weight	Total biomass	Harvest index	Yield
Variety	(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)	(g $plant^{-1}$)
MNR3	101.5 a	10.5 b	24.7 a	2.4 a	142.3 a	120.9 a	85.0 a	24.1	42.2 ab	60.4 a	25.4 a
OM5629	102.4 a	16.3 ab	23.6 ab	1.9 a	142.1 ab	119.2 ab	84.0 a	25.2	62.5 a	49.6 a	31.0 a
OM2395	86.0 d	12.4 b	20.3 b	2.0 a	100.7 c	80.3 bc	79.5 a	26.7	40.1 ab	59.7 a	24.0 a
AS996	89.4 cd	11.3 b	21.5 ab	2.5 a	112.7 abc	92.9 abc	82.5 a	23.2	41.7 ab	60.8 a	27.5 a
MNR4	91.7 bcd	12.0 b	21.4 ab	1.6 a	116.0 abc	88.9 abc	76.6 a	27.0	37.7 b	51.8 a	19.9 a
CM2	96.0 abc	12.7 b	22.2 ab	2.2 a	114.3 abc	90.7 abc	79.5 a	23.7	46.4 ab	60.6 a	28.2 a
OM6L	92.7 bcd	14.8 ab	23.2 ab	2.0 a	114.5 abc	99.8 abc	86.9 a	25.1	56.6 ab	54.5 a	29.7 a
OM5900	89.5 cd	19.9 a	21.4 ab	1.9 a	101.7 bc	88.3 abc	87.0 a	22.6	55.8 ab	66.7 a	37.3 a
OM4900	91.4 bcd	11.3 b	24.0 ab	2.7 a	139.8 abc	119.6 ab	85.7 a	29.4	48.3 ab	62.2 a	30.5 a
OM2718	91.7 bcd	11.6 b	21.5 ab	2.2 a	127.1 abc	106.5 abc	83.8 a	20.0	42.0 ab	56.7 a	23.9 a
OM8104	97.9 ab	12.1 b	23.4 ab	2.2 a	122.6 abc	104.4 abc	85.1 a	24.8	45.1 ab	58.2 a	26.3 a
OM9922	96.3 abc	11.9 b	23.9 ab	2.0 a	114.2 abc	96.3 abc	84.6 a	22.6	43.4 ab	54.0 a	24.1 a
OMCS2000	87.7 d	12.1 b	21.2 ab	2.0 a	100.1 c	75.5 c	75.2 a	27.3	43.3 ab	56.0 a	24.4 a
KD	90.9 bcd	13.9 b	22.8 ab	1.8 a	119.2 abc	99.0 abc	81.7 a	25.3	41.9 ab	55.3 a	24.3 a
Mean	93.2	13.1	22.5	2.1	119.1	98.8	82.6	24.8	46.2	57.6	26.9
SD†	4.9	2.5	1.3	0.3	14.4	14.2	3.7	2.4	7.2	4.5	4.3
CV†† (%)	5.3	19.1	5.9	13.8	12.1	14.4	4.5	9.6	15.6	7.8	15.9

Values followed by different letters are significantly different (Turkey's test, $P < 0.1$).

† SD: Standard deviation; †† CV: Coefficient of variation.

Table 4.8: Performance of rice varieties, in terms of agronomic traits and yield, in experimental plot A in summer–autumn of 2012

Trait	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1,000–grain weight	Total biomass	Harvest index	Yield
Variety	(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)	(g $plant^{-1}$)
MNR3	96.0 abc	7.5 abc	24.6 a	1.9 a	125.3 ab	81.1 ab	65.1 cde	24.0 bc	29.9 a	42.6 abc	12.7 a
OM5629	101.0 ab	7.8 abc	23.9 abc	2.4 a	142.1 ab	93.3 ab	66.2 bcd	25.3 ab	35.0 a	43.1 abc	15.1 a
OM2395	96.4 abc	7.9 abc	24.0 abc	1.7 a	95.6 b	76.9 ab	80.3 ab	22.6 bc	24.5 a	46.0 ab	11.3 a
AS996	87.5 c	7.9 abc	23.5 abc	1.8 a	129.9 ab	81.4 ab	65.0 cde	22.1 bc	24.7 a	43.3 abc	10.7 a
MNR4	101.0 ab	7.3 bc	24.5 ab	2.0 a	165.8 a	87.2 ab	52.9 def	23.4 bc	34.0 a	38.4 bcd	13.1 a
CM2	91.1 bc	9.5 ab	21.9 bc	1.6 a	105.3 ab	55.2 b	50.7 ef	28.2 a	32.4 a	43.0 abc	14.0 a
OM6L	95.8 abc	9.7 ab	23.3 abc	2.1 a	118.3 z	85.5 ab	72.6 abc	24.4 abc	31.0 a	49.3 a	15.3 a
OM5900	92.9 abc	9.3 ab	21.6 c	1.7 a	97.8 b	79.1 ab	82.3 a	21.8 bc	27.6 a	50.1 a	13.8 a
OM4900	96.3 abc	7.9 abc	24.0 abc	2.2 a	168.3 a	93.9 ab	55.8 def	23.0 bc	35.1 a	38.3 bcd	13.5 a
0M2718	97.8 abc	7.2 bc	23.7 abc	1.7 a	136.0 ab	74.7 ab	54.9 def	23.0 bc	29.4 a	37.7 cd	11.1 a
OM8104	91.1 abc	10.5 a	22.8 abc	1.8 a	97.2 b	73.3 ab	76.1 abc	24.8 abc	30.7 a	45.3 abc	13.9 a
OM9922	103.8 a	6.1 c	24.4 ab	1.7 a	138.3 ab	66.1 b	47.1 f	25.6 ab	29.0 a	33.8 d	9.9 a
OMCS2000	97.8 abc	8.1 abc	24.2 abc	2.1 a	105.3 ab	86.0 ab	80.9 ab	24.2 bc	28.0 a	45.0 abc	12.7 a
KD	93.9 abc	9.4 ab	23.0 abc	2.4 a	158.1 ab	117.8 a	73.3 abc	20.9 c	33.9 a	44.7 abc	15.2 a
Mean	95.9	8.3	23.5	1.9	127.4	82.2	66.0	23.8	30.4	42.9	13.0
SD†	4.4	1.2	0.9	0.3	25.4	14.5	12.0	1.9	3.5	4.5	1.7
CV †† (%)	4.6	14.5	3.9	13.3	19.9	17.7	18.3	7.8	11.4	10.6	13.2

Values followed by different letters are significantly different (Turkey's test, $P < 0.1$).

† SD: Standard deviation; †† CV: Coefficient of variation.

Table 4.9: Performance of rice varieties, in terms of agronomic traits and yield, in experimental plot B in summer–autumn of 2012

