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ARTICLE

Rice genotype and fertilizer management for improving rice productivity under saline soil conditions

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Abstract

Soil salinity is a threat to crop production in the Senegal River Delta where salt intrusion increases soil electrical conductivity and most of farmers had abandoned their rice farms. The objective of this study was to evaluate an integrated management to improve rice productivity under saline soil condition in the Senegal River Delta. Field experiments were conducted during four rice-growing seasons from July 2014 to July 2016 at Africa Rice Center research station at Ndiaye, Senegal. The performance of five rice genotypes (IR63275-B-1-1-3-3-2, WAS73-B-B-231-4, NERICA-L9, FL478, and IR29) was evaluated under three salinity levels (0.5–0.8 dS m^{-1}, 2.0 dS m^{-1}, 3.5 dS m^{-1}) and two fertilizer management options (basal dressing at 100 kg ha^{-1} of N–P–K (15–15–15) only and basal dressing at 200 kg ha^{-1} of N–P–K (15–15–15) + 50 kg N ha^{-1} urea at panicle initiation and at booting. Rice seedlings were raised at nursery for 21 days and transplanted at the density of 20 cm × 20 cm around March 15 and August 15 and harvested around July 15 and early December. The plots were drained canal when soil EC increased 0.1 dS m^{-1} above the designed EC levels. The results showed that rice yield decreased with the increasing soil salinity and were season dependent. Rice grain yield varied from 0.9 to 8 tons ha^{-1}. Rice grain yield was 20% higher during the hot and dry seasons than the wet season. The application of the recommended fertilizer improved rice yield by 52% compared to the basal fertilizer application only. Nitrogen application at panicle initiation and at booting stages in addition to the basal fertilizer application doubled rice grain yield and should be adopted under salinity condition across the Senegal River Delta. The analysis of the combination of yield index, yield stability index, stress susceptibility index and the stress tolerant index indicated that the newly developed rice genotypes IR63275-B-1-1-3-3-2 and WAS73-B-B-231-4 showed high salt tolerance with better yield stability and low stress susceptibility and constitute good candidate to be adopted under the best fertilizer management option in the Senegal River Delta climate, soil salinity and similar environmental conditions.

Keywords Soil salinity · Rice yield · Fertilizer · Semiarid climate

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Introduction

Soil salinization constitutes a major threat to irrigated agriculture (mainly rice, *Oryza sativa* L.) in the Senegal River Delta and middle valley (Tanaka et al. 2015; Diagne et al. 2013; Saito et al. 2013). Salinity is one of the major abiotic stress factors for grain yield of many crops (Sekmen et al. 2007; Maggio et al. 2011) and affects about 20% of irrigated land worldwide (Rozema and Flowers 2008). It has been projected that by the year 2050, there will be more than 50% of the farm land affected by salinity, worldwide (Jamil et al. 2011). Total salt-affected soils land area is estimated to be 18 billion hectares of which 23% are considered as saline soils and 37% are sodic soils (Borsani et al. 2003). In the coastal regions, aquifer salinization is also caused by salt water intrusion (Mongelli et al. 2013) because of groundwater overexploitation (Balia and Viezzoli 2015) where rainfall does not much compensate crop evapotranspiration usually high under arid and semiarid climates. Rhoades et al. (1997) and Szabolcs (1994) reported that more than 10% of irrigated lands have salt-affected soil which is a threat to rice production and is supposed to be intensified under changing climate (Playán et al. 2008). Soil salinization is a natural process with natural salts accumulation from the degradation of the parent materials or groundwater. Secondary, soil salinization is due to over-irrigation and poor saline irrigation water and drainage management (Yuan et al. 2007). Soil hydrological, physical, chemical, and microbial properties are affected by salinity. Salinity is one of the most important environmental constraints that affect adversely plant growth and metabolism, particularly in the arid and semiarid regions (Munns and Tester 2008). Salt stress affects plants by changing plant basic biological functions including photorespiration and photosynthesis, molecule synthesis, translation and transcription, and enzymes (Mittler 2002; Flexas et al. 2004; Neto De Azevedo et al. 2006; Türkan and Demiral 2009; Zribi et al. 2009). Crop growth and development are affected by soil salinity (Keren 2000; Liang et al. 2003; Gregorio et al. 2002; Jampeetong and Brix 2009a, b; Nishimura et al. 2011, Lekakis et al. 2015). Horie et al. (2012) indicated that plants under salinity showed unbalance nutrient uptake, stomatal closure, and reduction in photosynthetic activity. Moradi and Ismail (2007) reported genotypic variability in plant tissue concentration of Na^+ under salt stress associated with variation in photosynthesis. However, plant physiological, biochemical, and genetic characteristics play an important role in the adaptation of rice to saline environments (Hussain et al. 2018). Yuan et al. (2007) reported significant negative relationship between microbial biomass and soil electrical conductivity under salt-affected soil. Moradi and Ismail (2007) indicated that high salt concentrations contribute to leaf chlorosis, malfunction of the chloroplasts, and photoinhibition or photooxidation.

The impact of soil salinity on rice crop is dependent on the salinity level and the occurring period relative to crop growth stages. Rice crop is very sensitive to salinity at early growth stages and reproductive stage. It also disturbs the antioxidants mechanisms and osmo-protectants balance of the plant (Singh et al. 2007). Asch et al. (2000) reported salt susceptible rice cultivar yield reduction to nearly zero and biomass accumulation by 90%. Van Genuchten and Gupta (1993) reported rice critical salinity level of 6.9 dS m^{-1} that causes 50% grain yield loss. However, there is great variation in the effects of salt stress on the rice crop as the effects vary with crop growth stage (Khan et al. 1997; Zeng and Shannon, 2000a, b). Salt tolerance in rice resulting in 50% yield and at 50% emergence was 3.6 dS m^{-1} and 18 dS m^{-1} of ECe, respectively (Wahhab 1961). High salinity level of the ECe of greater than 8.0 dS m^{-1} reduces grain yield and rice qualities, including softness, stickiness, whiteness and glassiness of boiled rice, but increases the aromatic substance contents (Suwanarit et al. 1991; Wanichananan et al. 2003; Suwiphaporn et al. 2014).

Rice planted area in West Africa is more than 4.4 million ha of which 25% are affected by salinity mainly in semiarid coastal regions (Sylla et al. 1995; Lançon and Erenstein 2002; Meena et al. 2016a, b). Moreover, 1.5 million ha of cultivable mangrove swamps in West Africa are affected by salinity (Jones 1986). Salinity problem is expected to increase due to the combination of current agricultural practices and change in climatic parameters. In the Senegal River Valley and Delta, salt-affected area approximates 179,765 ha representing 74% of the potential of irrigated land (Dumas et al. 2010). However, irrigated rice cropping is the main agricultural activity in the region with reduced paddy yield due to salinity and which may contribute to more than 50% of the domestic paddy rice production in the Senegal (MAER 2014). Several strategies have been developed to mitigate the impact of salinity on rice grain yield including soil amendment using gypsum, irrigation amount and frequency management, and the good agricultural practices, chemical remediation, nitrogen fertilizer management, and the use of salt tolerant varieties (Ilyas et al. 1997; Cassman et al. 2003; Sharma and Minhas 2005; Yoshida et al. 2006; Peng et al. 2009, 2010; De Vries et al. 2010; Ghanbari-Malidareh 2011; Harrell et al. 2011; Boling et al. 2011; Fan et al. 2012; Norman et al. 2013; Roberts et al. 2013; Plaut et al. 2013; El-Hafez et al. 2016; Mel et al. 2018). Hamid et al. (1993) reported that a combination of superphosphate fertilizer and N-fertilizers resulted in an increase in the uptake of NPK as compared with control. Deposits of marine origin in the sub-soil result in a saline ground water with electrical conductivity of 20 dS m^{-1} or more across the Senegal River Delta (Ceuppens 2000), and the water table fluctuates between 0.4 and 0.9 m below the soil surface. Due to the high soil electrical conductivity in the Senegal river lower delta, most of the field are abandoned. As an alternative solution, the Diama dam completed in 1986 was primarily designed to block sea water intrusion within the Senegal River Valley (SRV) and now serves as a reservoir that facilitates perennial irrigation. The Diama dam changed the ecology and livelihoods of the lower Senegal River in Mauritania and Senegal. In addition to the aforementioned integrated approach combining land reclamation and crop management, salinity can be addressed by crop breeding program by developing salt tolerant varieties for yield stability under salinity condition. Ismail and Tuong (2009) indicated that management practices are not always feasible in the long term, as in coastal areas where salt stress is seasonal or in inlands where land reclamation cost is high. The development and the use of tolerant varieties can alleviate salinity problems in salt-affected rice-growing areas, but this must be combined with other crop management technologies such as a suitable cropping schedule, good agricultural practices, and soil amendment (Epstein et al. 1980; Plaut et al. 2013; Mel et al. 2018). The objective of this study was to evaluate yield performance of four salt tolerant rice genotypes under two fertilizer doses under different salt salinity conditions.

Materials and methods

Site description

The field experiments were conducted at the Sahel research station of Africa Rice Center (AfricaRice), at Ndiaye (16°11′N, 16°15′W), located in a depression along one of the branches of the Senegal River (Haefele et al. 2001). The soil at the research site is characterized as an orthothionic Gleysol, with a clayey structure that contains 40–54% clay, composed of smectite and kaolinite (Haefele et al. 2001). Average percolation rate of this soil was estimated at 2.8 mm d^{-1} (Haefele et al. 2001). The climate in the region is semi-arid, with a wet season (WS) average rainfall of about 250 mm (Salack et al. 2011; Djaman et al. 2015) from July to October, a cold dry season (CDS) from November to February, and the hot dry season (HDS) from March to June. Between March and July, solar radiation and maximum temperatures are high. The study was conducted during the wet season 2014 (WS2014), hot and dry season 2015 (HDS2015), wet season 2015 (WS2015) and hot and dry season 2016 (HDS2016). Weather variables such as wind speed, air temperature, relative humidity, solar radiation, and precipitation were measured using an automated weather station (CimAGRO) installed within AfricaRice research station. Typically, rice production takes place twice a year, i.e., February–July in the HDS, and August–December in WS. Seeds are sown at nursery on February 15 during the HDS and on July 15 during the WS, and rice seedlings are transplanted 21 days after sowing.

Experimental design

Three factors, such as salinity with three levels, fertilizer rate with two levels, and rice genotypes with five levels, were under the study. Prior to the establishment of the research plots, soil electrical conductivity (EC) was extensively measured throughout the Senegal River Delta and the data were used for the choice of the salinity levels to match the study area's conditions for results transferability. Salinity levels were set as three soil EC values as (S1) EC about 0.5–0.8 dS m^{-1}, (S2) EC about 2.0 dS m^{-1}, and (S3) EC about 3.5 dS m^{-1}. Three plots were therefore selected at different areas of the research farm with the appropriate soil salinity conditions which vary spatially in relationship with plot history. The Senegal River was the source of irrigation water. Water was pumped from the Senegal River into a canal and conducted to the plot by gravity. The plots were drained into a drainage canal when soil EC increased 0.1 dS m^{-1} above the designed EC levels. The two fertilizer levels were (F1) basal dressing at 100 kg ha^{-1} of N–P–K(15–15–15) only and (F2) N–P–K(15–15–15) at 200 kg ha^{-1} of N–P–K(15–15–15) and 50 kg N ha^{-1} urea at panicle initiation and at booting. Rice genotypes were selected after field screening of several rice lines developed at Africa Rice and/or introduced from the International Rice Research Institute (IRRI) under the Stress-Tolerant Rice for Africa and South Asia (STRASA) project. Selected rice genotypes with their respective pedigree were: NERICA-L-9 (TOG5681-3/IR64), IR29 (R1561-149-1/R833-6-2-1-1), WAS73-B-B-231-4 (R4630-22-2/R31785-58-1-2-3-3), IR63275-B-1-1-3-3-2 (IR68/TCCP266-2-49-B-B-3), and FL478 (IR29/Pokkali) (Walia et al. 2005; Moukoumbi et al. 2011; Islam et al. 2012). The combination of the three factors (salinity, fertilizer rates, and rice genotypes) were arranged under a split-split plot design with four replications. Soil salinity, fertilizer rates, and the rice genotypes were the main plot, subplot, and sub-subplot, respectively. The rice genotype FL478 was used as salt tolerant variety check. Rice plants were transplanted 21 days after sowing (1 seedling per hill) at the density of 0.20 m x 0.20 m (250000 plants/ha). Herbicide and insecticide were applied, and manual weeding was done as necessary. Soil electrical conductivity (EC) and pH were monitored during the experiment periods. Soil EC was measured using a portable EC/pH meter at three different points on a diagonal within each subplot twice or three times a week mostly before irrigation or drainage cycle. Agronomic parameters collected were crop phenology, plant height, tiller number, above-ground biomass, panicle number, and number of filled and unfilled grains per hill. At crop physiological maturity, five hills were harvested for yield components. Plant heights were measured on ten hills randomly selected at harvesting. The rest of each sub-subplot was harvested after eliminating two border rows of each side for grain yield adjusted to 14% moisture content. The decrease in rice yield under stress condition (S2 and S3) was computed using the following equation:

$$YR = \frac{\left(YS1 - Y_{stress}\right)}{YS1} \times 100 \quad (1)$$

where YR = yield reduction in percent, YS1 is grain yield obtained in non-saline soil (S1), Y_{stress} = grain yield obtained under salt stress condition (S2 or S3).