Trait	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1,000−grain weight	Total biomass	Harvest index	Yield
Variety	(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)	(g $plant^{-1}$)
MNR3	88.9 bc	9.1 bcd	23.0 ab	2.1 abc	112.7 bc	78.0 c	69.1 ab	27.3 a	27.5 a	34.2 a	9.4 a
OM5629	104.7 a	8.8 bcd	24.5 ab	2.4 abc	158.6 abc	100.5 abc	63.7 b	24.2 abcd	43.1 a	30.7 a	13.3 a
OM2395	88.0 bc	17.8 a	22.6 b	1.9 bc	94.0 c	79.7 c	84.6 ab	23.6 abcd	45.4 a	35.1 a	15.6 a
AS996	85.7 bc	8.9 bcd	23.6 ab	1.8 bc	106.7 bc	76.7 c	72.6 ab	23.9 abcd	29.5 a	40.2 a	12.0 a
MNR4	92.6 abc	8.7 bcd	24.7 ab	2.8 ab	185.9 a	127.8 ab	69.4 ab	22.2 cde	37.9 a	34.3 a	13.2 a
CM2	87.2 bc	10.9 bcd	22.2 b	2.1 abc	108.4 bc	80.9 c	74.6 ab	26.1 ab	31.8 a	38.1 a	12.2 a
OM6L	94.7 abc	11.8 abcd	22.4 b	1.9 bc	106.2 bc	83.5 bc	78.0 ab	23.0 bcde	35.0 a	41.4 a	14.6 a
OM5900	92.1 abc	12.9 abc	21.4 b	2.1 abc	113.9 bc	97.1 abc	85.2 a	21.5 cde	31.9 a	38.1 a	12.1 a
OM4900	96.1 abc	7.1 cd	24.2 ab	3.0 a	192.9 a	141.5 a	73.6 ab	20.9 de	35.9 a	37.4 a	13.8 a
0M2718	84.8 c	10.7 bcd	23.0 ab	2.3 abc	140.8 abc	95.3 bc	68.3 ab	24.7 abc	34.0 a	39.4 a	13.3 a
OM8104	88.2 bc	11.9 abcd	22.2 b	1.6 c	103.7 bc	71.5 c	70.1 ab	22.9 bcde	34.1 a	31.5 a	10.6 a
OM9922	98.1 ab	5.8 d	26.1 a	2.7 abc	164.9 ab	107.2 abc	65.0 ab	25.0 abc	39.2 a	28.1 a	11.1 a
OMCS2000	90.2 bc	10.1 bcd	23.7 ab	2.0 abc	118.5 bc	85.2 bc	71.9 ab	23.9 abcd	31.8 a	31.1 a	9.9 a
KD	90.6 bc	13.5 ab	23.3 ab	1.7 c	133.8 abc	86.7 bc	66.5 ab	19.7 e	37.9 a	32.3 a	12.2 a
MEAN	91.6	10.6	23.3	2.2	131.5	93.7	72.3	23.5	35.3	35.1	12.4
SD†	5.4	3.0	1.2	0.4	32.2	20.2	6.5	2.0	5.0	4.1	1.8
CV†† (%)	5.9	28.2	5.3	19.1	24.5	21.6	9.1	8.6	14.2	11.5	14.2

Values followed by different letters are significantly different (Turkey's test, $P < 0.1$).

† SD: Standard deviation; †† CV: Coefficient of variation.

Table 4.10: Performance of rice varieties, in terms of agronomic traits and yield, in experimental plot C in summer–autumn of 2012

Trait	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1,000–grain weight	Total biomass	Harvest index	Yield
Variety	(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)	(g $plant^{-1}$)
MNR3	82.6 a	8.7 a	23.7 a	1.5 a	126.6 abc	67.4 a	53.9 bc	21.5 ab	27.5 a	34.9 abc	9.2 a
OM5629	85.5 a	8.5 a	23.0 a	1.5 a	121.6 abc	72.5 a	60.2 abc	21.1 ab	28.1 a	30.7 bc	8.7 a
OM2395	87.4 a	14.7 a	21.8 a	1.5 a	96.9 bc	67.7 a	66.2 abc	21.5 ab	43.5 a	43.3 ab	19.5 a
AS996	95.4 a	12.1 a	23.5 a	1.8 a	126.7 abc	86.3 a	67.6 abc	21.5 ab	37.5 a	43.9 ab	16.5 a
MNR4	94.6 a	9.9 a	24.3 a	1.5 a	158.0 ab	76.1 a	47.6 c	20.0 ab	35.7 a	33.9 bc	12.2 a
CM2	89.7 a	14.6 a	21.4 a	1.6 a	116.3 abc	66.2 a	56.7 abc	23.5 a	42.7 a	36.3 abc	15.9 a
OM6L	86.7 a	10.7 a	21.4 a	1.1 a	100.1 bc	52.7 a	51.1 bc	20.4 ab	27.4 a	34.5 abc	9.7 a
OM5900	87.0 a	12.3 a	21.7 a	2.0 a	122.5 abc	92.1 a	75.2 a	21.2 ab	35.7 a	47.9 a	17.3 a
OM4900	93.6 a	9.6 a	23.5 a	1.7 a	173.5 ab	88.6 a	50.3 bc	18.8 b	36.7 a	31.6 bc	11.7 a
0M2781	95.0 a	11.6 a	23.3 a	1.6 a	131.7 abc	72.0 a	53.5 bc	22.7 ab	40.9 a	37.2 abc	15.3 a
OM8104	92.3 a	11.6 a	21.4 a	1.4 a	87.6 c	62.1 a	70.6 ab	22.0 ab	30.9 a	41.9 ab	12.9 a
OM9922	85.4 a	9.1 a	23.3 a	1.3 a	123.7 abc	64.5 a	52.2 bc	20.8 ab	24.9 a	26.7 c	6.7 a
OMCS2000	96.1 a	11.5 a	22.4 a	1.4 a	109.6 abc	65.7 a	58.2 abc	20.8 ab	33.1 a	37.5 abc	12.6 a
KD	86.0 a	12.3 a	23.2 a	1.6 a	134.0 abc	86.5 a	66.5 abc	18.9 b	37.6 a	38.2 abc	14.3 a
Mean	89.8	11.2	22.7	1.5	123.5	72.9	59.3	21.1	34.4	37.0	13.0
SD†	4.5	2.0	1.0	0.2	22.7	11.6	8.6	1.3	6.0	5.7	3.7
CV†† (%)	5.1	17.5	4.4	13.9	18.4	15.9	14.4	6.1	17.3	15.5	28.1

Values followed by different letters are significantly different (Turkey's test, $P < 0.1$).

† SD: Standard deviation; †† CV: Coefficient of variation.

Table 4.11: Performance of rice varieties, in terms of agronomic traits and yield, in experimental plot B in winter−spring of 2013

Trait	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1,000−grain weight	Total biomass	Harvest index	Yield
Variety	(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)	(g $plant^{-1}$)
MNR3	92.6 abc	8.2 a	28.8 a	2.7 ab	125.7 abcd	100.5 ab	80.2 ab	26.4 bcde	39.5 a	49.0 ab	19.4 a
OM5629	99.1 a	6.9 a	21.5 b	2.2 abc	99.6 abcde	74.9 b	74.1 b	27.1 abcde	31.3 ab	41.9 bc	13.2 ab
0M2395	87.0 c	10.1 a	21.7 b	2.3 abc	95.7 bcde	85.2 ab	89.3 a	27.9 abc	35.0 ab	51.5 ab	18.1 ab
AS996	87.8 c	9.4 a	22.1 b	2.4 abc	108.1 abcde	87.0 ab	80.7 ab	27.6 abcd	38.4 ab	47.7 ab	18.3 ab
MNR4	93.5 abc	8.3 a	22.0 b	2.7 ab	129.7 ab	102.3 ab	79.2 ab	27.1 abcde	38.8 ab	50.0 ab	19.3 a
CM2	91.5 abc	8.5 a	20.9 b	2.5 abc	102.8 abcde	84.1 ab	82.3 ab	29.9 a	32.9 ab	54.3 a	17.9 ab
OM6L	86.6 c	8.8 a	20.2 b	1.9 c	93.7 cde	79.3 b	84.4 ab	24.0 e	28.4 ab	50.7 ab	14.3 ab
OM5900	86.4 c	9.5 a	20.2 b	1.9 c	84.6 e	76.1 b	89.8 a	24.6 de	27.4 ab	52.3 ab	14.4 ab
OM4900	96.3 ab	7.7 a	21.5 b	2.8 a	131.7 a	115.1 a	87.0 ab	24.8 cde	35.3 ab	52.3 ab	18.4 ab
OM2718	89.8 bc	7.6 a	21.7 b	2.4 abc	124.2 abcd	99.9 ab	78.7 ab	25.2 cde	31.0 ab	43.9 abc	13.6 ab
OM8104	90.1 bc	6.9 a	20.5 b	2.0 bc	83.9 e	69.7 b	83.1 ab	28.7 ab	25.9 b	42.7 bc	11.1 b
OM9922	94.8 abc	7.1 a	23.5 ab	2.3 abc	127.5 abc	98.3 ab	75.5 b	24.9 cde	35.4 ab	34.1 c	12.0 ab
OMCS2000	89.5 bc	8.4 a	21.6 b	2.0 bc	92.5 de	75.3 b	82.6 ab	26.9 abcde	30.7 ab	48.7 ab	15.0 ab
KD	88.6 bc	6.9 a	20.6 b	2.3 abc	114.9 abcde	98.5 ab	84.9 ab	25.0 cde	25.9 b	46.7 ab	12.1 ab
Mean	91.0	8.2	21.9	2.3	108.2	89.0	82.3	26.4	32.6	47.6	15.5
SD†	3.9	1.0	2.2	0.3	17.2	13.4	4.7	1.8	4.7	5.4	3.0
CV†† (%)	4.3	12.8	9.9	13.2	15.9	15.1	5.7	6.6	14.3	11.3	19.1