Yield performance evaluation indexes

To compare the selected rice genotypes between them under the three salinity levels and two fertilizer rates, four indices were used to determine resistant or susceptible genotypes:

Stress Tolerance Index, STI (Fernandez 1992):

$$\mathrm{STI} = Y_s \frac{Y_p}{\left(Y_p\right)^2} \tag{2}$$

Stress Susceptibility Index, SSI (Fischer and Maurer 1978):

$$\mathrm{SSI} = \left(1 - \frac{Y_s}{Y_p}\right) \Big/ \left(1 - \frac{Y_{smean}}{Y_{pmean}}\right) \tag{3}$$

Yield Index, YI (Gavuzzi et al. 1997):

$$\mathrm{YI} = Y_s / Y_{smean} \tag{4}$$

Yield Stability Index, YSI (Bienvenido 1993):

$$\mathrm{YSI} = Y_s / Y_p \tag{5}$$

where Y_p is the grain yields under S1 and Y_s is the grain yields under S1 and S3. Y_{smean} and Y_{pmean} are the mean yield of all five genotypes in stress and non-stress conditions, respectively. The least STI is, the most salt susceptible the genotype is. SSI greater than 1.0 indicates above-average susceptibility to salt stress, and SSI less than 1 indicates below-average susceptibility to salt stress. The YSI value ranges between zero and one, and the least YSI is the most salt susceptible; the genotype is with low grain yield under salt stress. A genotype is considered yield stable with high grain yield compared to all genotypes under salt stress condition if $\mathrm{YI} \geq 1$. The least YI is, the most salt susceptible the genotype is, compared to all genotypes under salt stress.

Statistical analysis

Analysis of variance (ANOVA) was performed to analyze the main effects of the three factors (salinity levels, fertilizer rates, and genotypes) and their interactions using the general linear model procedure in the Statistical Analysis System (SAS Institute 2003). In addition, the regression procedure was used to perform stepwise multiple regression analysis and the treatment means were separated using Fisher's protected least significance difference (LSD) test at the 95% level of probability to identify significant differences between the treatments.

Results and discussion

Weather conditions during the study period

Senegal River Delta is characterized by a semiarid climate with a long dry season from December to June and a short rainy season from July to October with inter-annual variability in the total precipitation that averaged 280 mm (Djaman et al. 2015). The weather condition of the study period is presented in Fig. 1. Air temperature ranged from 8.5 °C (December 2014) to 42.6 °C (May 2015). The lowest temperatures occurred in December–January and the highest temperatures occurred late April–early May (Fig. 1a). Daily average temperature increased from 27 °C in July 2014 to 31 °C late September 2014, and it decreased and reached its minimum value of 20 °C in December 2014. Average daily temperature increased from January to September and decreased thereafter up to late early February 2016 and stayed stable during the period of June–August 2015. Relative humidity at the site followed the same trend as air temperature and the lowest relative humidity occurred during the period of December–March, and the relative humidity is high during the rainy period from July to October (Fig. 1b). There was large fluctuation in the air relative humidity from November to May, and it was more consistently stable from June to early October when the yearly precipitation occurred (Fig. 1b). Average daily wind speed showed seasonality and decreased from an average of 3.6 m s^{-1} in July 2014 to an average of 1.2 m s^{-1} in December and increased up to a maximum of 4.1 m s^{-1} early April 2015 (Fig. 1c). It decreased up to 0.83 m s^{-1} in December 2016 and increased from January to early May in 2016 and showed downward trend toward the end of the HDS 2016. Solar radiation generally increases from January to mid-June and decreases hereafter toward December. Maximum daily solar radiation was 25 MJ m^{-2}, and the minimum daily solar radiation occurred in December. Average daily solar radiation was 19.8, 21.3, 18.3, and 22.5 MJ m^{-2} during the WS 2014, HDS 2015, WS 2015, and DHS 2016, respectively. Total precipitation was 358 mm in 2014, 288 mm in 2015 and 84 mm in June and July 2016 (Fig. 1d).

Rice response to soil salinity

Rice response to soil salinity significantly varied with the soil salinity, genotypes, fertilizer management options and the growing seasons (Table 1). The effect of salinity was significant on crop cycle duration, the number of tillers per hill, grain yield, spikelet sterility, plant height and the 1000-grain weight (Tables 2, 3). Rice yield components