Values followed by different letters are significantly different (Turkey's test, $P < 0.1$).

† SD: Standard deviation; †† CV: Coefficient of variation.

Table 4.12: Performance of rice varieties, in terms of agronomic traits and yield, in experimental plot C in winter−spring of 2013

Trait	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1,000−grain weight	Total biomass	Harvest index	Yield
Variety	(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)	(g $plant^{-1}$)
MNR3	93.2 ab	7.8 ab	22.9 a	2.5 a	115.0 ab	93.3 a	80.3 a	24.1 abc	28.9 a	50.6 ab	14.6 a
OM5629	98.4 a	8.8 ab	21.6 abc	2.4 ab	108.3 abc	83.3 ab	76.7 a	26.5 ab	32.3 a	47.7 ab	15.5 a
OM2395	89.5 b	9.7 ab	21.5 abc	1.9 ab	86.7 bc	68.0 ab	78.0 a	25.8 ab	28.1 a	52.3 ab	14.7 a
AS996	90.3 b	8.7 ab	22.5 ab	2.2 ab	107.9 abc	80.6 ab	74.6 a	25.1 ab	30.0 a	48.8 ab	14.8 a
MNR4	95.2 ab	7.3 b	22.0 abc	2.2 ab	103.7 abc	80.4 ab	77.2 a	25.7 ab	30.5 a	52.3 ab	16.0 a
CM2	92.5 ab	8.7 ab	20.7 abc	1.9 ab	87.9 bc	63.7 ab	72.4 a	29.3 a	25.4 a	53.6 a	13.7 a
OM6L	89.4 b	8.7 ab	21.7 abc	2.1 ab	98.6 abc	83.1 ab	83.5 a	22.1 bc	25.6 a	52.0 ab	13.3 a
OM5900	90.9 b	10.6 a	20.4 bc	1.9 ab	87.7 bc	74.2 ab	84.5 a	22.3 bc	28.5 a	54.5 a	15.6 a
OM4900	93.2 ab	8.1 ab	22.3 abc	2.3 ab	128.3 a	93.5 a	71.1 a	23.0 bc	32.9 a	49.2 ab	16.2 a
OM2718	93.7 ab	7.9 ab	21.7 abc	2.0 ab	100.3 abc	77.3 ab	76.2 a	23.5 bc	26.7 a	47.9 ab	12.7 a
OM8104	93.6 ab	8.9 ab	19.9 c	1.6 b	70.8 c	55.3 b	77.6 a	25.7 ab	28.8 a	41.3 b	12.0 a
OM9922	92.9 ab	8.1 ab	21.8 abc	2.0 ab	105.8 abc	76.9 ab	73.5 a	23.2 bc	26.1 a	43.4 ab	11.3 a
OMCS2000	91.1 ab	10.2 a	21.5 abc	1.9 ab	90.9 abc	75.1 ab	81.9 a	23.3 bc	29.5 a	49.0 ab	14.6 a
KD	90.6 b	8.1 ab	20.5 abc	1.9 ab	116.6 ab	93.9 a	80.1 a	18.8 c	25.4 a	45.5 ab	12.3 a
Mean	92.5	8.7	21.5	2.0	100.6	78.5	77.7	24.2	28.5	49.2	14.1
SD†	2.5	0.9	0.9	0.2	14.9	11.2	4.0	2.5	2.5	3.8	1.6
CV†† (%)	2.7	10.8	4.0	11.0	14.8	14.3	5.2	10.3	8.6	7.8	11.1

Values followed by different letters are significantly different (Turkey's test, $P < 0.1$).

† SD: Standard deviation; †† CV: Coefficient of variation.

4.3.4 Comparisons of agronomic traits and yield per plant among three experimental plots (A, B, and C) in each cropping season

Table 4.13 shows the mean performance of the 14 rice varieties, in terms of ten main agronomic traits and yield per plant, compared among the three plots A, B, and C in each cropping seasons. In the 2012 summer–autumn cropping season, the mean yield per plant was similar among the three plots (ranged from 12.4 – 13.0 g). In the 2013 winter–spring cropping season, the highest mean yield per plant was in plot B (15.5 g) and the lowest was in plot A (12.3 g). The mean plant height of the 14 studied rice varieties was less than 110 cm, ranging from 89.8 to 95.9 cm in the seven experiments. The mean grain fertility of the 14 varieties in plots A, B, and C ranged from 77.7% to 82.6% in the 2013 winter–spring cropping season, and from 59.3% to 72.3% in the summer–autumn cropping season. The mean values of the other agronomic traits of rice in the seven experiments were low.

4.3.5 Comparisons of agronomic traits and yield per plant for each experimental plot between two seasons (summer–autumn 2012 and winter–spring 2013)

The mean values for the ten main agronomic traits and yield per plant for the 14 rice varieties in each plot between two seasons are shown in Table 4.13. The mean yield per plant across the 14 studied rice varieties in plots A and C in the 2012 summer–autumn cropping season (13.0 g and 12.3 g, respectively) were similar to those in the 2013 winter–spring cropping season (13.0 g and 14.1 g, respectively). The mean yield per plant in plot B in the 2012 summer–autumn cropping season (12.4 g) was lower than that in the 2013 winter–spring cropping season (15.5 g). Mean grain fertility in plots A, B, and C was lower in the 2012 summer–autumn cropping season (66.0%, 72.3%, and 59.3%, respectively) than in the 2013 winter–spring cropping season (80.4%, 82.3%, and 77.7%, respectively). In each of the experimental plots, the four agronomic traits of panicle weight, grain fertility, 1,000–grain weight, and harvest index were higher in the 2013 winter–spring cropping season than in the 2012 summer–autumn cropping season. In contrast, the four traits of number of panicles per plant, panicle length, number of grains per panicle, and total biomass were lower in the winter–spring cropping season than in the summer–autumn cropping season. The number of filled grains per panicle did not differ between the two cropping seasons.

4.3.6 Correlations between agronomic traits and yield

The correlations between each of the ten main agronomic traits and yield per plant, based on data from the seven field experiments, are shown in Tables of 4.14, 4.15, and 4.16. Yield per plant or per hill were positively correlated with five traits; number of productive tillers, panicle weight, number of filled grains, total biomass, and harvest index. The number of grains per panicle and grain fertility were also positively correlated with yield per plant or per hill, but the correlations were weaker (r = 0.2 to 0.4), except for grain fertility in experimental plot C (r = 0.5*** in the 2012 summer–autumn cropping season). Plant height, panicle length, and 1,000–grain weight were not significantly correlated with yield per plant.

Table 4.13: Comparisons of agronomic traits and yield of rice varieties among three experimental plots (A, B, and C) and between two cropping seasons (summer–autumn of 2012 and winter–spring of 2013)

Plots	Plan height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1,000–grain weight	Total biomass	Harvest index	Yield
	(cm)	(plant^{-1})	(cm)	(g)	(panicle^{-1})	(panicle^{-1})	(%)	(g)	(g)	(%)	(g plant^{-1})
Summer–autumn 2012											
A	95.9 a A	8.3 b A	23.5 a A	1.9 B B	127.4 a A	82.2 b A	66.0 b B	23.8 a B	30.4 b A	42.9 a B	13.0 a A
B	91.6 b A	10.6 a A	23.3 a A	2.2 A B	131.5 a A	93.7 a A	72.3 a B	23.5 a B	35.3 a A	35.1 b B	12.4 a B
C	89.8 b B	11.2 a A	22.7 b A	1.5 c B	123.5 a A	72.9 c A	59.3 c B	21.1 b B	34.4 a A	37.0 b B	13.0 a A
Winter–spring 2013											
A	92.5 a B	7.4 c B	22.1 a B	2.2 b A	100.3 b B	81.0 b A	80.4 a A	27.2 a A	24.8 c B	49.4 a A	12.3 c A
B	91.0 b A	8.2 b B	21.9 ab B	2.3 a A	108.2 a B	89.0 a A	82.3 a A	26.4 b A	32.6 a B	47.6 a A	15.5 a A
C	92.5 a A	8.7 a B	21.5 b B	2.0 b A	100.6 b B	78.5 b A	77.7 b A	24.2 c A	28.5 b B	49.2 a A	14.1 b A

Different lowercase letters after values indicate significant difference among experimental plots (A, B and C) in each cropping season (Turkey's test, $P < 0.1$).

Different uppercase letters after values indicate significant difference between 2012 summer–autumn season and 2013 winter–spring season (Fisher's Least Significance Difference Test, $P < 0.1$).

Table 4.14: Correlation matrices between agronomic traits and yield, calculated using data from experimental plot B in winter–spring of 2012

Plot	Traits	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1000–grain weight	Total biomass	Harvest index
		(cm)	($hill^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)
B	Number of productive tillers	-0.2									
	Panicle length	0.6 ***	-0.1								
	Panicle weight	0.2	-0.3 *	0.4 **							
	Number of grains	0.6 ***	-0.1	0.6 ***	0.5 ***						
	Number of filled grains	0.6 ***	0.0	0.7 ***	0.5 ***	1.0 ***					
	Grain fertility	0.3	0.2	0.5 **	0.3	0.3 *	0.6				
	1,000–grain weight	-0.2	-0.1	0.0	0.0	0.0	0.0	-0.2			
	Total biomass	0.4 *	0.7 ***	0.3	0.2	0.3 *	0.4 *	0.3 *	0.0		
	Harvest index	-0.1	0.2	0.2	0.6 ***	0.2	0.2	0.3 *	-0.1	0.2	
	Yield $hill^{-1}$	0.2	0.6 ***	0.3	0.5 ***	0.3 *	0.4 **	0.4 **	-0.1	0.8 ***	0.7 ***

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$

Table 4.15: Correlation matrices between agronomic traits and yield, calculated using data from experimental plots A, B, and C in summer-autumn of 2012

Plot	Traits	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1000−grain weight	Total biomass	Harvest index
		(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)
A	Number of productive tillers	-0.5 ** **									
	Panicle length	0.5 *	-0.5 ***								
	Panicle weight	0.2	0.0	0.3 *							
	Number of grains	0.4 *	-0.3 *	0.5 **	0.6 ***						
	Number of filled grains	0.2	0.0	0.2	0.9 ***	0.7 ***					
	Grain fertility	-0.2	0.4 **	-0.2	0.3	-0.4 **	0.3 *				
	1,000−grain weight	0.0	0.0	-0.1	-0.2	-0.3 *	-0.6 ***	-0.3 *			
	Total biomass	0.1	0.4 *	0.0	0.4 **	0.5 ***	0.4 *	-0.2	0.0		
	Harvest index	-0.4 *	0.5 ***	-0.4 *	0.3 *	-0.3	0.3 *	0.8 ***	-0.2	0.0	
	Yield $plant^{-1}$	-0.1	0.6 ***	-0.2	0.5 ***	0.2	0.5 ***	0.3	-0.1	0.8 ***	0.6 ***

*P < 0.05; **P < 0.01; ***P < 0.001

Table 4.15: Continued

Plot	Traits	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1000−grain weight	Total biomass	Harvest index
		(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)
B	Number of productive tillers	-0.3									
	Panicle length	0.6 ***	-0.5 **								
	Panicle weight	0.5 **	-0.5 **	0.6 ***							
	Number of grains	0.6 ***	-0.4 **	0.7 ***	0.8 ***						
	Number of filled grains	0.5 ***	-0.4 *	0.6 ***	0.9 ***	0.9 ***					
	Grain fertility	-0.2	0.3	-0.4 **	0.0	-0.4 **	0.0				
	1,000−grain weight	-0.2	-0.2	0.0	0.1	-0.3	-0.3 *	-0.1			
	Total biomass	0.5 ***	0.4 *	0.4 **	0.3 *	0.5 **	0.4 *	-0.2	-0.2		
	Harvest index	-0.1	0.2	-0.1	0.2	-0.1	0.2	0.5 **	0.0	-0.1	
	Yield $plant^{-1}$	0.4 *	0.4 *	0.3	0.4 **	0.3 *	0.4 **	0.2	-0.2	0.7 ***	0.6 ***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

Table 4.15: Continued

Plot	Traits	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1000−grain weight	Total biomass	Harvest index
		(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)
C	Number of productive tillers	0.3 *									
	Panicle length	0.5 ***	-0.1								
	Panicle weight	0.6 ***	0.3	0.6 ***							
	Number of grains	0.5 **	0.0	0.7 ***	0.6 ***						
	Number of filled grains	0.5 ***	0.3	0.6 ***	0.9 ***	0.8 ***					
	Grain fertility	0.2	0.4 *	0.0	0.6 ***	-0.2	0.5 **				
	1,000−grain weight	0.1	0.2	0.0	0.2	-0.3 *	-0.1	0.3			
	Total biomass	0.6 ***	0.7 ***	0.3 *	0.6 ***	0.4 **	0.6 ***	0.3	0.1		
	Harvest index	0.4 *	0.5 ***	0.0	0.5 ***	-0.1	0.4 **	0.7 ***	0.3 *	0.4 *	
	Yield $plant^{-1}$	0.6 ***	0.8 ***	0.3	0.7 ***	0.3	0.6 ***	0.5 ***	0.2	0.9 ***	0.7 ***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

Table 4.16: Correlation matrices between agronomic traits and yield, calculated using data from experimental plots A, B and C in winter-spring of 2013

Plot	Traits	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1000−grain weight	Total biomass	Harvest index
		(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)
A	Number of productive tillers	-0.3 *									
	Panicle length	0.1	-0.1								
	Panicle weight	0.2	-0.1	0.7 ***							
	Number of grains	0.3	-0.3	0.7 ***	0.9 ***						
	Number of filled grains	0.2	-0.3	0.7 ***	0.9 ***	0.9 ***					
	Grain fertility	-0.3	0.0	0.1	0.3 *	-0.1	0.3 *				
	1,000−grain weight	-0.1	0.2	-0.2	0.1	-0.2	-0.2	0.1			
	Total biomass	0.2	0.5 **	0.4 *	0.4 **	0.3	0.3 *	0.2	0.2		
	Harvest index	-0.2	0.5 **	0.4 **	0.4 **	0.2	0.3 *	0.4 *	0.3	0.4 **	
	Yield $plant^{-1}$	0.0	0.6 ***	0.5 **	0.5 ***	0.3	0.4 *	0.3	0.3	0.9 ***	0.8 ***