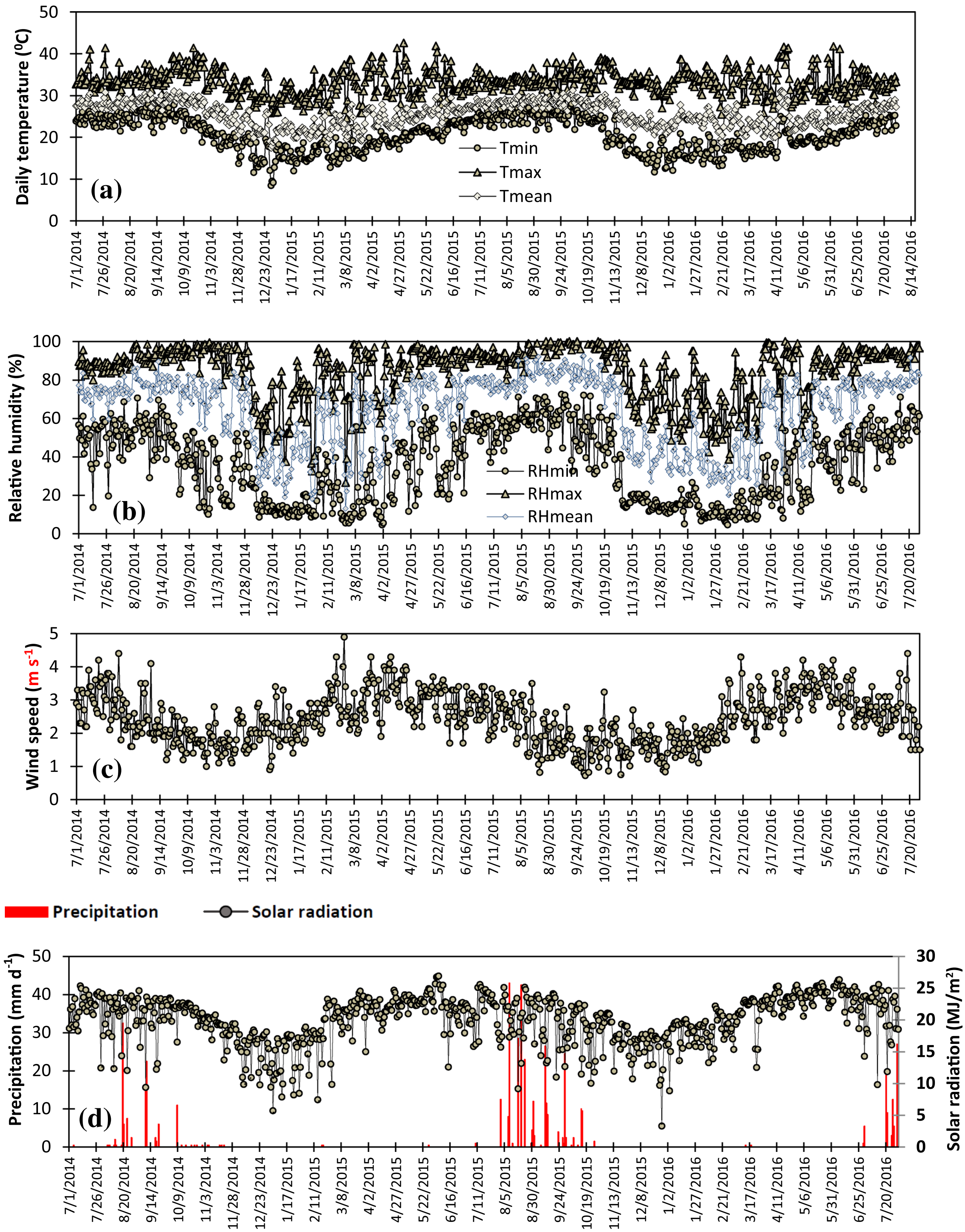

Fig. 1 Evolution of the weather conditions (air temperature, relative humidity, wind speed, precipitation and solar radiation) during the study period (2014–2016)

Table 1 Analysis of variance of measured parameters (values in the table are *p* values except for the df; effect of treatment or interaction between treatment is significant if *p* value is lower than 0.05)

Sources	df	Cycle duration	Tillers/hill	Panicles/hill	Grain yield	Harvest Index	Spikelet sterility	Plant height	1000 grain weight
Salinity	2	<.0001	0.0273	0.0029	<.0001	0.0137	<.0001	<.0001	0.002
Fertilization	1	0.0022	<.0001	0.0002	<.0001	0.3744	0.0001	<.0001	0.001
Variety	4	<.0001	<.0001	<.0001	0.009	<.0001	<.0001	<.0001	<.0001
Season	3	<.0001	0.25	0.41	0.005	<.0001	<.0001	0.7672	0.34
Salinity * fertilization * variety	8	0.55	0.34	0.75	0.88	0.45	0.18	0.92	0.16
Salinity * fertilization	2	0.00	0.08	0.39	0.66	0.06	0.15	0.76	0.18
Salinity * variety	8	0.55	0.67	0.23	0.29	0.38	0.05	0.75	0.33
Fertilization * variety	4	0.51	0.14	0.22	0.77	0.85	0.12	0.39	0.05
Variety * season	12	<.0001	0.86	0.65	0.05	0.01	0.01	<.0001	0.08

were reported only for the WS2014 and HDS2015 due to rodent damage on the five hills harvested for yield components in the storage in WS2015 and HDS2016. Fertilizer management options showed significant effect of the above-mentioned variables except rice harvest index. Different interactions of the studied factors showed different response as presented in Table 1. Overall, rice grain yield decreased with increasing soil salinity and the crop duration was longer under the highest salinity with decreased tiller number and the plant population. Average rice yields are summarized in Table 4. The fertilizer rate F2 improved rice yield by 1.26, 0.72, and 1.36 tons ha^{-1} under S1, S2, and S3, respectively. The highest yield increase of 1.98, 1.06, and 1.84 tons ha^{-1} under S1, S2, and S3, respectively, was obtained by the salt tolerant variety FL478. Under soil salinity S2, there was yield decrease of 29, 19, 15, 18, and 13% for WAS73-B-B-231-4, NERICA-L9, FL478, IR29 and IR63275-B-1-1-3-3-2, respectively, compared to the yield under soil salinity S1, while yield decrease was 43, 47, 39, 44, and 41% for the respective genotypes under S3 compared to the respective yield under S1(Fig. 2). Seasonal rice grain yield averaged 4.03 tons ha^{-1} for the wet season (WS) and 4.8 tons ha^{-1} in the hot and dry season (HDS). In other words, the HDS rice yield was 20% higher than the WS average grain yield. The results of this study are in agreement with Radanielson et al. (2018), Ulery et al. (1998), Steppuhn and Asay (2005), and Steppuhn et al. (2005). Zeng and Shannon (2000b) reported highly significant effects of salinity on grain yield, plant stand, seed weight per plant, panicle weight, and spikelet number per panicle. Ren et al. (2005) and Platten et al. (2013) reported that variability in rice genotypic response to salinity is due to the ability of the genotype to exclude Na + from the shoot (Radanielson et al. 2018). In addition, genotype response to salinity is dependent on the salinity timing, growth stage (Moradi et al. 2003); however, the seedling and the reproductive stages are the most sensitive to salinity. The seasonal variability in rice yield was reported by Djaman et al. (2018), de Vries et al. (2010) in the Senegal River Valley. Rice yield was positively correlated with the average daily income radiation during crop-growing period (Peng et al. 2004; Yang et al. 2008). Kang et al. (2007) and Yang et al. (2008) indicated that salinity causes growth inhibition and yield decrease in rice due to biochemical and physiological changes induced by salt stress. Rice flowering stage was delayed by salinity, and the yield components such as the number of productive tillers, spikelet fertility, 1000 grain weight and the grain yield were affected (Table 1): These results are in agreement with Khatun et al. (1995), Lutts et al. (1995), and Asch and Wopereis (2001) who reported more severe effects of salinity when it occurred during rice reproductive phase with genotypic response variability. Asch and Wopereis (2001) found that most susceptible rice cultivars were affected at seedling stage with 50 to 80% yield loss at high salinity in the Senegal River Delta and suggested that adoption of salt tolerant genotypes, early sowing in the wet season and regular plot drainage are ways to increase rice productivity in the Senegal River Delta. Agronomical parameters (crop growth, leaf area, biomass, yield and yield components) are the main traits of first choice for salinity tolerance screening (Zeng et al. 2002; Moradi and Ismail 2007; El-Hendawy et al. 2009; Bimpong et al. 2016). Soil salinity management is very complex as salt is within the root zone and plot drainage does not always lower soil EC due to the surface drainage. Irrigation–drainage cycles were scheduled to maintain soil EC. Drainage frequency increased in the case of increase in the targeted soil EC, and it decreased when soil EC is lower than the targeted soil EC. Nitrogen fertilizer application timing was challenging as it was function of soil EC level and the rice genotypes under the same salinity level did not have the same phenology and synchronized flowering. Rice flowering stage was delayed under higher

Table 2 Grain yield and yield components of five rice genotypes under three soil salinity levels (S) and two fertilizer rates (F) during the wet season (WS) 2014

Treatments	Genotypes	Phenologic cycle (days)	plant height (cm)	Tiller number	Panicle number	Sterility (100%)	1000 grain weight (g)	Harvest index	Grain yield (tons ha^{-1})
S1.F1	IR63275-B-1-1-3-3-2	110	96.63	14	12.25	31	29.7	0.50	5.92
	WAS73-B-B-231-4	106	90.53	20	18.75	9	22.0	0.56	6.1
	NERICA-L9	107	79.73	21	20.75	13	27.8	0.62	5.74
	FL478	109	82.88	15	14.5	28	28.4	0.51	5.49
	IR29	107	83.85	24	26.5	15	24.5	0.62	6.86
S1.F2	IR63275-B-1-1-3-3-2	110	101.2	16	18.5	23	27.6	0.57	6.56
	WAS73-B-B-231-4	108	91.55	22	18.5	7	18.3	0.58	6.87
	NERICA-L9	105	76.05	18	17.5	11	27.1	0.64	6.2
	FL478	110	80.88	15	14.75	40	32.4	0.49	5.29
	IR29	107	81.3	27	26	11	21.4	0.64	8.05
S2.F1	IR63275-B-1-1-3-3-2	113	87.65	18	17	28	26.7	0.48	3.45
	WAS73-B-B-231-4	107	80.45	24	23.25	11	13.4	0.49	4.15
	NERICA-L9	105	70.3	23	21.75	13	24.2	0.57	4.6
	FL478	112	74.53	15	15.25	26	24.7	0.42	3.97
	IR29	109	76.8	20	19.25	27	24.2	0.47	4.93
S2.F2	IR63275-B-1-1-3-3-2	116	90.78	17	16.5	43	30.4	0.46	4.01
	WAS73-B-B-231-4	108	85.98	26	25.75	12	22.0	0.61	5.43
	NERICA-L9	105	72.28	24	23.25	17	25.3	0.61	5.35
	FL478	113	78.88	16	16	27	25.4	0.47	4.26
	IR29	108	80.68	20	18	22	24.0	0.62	6.59
S3.F1	IR63275-B-1-1-3-3-2	126	79.2	15	12.75	34	24.6	0.43	1.79
	WAS73-B-B-231-4	124	73.33	13	12.5	18	34.7	0.57	1.12
	NERICA-L9	118	61.8	19	19	12	20.8	0.62	2.15
	FL478	126	62.93	12	11.5	39	26.1	0.51	1.08
	IR29	125	69.55	14	13	19	16.7	0.55	2.18
S3.F2	IR63275-B-1-1-3-3-2	134	80.98	19	19	40	28.1	0.44	2.71
	WAS73-B-B-231-4	124	73.33	25	22.25	18	25.3	0.53	0.9
	NERICA-L9	123	61.83	18	16.75	18	22.1	0.58	2.24
	FL478	132	64.08	16	15.5	39	28.8	0.46	1.8
	IR29	124	63.8	23	16.75	35	18.4	0.50	2.37

soil EC, and the second nitrogen application usually coincided with the highest air temperature, driving high crop evapotranspiration (Djaman et al. 2016). Also, the reduced drainage frequency to avoid nitrogen drainage and leaching lead to soil EC increase and impacted spikelet fertility mostly under high soil salinity conditions. Rice genotype WAS73-B-B-231-4 presents erected plant stand with closed canopy and offers opportunity to increase plant density for improving radiation efficiency, photosynthesis and finally its productivity. Integrated management of soil salinity, vegetal material and agricultural practices can sustain rice production under saline soil condition in the Senegal River Delta.

Table 3 Grain yield and yield components of five rice genotypes under three soil salinity levels (S) and two fertilizer rates (F) during the hot and dry season (HDS) 2015

Treatments	Genotypes	Phenologic cycle (days)	plant height (cm)	Tiller number	Panicle number	Sterility (%)	1000 grain weight (g)	Harvest index	Grain yield (tons ha^{-1})
S1.F1	IR63275-B-1-1-3-3-2	134	80.08	12	11	15	29.54	0.42	4.12
	WAS73-B-B-231-4	135	74.33	19	19	6	24.47	0.43	5.32
	NERICA-L9	134	70.88	15	15	8	28.94	0.47	4.18
	FL478	135	76.23	14	13	22	29.52	0.48	4.44
	IR29	127	68.35	17	16	14	25.29	0.57	3.65
S1.F2	IR63275-B-1-1-3-3-2	141	94.28	16	15	21	33.9	0.49	6.53
	WAS73-B-B-231-4	140	87.10	22	22	11	21.79	0.51	6.22
	NERICA-L9	142	82.08	21	21	8	32.96	0.47	7.44
	FL478	143	88.40	16	16	36	30.85	0.49	6.96
	IR29	139	81.58	21	20	14	25.2	0.51	5.54
S2.F1	IR63275-B-1-1-3-3-2	144	80.98	13	13	22	31.41	0.46	3.62
	WAS73-B-B-231-4	144	77.10	19	19	12	22.75	0.49	4.55
	NERICA-L9	149	71.93	18	18	12	27.97	0.53	4.85
	FL478	14	76.45	15	15	24	26.64	0.41	4.00
	IR29	141	71.20	26	25	15	24.05	0.51	4.38
S2.F2	IR63275-B-1-1-3-3-2	151	88.23	19	18	32	29.18	0.53	5.3
	WAS73-B-B-231-4	146	85.00	22	22	22	23.14	0.46	4.77
	NERICA-L9	148	84.40	21	21	14	28.77	0.52	6.57
	FL478	146	77.90	15	15	38	30.73	0.47	4.62
	IR29	146	77.38	24	23	25	24.49	0.53	6.36
S3.F1	IR63275-B-1-1-3-3-2	156	76.55	15	14	22	26.72	0.49	2.93
	WAS73-B-B-231-4	153	72.85	19	19	17	23.56	0.47	2.83
	NERICA-L9	156	67.65	18	17	13	26.51	0.5	2.59
	FL478	158	70.70	14	14	22	25.56	0.45	2.55
	IR29	155	69.25	20	19	23	22.41	0.5	3.27
S3.F2	IR63275-B-1-1-3-3-2	151	87.85	16	15	26	28.68	0.46	5.45
	WAS73-B-B-231-4	149	86.38	29	24	13	23.72	0.51	5.73
	NERICA-L9	151	77.48	21	21	12	30.05	0.44	5.8
	FL478	151	81.03	14	14	27	30	0.45	5.01
	IR29	149	76.28	20	20	16	25.93	0.44	5.04