*P < 0.05; **P < 0.01; ***P < 0.001

Table 4.16: Continued

Plot	Traits	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1000−grain weight	Total biomass	Harvest index
		(cm)	($plant^{-1}$)	(cm)	(g)	($panicle^{-1}$)	($panicle^{-1}$)	(%)	(g)	(g)	(%)
B	Number of productive tillers	-0.2									
	Panicle length	0.3 *	0.1								
	Panicle weight	0.4 *	0.0	0.3 *							
	Number of grains	0.3 *	-0.1	0.3 *	0.8 ***						
	Number of filled grains	0.2	0.0	0.3	0.9 ***	0.9 ***					
	Grain fertility	-0.3	0.4 *	-0.1	0.1	-0.2	0.2				
	1,000−grain weight	0.1	0.0	0.0	0.1	-0.4 *	-0.4 **	0.0			
	Total biomass	0.4 **	0.6 ***	0.5 **	0.5 ***	0.5 **	0.4 *	-0.2	0.1		
	Harvest index	-0.2	0.5 ***	0.0	0.3	-0.1	0.2	0.6 ***	0.1	0.1	
	Yield $plant^{-1}$	0.2	0.7 ***	0.4 *	0.5 ***	0.3 *	0.4 *	0.2	0.2	0.8 ***	0.6 ***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

Table 4.16: Continued

Plot	Traits	Plant height	Number of productive tillers	Panicle length	Panicle weight	Number of grains	Number of filled grains	Grain fertility	1000−grain weight	Total biomass	Harvest index
		(cm)	(plant^{-1})	(cm)	(g)	(panicle^{-1})	(panicle^{-1})	(%)	(g)	(g)	(%)
C	Number of productive tillers	-0.2									
	Panicle length	0.2	-0.2								
	Panicle weight	0.4 *	-0.1	0.7 ***							
	Number of grains	0.1	-0.3 *	0.7 ***	0.8 ***						
	Number of filled grains	0.1	-0.2	0.6 ***	0.8 ***	0.9 ***					
	Grain fertility	-0.1	0.3	0.0	0.2	-0.1	0.3 *				
	1,000−grain weight	0.3 *	0.1	-0.1	0.0	-0.4 **	-0.5 ***	-0.2			
	Total biomass	0.3 *	0.4 **	0.3	0.5 ***	0.2	0.2	0.1	0.3		
	Harvest index	-0.2	0.3	0.3 *	0.3	0.1	0.2	0.3	0.0	0.2	
	Yield plant^{-1}	0.2	0.5 **	0.4 **	0.5 ***	0.3	0.3 *	0.2	0.2	0.9 ***	0.6 ***

*P < 0.05; **P < 0.01; ***P < 0.001

4.4 Discussion

Yield is the main trait targeted to improve rice productivity; therefore, it was the key trait used to evaluate the performance of these 14 rice varieties in this specific region of Vietnam. I cultivated the 14 varieties in seven experimental plots with different ECw levels and in two different cropping seasons. The newly introduced varieties MNR3 and OM5629 in experimental plot A (winter–spring cropping season of 2013; ECw from 3.9 to 4.5 dS m^{-1}) produced higher yields than that of the local variety KD (Table 4.4). In addition, the statistical analysis performed using all the values of three experimental plots A, B, and C in the winter–spring cropping season of 2013 that the newly introduced rice varieties of MNR3, MNR4, OM4900, AS996, and OM2395 produced higher yields per plant than that of the local varieties, 16.9 g, 16.2 g, 15.6 g, 15.5 g, and 15.4 g compared with 10.9 g, respectively (Table 4.5). Therefore, we suggest that these newly introduced rice varieties of MNR3, MNR4, OM4900, AS996, and OM2395 are suitable for cultivation on saline soils in the winter–spring cropping season in the north central coastal region of Vietnam. Since the yield per plant of new variety OM5629 was significantly higher than that of the local variety only in the experimental plot A in the winter–spring cropping season (Table 4.4), OM5629 is considered to be suitable only in saline soils with ECw $\leq$ 4.5 dS m^{-1} in this cropping season. On the other hand, in the summer–autumn cropping season, the yield per plant value did not show any significant difference between local variety and newly introduced rice varieties neither when analyzing separately for each of three plots nor for analyzing three plots altogether. Therefore, they can not be proposed as new varieties for cultivation on saline soils in the summer–autumn cropping seasons in this region; that is because high soil salinity, low soil pH and low soil fertility in this cropping season lower yields per plant of all newly introduced rice varieties. The fact that there were few significant differences in yields among the 14 varieties in these experiments is because of the high standard deviations of yield values. However, most of the new varieties showed higher mean values for yield, compared with that of KD.

The performance of the 14 cultivars was evaluated by measuring ten main agronomic traits and yield per plant. All of the varieties performed poorly on the saline soils in this region of north central coastal Vietnam (Table 4.13). That was probably because of effects of high ECw and low soil fertility and low pH (summer–autumn) (Table 4.3). In the 2012 summer–autumn cropping season, mean yield per plant was low and similar among plots A, B, and C (13.0, 12.4, and 13.0 g plant^{-1}, respectively); this may be because of the high temperature, the poor fertility and the low pH in this cropping season (Tables 4.2 and 4.3). Thus, differences in ECw levels did not affect rice yield in the 2012 summer–autumn cropping season in this region of north central coastal Vietnam. In contrast, in the 2013 winter–spring cropping season, the mean yield per plant differed significantly among plots A, B, and C (12.3, 15.5, and 14.1 g plant^{-1}, respectively). In the 2013 winter–spring cropping season, therefore, rice yield was significantly affected by the different ECw levels in the three plots. Mean yield per plant of plot A was the lowest among three plots, only 12.3 g, which may be because this plot had the lowest number of productive tillers per plant of 7.4. Mean yield per plant of plot B was the highest among three plots, 15.5 g, because this plot had high number of productive tillers plant (8.2), panicle weight (2.3 g), number of filled–grains per panicle (89), and 1,000–grain weight (26.4 g). The values for panicle length and 1,000–grain weight in plot C were lower than those in plots A and B in both cropping seasons (Table 4.13); thus, the values for these two traits decreased when ECw was higher than 6.5 dS m^{-1} (Table 4.3 and Fig. 4.2). The responses of other traits to different ECw levels in both cropping seasons were unclear (Table 4.13). The mean plant height of the 14 rice varieties in all plots was less than 110 cm. Based on these mean heights, these varieties can be classified as semi–dwarf rice plants (IRRI, 1996). The mean grain fertility of 14 varieties in the three experimental plots ranged from 59.3% to 72.3% in the 2012 summer–autumn cropping season, and from 77.7% to 82.6% in the 2013 winter–spring cropping season. This result indicated that the fertility rate of all rice cultivars was quite high in the winter–spring cropping season, but low in the summer–autumn cropping season (IRRI, 1996). For all varieties, and in all plots, there was poor performance of other traits including total number of productive tillers per plant, panicle length, panicle weight, number of grains per panicle, number of filled grains per panicle, 1,000–grain weight, total biomass, and harvest index, and yield per plant (IRRI, 1996). Thus, although these 13 new varieties showed high yield potential (approximately 7 – 8 tons ha^{-1}) on saline soils in soils with ECw $\leq$ 10 dS m^{-1} in regions of the Mekong River Delta and the

South Central Coast of Vietnam, their performance in terms of yield per plant and agronomic traits (except grain fertility) was poor on saline soils in the north central coastal region of Vietnam.

Across all 14 cultivars, the yield per plant was higher in experimental plot B (ECw of 6.2 to 6.5 dS m^{-1}) in the 2013 winter–spring cropping season (15.5 g) than in the 2012 summer–autumn cropping season (12.4 g) (Table 4.13). This may be because of the higher temperature, lower air humidity, and lower pH in the summer–autumn cropping season than in the winter–spring cropping season (Tables 4.2 and 4.3). Mean grain fertility in plots A, B, and C was lower in the 2012 summer–autumn cropping season (66.0%, 72.3%, and 59.3%, respectively) than in the 2013 winter–spring cropping season (80.4%, 82.3%, and 77.7%, respectively). This was because the air humidity was much lower in the summer–autumn cropping season than in the winter–spring cropping season (Table 4.2). When the air humidity is higher, the mucus on the surface of stigmas takes longer to dry. Therefore, the pollination process is more successful under higher air humidity (winter–spring cropping season). The mean number of filled grains per panicle did not differ significantly between the two cropping seasons. This is because the mean number of grains per panicle was higher in the summer–autumn cropping season than in the winter–spring cropping season, but mean grain fertility was higher in the winter–spring cropping season than in the summer–autumn cropping season (i.e. number of filled grains $panicle^{-1}$ = number of grains $panicle^{-1}$ × grain fertility). The mean 1,000–grain weight was higher in the winter–spring cropping season than in the summer–autumn cropping season, but the number of filled grains per panicle was similar in the two cropping seasons. Therefore, panicle weight was greater in winter–spring than in summer–autumn (panicle weight = number of filled grains $panicle^{-1}$ × 1,000–grain weight). The mean total biomass was lower in the winter–spring cropping season than in the summer–autumn cropping season. The harvest index was higher in the winter–spring cropping season than in the summer–autumn cropping season (harvest index = yield $plant^{-1}$/total biomass × 100).

The correlation matrix results are shown in Tables of 4.14, 4.15, and 4.16. The matrix values indicated that yield per plant or per hill were positively correlated with five traits: number of productive tillers, panicle weight, number of filled grains per panicle, total biomass, and harvest index. These correlations were found in all of the experiments, indicating that these five traits were the best indicators of yield, and contributed more to yield per plant than did the other agronomic traits. Therefore, rice varieties suitable for cultivation in this region of Vietnam should be selected based on these traits. Because correlations between the agronomic traits and yield of rice are strongly influenced by environmental conditions and genotype, the correlation matrix results are not identical to those obtained under different experimental conditions (Senanayake and Wijerathen, 1988). For example, Oad *et al*. (2002) reported positive correlations between yield and 1,000–grain weight, number of panicles per plant, and panicle length; Sajjiad (1990) reported positive correlations between yield and number of productive tillers per plant, number of grains per panicle, grain fertility, and harvest index; Khan *et al.* (2009) indicated that yield was positively correlated with panicle length and number of grains per panicle; Akinwale *et al.* (2011) reported that yield was positively correlated with number of tillers per plant, panicle weight, and number of grains per panicle; and Sürek and Beser (2003) reported that yield was positively correlated with total biomass, harvest index, and number of filled grains per panicle. Based on these results, we conclude that the correlations between agronomic traits and yield should be analyzed for rice varieties grown under the specific environmental conditions in this region, to select the best yield indicators.

4.5 Conclusions

I conducted seven field experiments in which I grew 14 varieties of rice in three plots with different salinity levels in two different cropping seasons. Since the newly introduced rice varieties of MNR3, MNR4, OM4900, AS996, and OM2395 produced higher yields per plant than that of the local varieties, we propose that these five newly introduced rice varieties are suitable for cultivation in saline soils in the winter–spring cropping season in the north central coastal region of Vietnam. In addition, the newly introduced rice variety of OM5629 produced greater yields per plant than that of the local variety KD only in the experimental plot A (winter–spring 2013, ECw from 3.9 to 4.5 dS m^{-1}). Therefore, OM5629 may be suitable for cultivation under the condition of saline soils with ECw $\leq$ 4.5 dS m^{-1} in the winter–spring cropping season. None of the 13 new rice varieties can be suggested as new varieties for cultivation on saline soils in the summer-autumn cropping season in this region; This is because the high ECw, low soil fertility, and low pH (summer–autumn cropping season) resulted in low yields for all of the studied rice varieties. My results of correlations between yield and various agronomic traits showed that, under these conditions, yield was positively correlated with five traits: number of productive tillers, panicle weight, number of filled grains per panicle, total biomass, and harvest index. As these correlations were observed in all seven experiments, I conclude that these five traits are the best yield indicators, and contribute more to yield than do the other agronomic traits. Therefore, I suggest that these traits should be used to select the best rice varieties for cultivation in this region, which is characterized by sandy loam saline soils with low pH and poor in fertility.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 General summary

In the north central coastal region of Vietnam, some agricultural land is seriously affected by soil salinization. Therefore, income of farmers in this region is very low. In order to increase income of farmers, the improvement of rice cropping in saline soils is a crucial and effective solution. To solve these needs, in my doctorate study program, I conducted two studies. The first study entitled *spatiotemporal variability of salinity and its effects on rice production* and the second study entitled *assessment of performance of newly introduced salt–tolerant rice varieties on saline soils*. The objective of the first study is to clarify the current status, variability, and mechanisms of soil salinity. The second study is conducted with a main aim to identify the newly introduced rice varieties that has higher yield than the local variety KD in the saline soils; this is one of an effective solution to promote rice yield in saline soils. In addition, the other aim of the second study is to determine the best yield indicators and quantify their contribution to yield, which can optimize selection of rice breeding lines for the region of the north central coastal of Vietnam.

5.2 Spatiotemporal variability of soil salinity and its effects on rice production

To clarify the current status, variability and mechanisms of soil salinity, I examined the spatial distribution and temporal variability of soil salinity in paddy fields and evaluated the influence of relative elevation in tens–centimeters scale, ECe, ECw and soil properties on rice yield. Experiments were conducted at 19 different paddy field plots distributed in Quang Phuoc commune, Quang Dien district of Thua Thien Hue province, in the north central coastal region of Vietnam.

Results of physicochemical analysis indicated that soil fertility of all soil samples was low with pH of saturation paste (4.1 – 6.2), CEC (2.0 – 6.4 $cmol_c\ kg^{-1}$), total C (7.8 to 15.2 $g\ kg^{-1}$), and total N (0.8 to 1.6 $g\ kg^{-1}$). Salinity of main irrigation rivers was low, ranging from 0.06 to 0.11 dS m^{-1}. In saturation extracts, main cations were Na^{+}, Ca^{2+}, Mg^{2+}; and anions were Cl^{-} and SO_4^{2-}. Na^{+} and Cl^{-} are considered to be brought by the seawater intrusion. Based on the values of relative elevations and ECe of 19 representative plots, the research site can be divided into low– and high–elevation plots, with elevation of the low–elevation plots ranging from –0.52 to 0.07 m and the high–elevation plots from 0.26 to 0.86 m. The low–elevation plots distributed in the central part of the commune and along the lagoon, and the higher plots were along two main irrigation rivers. ECe and ECw in the high–elevation plots were less than 1.9 dS m^{-1}. Meanwhile ECe and ECw in the low–elevation areas were much higher than the threshold value of 1.9 dS m^{-1}, above which the rice growth is negatively affected. In both high– and low–elevation plots, ECe and ECw from May to September were much higher than in January and the differences between May and September were small. Rice yield in the summer–autumn cropping season was lower than in the winter–spring cropping season. Rice yield in summer–autumn cropping was negatively correlated with ECe (rs = –0.51, $P < 0.05$), while a non–significant correlation was observed in winter–spring cropping.