Evaluation of rice genotypes using yield performance evaluation indices

Four indexes (STI, YI, YSI, SSI) were used to identity salt tolerance or susceptibility of rice genotypes to tolerate soil salinity. STI varied from 0.13 to 1.55 and averaged 0.79, 0.68, 0.75, 0.60, and 0.76 for IR63275-B-1-1-3-3-2, WAS73-B-B-231-4, NERICA-L9, FL478, and IR29, respectively (Table 5). FL478 was the least stress tolerant genotypes among the five genotypes. All four tested genotypes showed higher salt tolerance level than the check salt tolerant variety FL478 and could be candidates for variety

Table 4 Average grain yield (tons ha^{-1}) of five rice genotypes under three soil salinity levels (S) and two fertilizer rates (F) S) during two wet seasons (WS) and two hot and dry seasons (HDS) (WS2014, HDS2015, WS2015, and HDS2016)

Genotypes	Treatments					
	S1F1	S1F2	S2F1	S2F2	S3F1	S3F2
IR63275-B-1-1-3-3-2	5.02 ± 0.99 a	6.59 ± 0.59 a	4.03 ± 1.20 b	4.23 ± 1.18 b	2.69 ± 1.03 ab	3.88 ± 1.96 a
WAS73-B-B-231-4	5.31 ± 1.29 a	6.01 ± 1.47 a	4.14 ± 0.61 b	5.05 ± 0.99 a	2.35 ± 0.99 b	3.65 ± 2.23 a
NERICA-L9	4.48 ± 1.00 b	6.47 ± 1.43 a	4.12 ± 0.76 b	5.18 ± 1.32 a	2.44 ± 0.74 b	4.28 ± 2.54 a
FL478	4.58 ± 0.74 b	5.61 ± 0.93 b	4.01 ± 0.67 b	4.38 ± 0.60 b	1.99 ± 0.85 b	3.75 ± 1.55 a
IR29	5.25 ± 1.24 a	6.28 ± 1.90 a	4.50 ± 0.70 a	5.57 ± 1.17 a	3.06 ± 0.94 a	3.78 ± 2.25 a

Each number represents average of 32 single yield data (four replications in four growing seasons)

In each column, numbers followed by the different letters are statistically significant at 95% level of probability

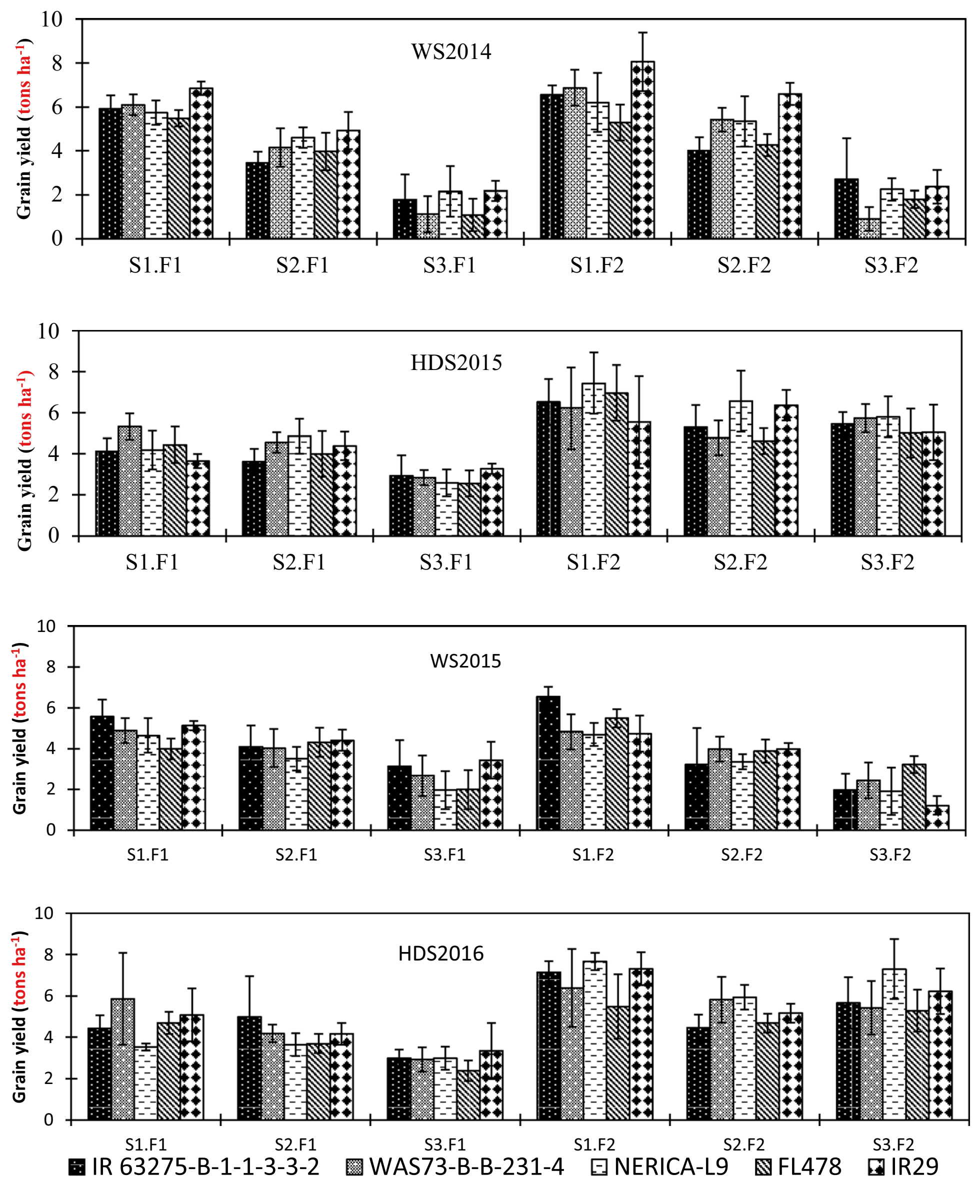

Fig. 2 Rice grain yield as function of salinity (S), fertilizer management (F), and genotype during two wet seasons (WS) and two hot and dry seasons (HDS) (WS2014, HDS2015, WS2015, and HDS2016)

Table 5 Comparison of five rice genotypes for tolerance or susceptibility to soil salinity (S) under two fertilizer rates (F) during two wet seasons (WS) and two hot and dry seasons (HDS) (WS2014, HDS2015, WS2015, and HDS2016) using the performance evaluation indexes

Seasons	Traitements	Stress Tolerance Index (STI)					Stress Susceptibility Index (SSI)				
		IR 63	WAS73	NERICA-L9	FL478	IR29	IR 63	WAS73	NERICA-L9	FL478	IR29
WS2014	S1.F1	0.89	0.96	0.82	0.67	1.27	0.19	0.22	0.15	-0.07	0.29
	S2.F1	0.52	0.66	0.66	0.48	0.91	0.94	0.78	0.51	0.49	0.77
	S3.F1	0.27	0.18	0.31	0.13	0.40	1.44	1.65	1.29	1.57	1.44
	S1.F2	0.99	1.09	0.89	0.64	1.49	0.00	0.00	0.00	0.00	0.00
	S2.F2	0.60	0.86	0.76	0.52	1.22	0.77	0.42	0.27	0.38	0.36
	S3.F2	0.41	0.14	0.32	0.22	0.44	1.16	1.72	1.26	1.30	1.39
HDS2015	S1.F1	0.72	0.68	0.76	0.66	0.51	1.32	0.93	1.57	1.15	0.74
	S2.F1	0.62	0.65	0.89	0.65	0.58	1.62	1.04	1.23	1.19	0.37
	S3.F1	0.49	0.42	0.50	0.40	0.42	2.00	1.92	2.22	2.07	1.21
	S1.F2	1.15	0.92	1.37	0.98	0.65	0.00	0.00	0.00	0.00	0.00
	S2.F2	0.90	0.77	1.14	0.74	0.84	0.75	0.59	0.59	0.85	-1.05
	S3.F2	0.89	0.85	1.07	0.75	0.68	0.78	0.26	0.78	0.82	-0.19
WS2015	S1.F1	1.32	0.85	0.79	0.79	0.88	0.36	-0.03	0.02	0.67	-0.20
	S2.F1	0.97	0.70	0.60	0.86	0.76	0.91	0.40	0.62	0.52	0.17
	S3.F1	0.74	0.47	0.33	0.40	0.59	1.28	1.09	1.42	1.56	0.67
	S1.F2	1.55	0.84	0.80	1.09	0.81	0.00	0.00	0.00	0.00	0.00
	S2.F2	0.76	0.70	0.57	0.77	0.68	1.24	0.42	0.70	0.72	0.39
	S3.F2	0.47	0.32	0.33	0.64	0.21	1.71	1.52	1.45	1.01	1.81
HDS2016	S1.F1	0.68	0.81	0.58	0.56	0.80	1.16	0.25	1.64	0.44	0.93
	S2.F1	0.77	0.58	0.60	0.44	0.66	0.92	1.05	1.60	0.99	1.31
	S3.F1	0.46	0.40	0.49	0.28	0.53	1.77	1.65	1.86	1.72	1.65
	S1.F2	1.11	0.88	1.27	0.65	1.16	0.00	0.00	0.00	0.00	0.00
	S2.F2	0.69	0.80	0.98	0.56	0.82	1.14	0.27	0.69	0.44	0.89
	S3.F2	0.88	0.75	1.21	0.63	0.99	0.63	0.45	0.15	0.11	0.45
		Yield Index (YI)					Yield Stability Index (YSI)				
WS2014	S1.F1	1.82	1.87	1.76	1.68	2.11	0.90	0.89	0.93	1.04	0.85
	S2.F1	1.06	1.27	1.41	1.22	1.51	0.53	0.60	0.74	0.75	0.61
	S3.F1	0.55	0.34	0.66	0.33	0.67	0.27	0.16	0.35	0.20	0.27
	S1.F2	2.01	2.11	1.91	1.63	2.47	1.00	1.00	1.00	1.00	1.00
	S2.F2	1.23	1.67	1.64	1.31	2.03	0.61	0.79	0.86	0.81	0.82
	S3.F2	0.83	0.28	0.69	0.55	0.73	0.41	0.13	0.36	0.34	0.29
HDS2015	S1.F1	0.94	0.99	0.90	0.93	0.89	0.62	0.74	0.55	0.67	0.79
	S2.F1	0.81	0.94	1.06	0.91	1.01	0.54	0.70	0.65	0.66	0.89
	S3.F1	0.64	0.61	0.60	0.57	0.74	0.43	0.45	0.37	0.41	0.65
	S1.F2	1.50	1.34	1.64	1.39	1.13	1.00	1.00	1.00	1.00	1.00
	S2.F2	1.18	1.12	1.37	1.05	1.46	0.79	0.83	0.83	0.76	1.30
	S3.F2	1.17	1.24	1.28	1.06	1.19	0.78	0.92	0.78	0.76	1.06
WS2015	S1.F1	1.79	1.57	1.50	1.29	1.65	0.85	1.01	0.99	0.73	1.08
	S2.F1	1.32	1.30	1.13	1.39	1.42	0.63	0.84	0.75	0.79	0.93
	S3.F1	1.01	0.86	0.63	0.64	1.11	0.48	0.55	0.42	0.36	0.73
	S1.F2	2.10	1.55	1.51	1.77	1.52	1.00	1.00	1.00	1.00	1.00
	S2.F2	1.04	1.28	1.08	1.25	1.28	0.49	0.83	0.72	0.71	0.84
	S3.F2	0.63	0.59	0.62	1.04	0.39	0.30	0.38	0.41	0.59	0.26

Table 5 (continued)

Seasons	Traitements	Stress Tolerance Index (STI)					Stress Susceptibility Index (SSI)				
		IR 63	WAS73	NERICA-L9	FL478	IR29	IR 63	WAS73	NERICA-L9	FL478	IR29
HDS2016	S1.F1	0.97	1.28	0.77	1.03	1.11	0.62	0.92	0.46	0.86	0.69
	S2.F1	1.09	0.92	0.80	0.81	0.91	0.70	0.66	0.47	0.67	0.57
	S3.F1	0.65	0.64	0.65	0.52	0.73	0.42	0.46	0.39	0.43	0.46
	S1.F2	1.57	1.40	1.68	1.20	1.60	1.00	1.00	1.00	1.00	1.00
	S2.F2	0.98	1.28	1.30	1.03	1.13	0.62	0.91	0.77	0.85	0.71
	S3.F2	1.24	1.19	1.60	1.16	1.37	0.79	0.85	0.95	0.96	0.85

IR63 was made for IR63275-B-1-1-3-3-2; WAS73 was made for WAS73-B-B-231-4

release after extensive farmer's field evaluation. Rice yield loss under recommended fertilizer was reduced as nitrogen fertilizer compensated yield loss under high soil salinity. The results of this study confirm the findings of Hussain et al. (2018) who indicated that integration of different management options can lead to sustainable rice production in saline areas. Average STI values were 0.63 and 0.80 under F1 and F2 fertilizer rates, representing 28% improvement of STI when adopting F2 compared to F1.