In conclusion, soils in research site were not suitable for rice growth (production), because of low soil fertility indicated by low pHe, CEC, total C, total N and high ECe. Although the differences in relative elevations between the 19 plots were very small (tens of centimeters), they can lead to large differences in soil salinity; ECe and ECw in the low–elevation plots were much higher than in the high–elevation plots. In the high–elevation plots, soils were irrigated by freshwater with low EC, and not considered to seawater intrusion; thus their ECe and ECw were kept low throughout the year. Because ECe levels were much lower than the threshold for rice growth of 1.9 dS m^{-1}, rice growth and production was not influenced by salinity. However, as introduced in Chapter 2, soils were poor in fertility, as indicated by the low pHe, CEC, total C, and total N; soil fertility is therefore also considered one of the main factors limiting rice production in the high–elevation plots, even if soil salinity is not a serious problem. In the low–elevation plots, soils were subject to seawater intrusion, thus their ECe and ECw were much higher than the threshold value of 1.9 dS m^{-1} for rice growth and soils also had poor fertility; hence, rice yield at the low–elevation plots was considered to be affected by soil salinity, in addition to inherently low soil fertility. Salinity level of soil solution from May to

September was the highest in year, which is considered to be caused by seawater intrusion due to the shortage of irrigation water, high temperature, and high surface water evaporation rate during this period.

5.3 Performance of newly introduced salt–tolerant rice cultivars on saline soils

To increase the yield of rice in the region of the Thua Thien Hue Province, high–yielding varieties can be cultivated instead of low–yielding local rice varieties. However, it is time–consuming and expensive to breed new high–yielding salt–tolerant varieties for specific regions. The most effective strategy, therefore, is to introduce high–yielding, salt–tolerant varieties that have been bred and/or cultivated in other regions to the Thua Thien Hue Province. To achieve this objective, I evaluated the performance of 13 newly introduced, high–yielding, salt–tolerant rice varieties and one local variety KD on saline soils. Although the correlations between rice agronomic traits and yield have been intensively studied, there have been no reports on these relationships for the new rice varieties cultivated in this province. Therefore, it is important to analyze the relationships between various rice traits and yield to identify the best yield indicators and their contributions to yield. This information can be used to select the best breeding lines to cultivate in the north central coastal region of Vietnam.

Among the 14 studied rice varieties in the seven field experiments, only MNR3 and OM5629 in experimental plot A (2013 winter–spring cropping season; ECw from 3.9 to 4.5 dS m^{-1}) showed significantly higher yields per plant than that of the local variety KD (16.5 g and 15.3 g compared with 8.3 g, respectively). The other varieties showed low yields per plant (9.0 – 13.5 g). In the statistical analysis performed using all the values of three experimental plots in the winter–spring cropping season, the five newly introduced rice varieties of MNR3, MNR4, OM4900, AS996, and OM2395 recorded significantly higher yields per plant, that is, 16.9 g, 16.2 g, 15.6 g, 15.5 g, and 15.4 g, respectively, than that of the local variety KD, 10.9 g. In contrast, the analysis including all the experimental plots did not give any statistically significant difference for yields per plant between thirteen newly introduced rice varieties and local variety KD in the summer–autumn cropping season. The yield per plant of the 14 studied rice varieties in the other six experimental plots was not significantly different from that of the local variety KD.

Yield per plant or per hill were positively correlated with five traits; number of productive tillers, panicle weight, number of filled grains, total biomass, and harvest index. The number of grains per panicle and grain fertility were also positively correlated with yield per plant or per hill, but the correlations were weaker (r = 0.2 to 0.4), except for grain fertility in experimental plot C (r = 0.5*** in the 2012 summer–autumn cropping season). Plant height, panicle length, and 1,000–grain weight were not significantly correlated with yield per plant.

In conclusion, since the newly introduced rice varieties of MNR3, MNR4, OM4900, AS996, and OM2395 produced higher yields per plant than that of the local variety, we propose that these five newly introduced rice varieties are suitable for cultivation in saline soils in the winter–spring cropping season in the north central coastal region of Vietnam. In addition, the newly introduced rice variety of OM5629 produced greater yields per plant than that of the local variety KD only in the experimental plot A (winter–spring 2013, ECw from 3.9 to 4.5 dS m^{-1}). Therefore, OM5629 may be suitable for cultivation under the condition of saline soils with ECw $\leq$ 4.5 dS m^{-1} in the winter–spring cropping season. None of the 13 new rice varieties can be suggested as new varieties for cultivation on saline soils in the summer-autumn cropping season in this region; This is because the high ECw, low soil fertility, and low pH (summer–autumn cropping season) resulted in low yields for all of the studied rice varieties. My results of correlations between yield and various agronomic traits showed that, under these conditions, yield was positively correlated with five traits: number of productive tillers, panicle weight, number of filled grains per panicle, total biomass, and harvest index. As these correlations were observed in all seven experiments, I conclude that these five traits are the best yield indicators, and contribute more to yield than do the other agronomic traits. Therefore, I suggest that these traits should be used to select the best rice varieties for cultivation in this region, which is characterized by sandy loam saline soils with low pH and poor in fertility.

5.4 Solutions to mitigate the unfavorable effects of salinity and promote rice cropping

Based on these results, some solutions are recommended to mitigate the unfavorable effects of soil salinization and promote rice cropping. A dike with sluice gates stretching along the lagoon was constructed from 1994 to 1995 for preventing saltwater intrusion from the lagoon onto land; however, there are some sections of the dike that haven't been constructed, because of the financial constraints. Therefore, a complete dike system has to be constructed along the lagoon to completely prevent seawater intrusion onto land. Second, because there are difficulties associated with draining in the depression plots, it is necessary to construct adequate drainage facilities to promote rapid drainage of water into the canals during and after flooding and irrigation in these plots. Third, because ECe and ECw increase from May to September, appropriate fresh irrigation water should be supplied frequently for rice fields to lower the ECe and ECw during this period. Farmers must maintain appropriate freshwater levels on the rice fields to compensate for the water lost by evaporation when high air–temperature. In addition, the irrigation freshwater quantity in the rivers must be provided appropriately to push back the saltwater intrusion from lagoon, thus famers can use freshwater for their fields. Fourth, since soil fertility was poor with low organic matter content and low pH, application of organic fertilizers and lime should be repeated annually over a long time period (Corwin and Lesch, 2003). Finally, regarding improving rice breeding: at present, farmers in the Quang Phuoc commune are cultivating the low–yielding local rice variety of KD. Hence, to increase rice yield and income of farmers, this local variety need to be replaced by the six newly introduced rice varieties of MNR3, MNR4, OM4900, AS996, OM2395, and OM5629. However, the newly introduced rice variety of OM5629 may be suitable for cultivation under the condition of saline soils with ECw ≤ 4.5 dS m^{-1} in the winter–spring cropping season.

REFERENCES

Akinwale, M.G., Gregorio, G., Nwilene, F., Akinyele, B.O., Ogunbayo, S.A., Odiyi, A.C., 2011. Heritability and correlation coefficient analysis for yield and its components in rice (Oryza sativa L.). African J. Plant Sci., 5(3): 207–212.

Allakhverdiev, S.I., Sakamoto, A., Nishiyama, Y., Inaba, M., Murata, N., 2000. Ionic and osmotic affects of NaCl–induced inactivation of photo–systems I and II in synechococcus sp. Plant Physiol., 123(3): 1047–1056.

Blakemore, L.C., Searle, P.L., Daly, B.K., 1987. Methods for chemical analysis of soils. NZ Soil Bureau Scientific Report. No. 80. Department of Scientific and Industrial Research, Lower Hutt, New Zealand. pp. 11–12.

Bresler, E., McNeal, B.L., Carter, D.L., 1982. Saline and Sodic Soils: Principles–Dynamics–Modeling. Springer–Verlag Berlin Heidelberg, New York, USA. pp. 170.

Corwin, D.L., Lesch, S.M., 2003. Application of Soil Electrical Conductivity to Precision Agriculture: Theory, Principles, and Guidelines. Agron. J., 95: 455–471.

Dan, N.V., Hai, H.T., An, N.H., 2006. Results of Livelihood Analysis by Participatory Rural Appraisal in Quang Phuoc Commune 2006: Integrated Management of Lagoon Activities in Tam Giang Cau Hai Lagoon (IMOLA) Project. People's Committee of Thua Thien Hue Province, Hue City, Vietnam. pp. 1–8.

Funakawa, S., Kosaki, T., 2007. Potential risk of soil salinization in different regions of Central Asia with special reference to salt reserves in deep layers of soils. Jpn. J. Soil Sci. Plant Nutr., 53: 634–649.

Funakawa, S., Suzuki, R., Karbozova, E., Kosaki, T., Ishida, N., 2000. Salt–affected soil under rice–based irrigation agriculture in southern Kazakhtan. Geoderma, 97: 61–85.

General statistics office of Vietnam 2014a. Yield of main annual crops. http://www.gso.gov.vn/default_en.aspx?tabid=469&idmid=3&ItemID=14321 (July, 2014).

General statistics office of Vietnam 2014b. Planted area of main annual crops. http://www.gso.gov.vn/default_en.aspx?tabid=469&idmid=3&ItemID=14322 (July, 2014).

Ghafoor, A.G., Qudir, M., Murtaza, G., 2004. Salt Affected Soil: Principles of Management. Institute of Soil and Environmental Science, University of Agriculture, Faisalabad. Pakistan. pp.110–111.

Grattan, S.R., Zeng, L., Shannon, M.C., Roberts, S.R., 2002. Rice is more sensitive to salinity than previously thought. Calif. Agric., 56(6):189–198.

Gregorio, GB., 1997. Tagging salinity tolerance genes in rice using amplified fragment Length polymorphism (AFLP). PhD. Thesis University of the Philippines Los Bãnos. Laguna. Philippines.

Haque, S.A., 2006. Salinity problems and crop production in coastal regions of Bangladesh. Pak. J. Bot., 38(5): 1359–1365.

Haruyama, S., Dinh, H.T., Le, V.T., 2006. Problem Soils of the Paddy Fields in the Eastern Coastal Plain of the Red River Delta, Vietnam. J. Geogr., 115(6): 737–749.

International Rice Research Institute (IRRI), 1996. Standard Evaluation System for rice. 4th Edition. Manila, Philippines. pp. 11–13.

Jackson, M.L., Lim, C.H., Zelazny, L.W., 1986. Part 1. Physical and Mineralogical Methods. Method of Soil Analysis: 2nd edition. Ed. Klute A., American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA pp. 383–411.

Khan, A.S., Imran, M., Ashfaq, M., 2009. Estimation of genetic variability and correlation for grain yield component in rice (Oryza sativa L.). American–Eurasian J. Agric. & Environ. Sci., 6(5): 585–590.

Lang, N.T., Buu, B.C., Viet, N.V., Ismail, A.M., 2010. Part III: Agriculture. Strategies for Improving and Stabilizing Rice Productivity in the Coastal Zones of the Mekong Delta, Vietnam. Tropical Deltas and Coastal Zones: Food Production, Communities and Environment at the Land–Water Interface. Eds. Hoanh C.T, Szuster BW, Suan–Pheng K, Ismail AM, Noble AD. CPI Antony Rowe Ltd, Wallingfprd, UK. pp. 209–222.

Li, Y., Shi, Z., Li, F., 2007. Delineation of Site–Specific Management Zones Based on Temporal and Spatial Variability of Soil Electrical Conductivity. Pedosphere, 17(2): 156–164.

Miller, J.J., Curtin, D., 2006. Chapter 15. Electrical Conductivity and Soluble Ions. Soil Sampling and Methods of Analysis. 2nd Edition. Eds. Carter M.R., Gregorich E.G., Can. J. Soil Sci., pp. 161–171.

Moral, F.J., Terrón, J.M., Marques, J.R., 2010. Delineation of management zones using mobile measurements of soil apparent electrical conductivity and multivariate geostatistical techniques. Soil Tillage Res., 106: 335–343.

Oad, F.C., Samo, M.A., Zia–Ul–hassan, S.C.P., Oad, N.L., 2002. Correlation and path analysis of quantitive characters of rice ratoon cultivars and advance lines. Int. J. Agri. Biol., 4(2): 204–207.

Qadir, M., Ghafoor, A., Murtaza, G., 2000. Amelioration strategies for saline soils: A review. Land Degrad. Dev., 11: 501–521.

Ramakrishnan, S.H., Anandakumar, C.R., Saravanna, S., Malini, N., 2006. Association analysis of some yield traits in rice (Oryza sativa L.). J. Appl Sci Res., 2(7): 402–404.

Rasheed, S.M., Sadaqat, H.A., Babar, M., 2002. Correlation and path coefficient analysis for yield and its components in Rice (Oryza sativa L.). Asian J Plant Sci., 1(3): 241–245.

Rowell, D.L., 1994. Chapter 14. The preparation of saturation extracts and the analysis of soil salinity and sodicity. Soil Science: Methods and Applications. Ed. Rowell D.L., Longman Group, Essex, UK. pp. 277–302.

Sajiad, M.S., 1990. Correlations and path coefficient analysis of rice under controlled saline environment. Pakistan. J. Agric. Res., 11(3): 164–168.

Senanayake, S.G.J.N., Wijerathen, V., 1988. Heritability and genotypic and phenotypic correlations of yield, yield components, and protein content in Cowpea (Vigna unguiculata (L.) Walp.). Beitrage zur Tropischen Landwirtschaft and Veterinarmedizin. 26(3): 279–283.

Sugimori, Y., Funakawa, S., Pachikin, K.M., Ishida, N., Kosaki, T., 2008. Soil salinity dynamics in irrigated fields and its effects on paddy–based rotation systems in southern Kazakhstan. Land Degrad. Dev., 19: 305–320.

Sürek, H., Beşer, N., 2003. Correlation and path coefficient analysis for some yield–related traits in rice (Oryza sativa L.) under Thrace condition. Turk. J. Agric., 27: 77–83.

United States Salinity Laboratory Staff, 1954. Diagnosis and Improvement of Saline and Alkali soils. Agriculture Handbook. No. 60. Ed. Richards L.A., U.S. Government Printing Office, Washington DC., USA. pp. 69–81.

Vietnam Soil Science Society (VSSS), 1996. The Soils of Vietnam. Agricultural Publishing House, Ha Noi, Vietnam (in Vietnamese).

Yoshida, S., 1981. Fundamentals of Rice Crop Science. International Rice Research Institute (IRRI). Los Baños, Laguna, Philippines. pp. 29–61.

Zeng, L., Shannon, M.C., 2000. Salinity effects on seedling growth and yield components of rice. Crop Sci. 40: 996–1003.

Zeng, L., Shannon, M.C., Grieve, C.M., 2002. Evaluation of salt tolerance in rice genotypes by multiple agronomic parameters. Euphytica 127: 235–245.

Zheng, Z., Zhang, F., Ma, F., Chai, X., Zhu, Z., Shi, J., Zhang, S., 2009. Spatiotemporal changes in soil salinity in a drip–irrigated field. Geoderma, 149: 243–248.

PUBLICATIONS

Chapter 3

Nguyen, L., Watanabe, T., Funakawa, S., 2014. Spatiotemporal variability of soil salinity and its effects on rice production in north central coastal of Vietnam. Proceeding of 20th World Congress of Soil Science, Korea. Abstract No. AF1372.

Nguyen, L., Watanabe, T., Funakawa, S., 2014. Spatiotemporal variability in soil salinity and its effects on rice production in the north central coastal region of Vietnam. Soil Sci. Plant Nutr., 1–12.

Chapter 4

Nguyen, L., Watanabe, T., Phan, N., Hoang, K., Funakawa S., 2014. Assessment of performance of newly introduced salt–tolerant rice cultivars on saline soil in the north central coastal region of Vietnam. (Submitted to the Journal of Tropical Agriculture and Development, under review).