There was large variation in rice SSI from -1.05 to 2.22 and averaged 0.92, 0.69, 0.83, 0.75 and 0.56 for IR63275-B-1-1-3-3-2, WAS73-B-B-231-4, NERICA-L9, FL478, and IR29, respectively (Table 5). IR29 was the most susceptible to soil salinity, and IR63275-B-1-1-3-3-2 was the least salt susceptible genotype. IR63275-B-1-1-3-3-2 and NERICA-L9 were less susceptible to salt stress than FL478 and could be opted under soil salinity conditions (Fig. 3). The SSI decreased from 1.01 under F1 fertilizer rate to 0.49 under F2 fertilizer rate. Proper fertilizer management option (F2) reduced rice susceptibility index by 52% which is equivalent to yield increased by 52% compared to the yield under F1 fertilizer management option.

The yield index defined as the ratio of yield under salinity to the average yield under salinity varied from 0.28 to 2.47 (Table 3). Average YI values were 1.17, 1.15, 1.18, 1.07 and 1.26 for IR63275-B-1-1-3-3-2, WAS73-B-B-231-4, NERICA-L9, FL478, and IR29, respectively. Yield index was higher for the tested genotypes than for FL478 showing lower relative yield loss for the tested genotypes under soil salinity than the relative yield loss for FL478 (Fig. 3). Average YI under F1 was 1.04, while it was 1.29 with 29% average yield increase under soil salinity conditions. In other words, under F1 fertilizer rate, the yield of each single genotype was equal to the average yield of all genotypes while the application of F2 fertilizer rate increased rice yield by 29%.

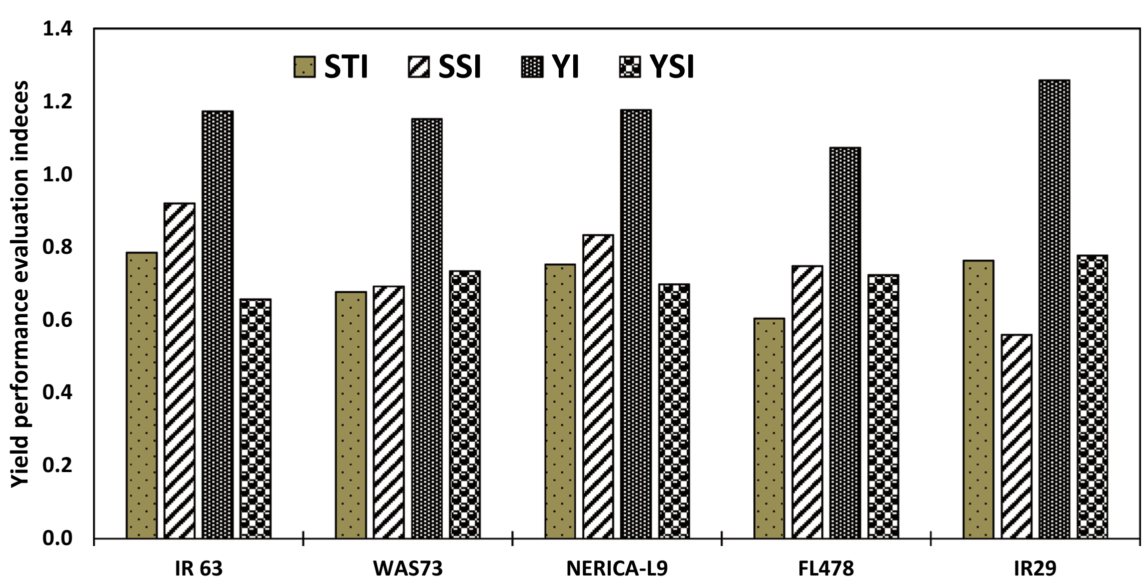

Fig. 3 Four-season average stress tolerance index (STI), stress susceptibility index (SSI), yield index (YI) and yield stability index (YSI) of five rice genotypes grown under salt-affected soil conditions

The yield stability index varied from 0.13 to 1.30 averaging 0.66, 0.73, 0.70, 0.72 and 0.78 for IR63275-B-1-1-3-3-2, WAS73-B-B-231-4, NERICA-L9, FL478, and IR29, respectively (Table 5). IR63275-B-1-1-3-3-2 and NERICA-L9 showed slightly lower YSI than the check FL478. Therefore, IR63275-B-1-1-3-3-2 would have 0.34% yield loss under soil salinity conditions relative to the yield under S1, while IR29 would have 22% yield reduction under salinity compared to the yield under S1 (Fig. 2). Increasing fertilizer regime from F1 to F2 improved YSI from 0.64 to 0.80.

Rice genotypes had different response to fertilizer rates under saline soil conditions. Nerica-L9 obtained the highest increase in STI value of 46% followed by FL478 (30%). Nerica-L9 obtained the highest reduction in SSI of 58% followed by IR29 (57%) and FL478 (54%), WAS73-B-B-231-4 (48%) and IR63275-B-1-1-3-3-2 (41%). Like for STI and SSI, Nerica-L9 showed the highest response to fertilizer applied rates in terms of YI and YSI with 37% improvement for both indexes followed by FL478, while IR29 showed the lowest improvement of 18% for YI and 19% for YSI. Radanielson et al. (2018) reported yield reduction in rice genotypes with higher salt stress levels causing 50% reduction in net leaf photosynthesis and transpiration rates in the tolerant genotype BRRI Dhan47 than in salt sensitive genotype (IR29) under greenhouse study in Los Baños, Philippines.

Krishnamurthy et al. (2016) reported YSI of 26 rice genotypes that varied from 0.87 to 1.21. The genotype with the lowest YSI is considered the most stable with high grain yield. Rice genotype IR63275-B-1-1-3-3-2 showed the lowest YSI and is therefore considered the most stable with high grain yield (Khan and Kabir 2014; Krishnamurthy et al. 2016), and IR29 with the highest YSI had the most instable yield under salt stress condition, while WAS73-B-B-231-4 and Nerica-L9 had similar yield stability as FL478. IR29 and WAS73-B-B-231-4 with the lowest SSI are considered low salt susceptibility genotypes (Nouri et al. 2011; Singh et al. 2015). The stress susceptibility index (SSI) proposed by Fischer and Maurer (1978) was successfully used by Guttieri et al. (2001), and Akçura et al. (2011) for drought tolerance in wheat genotypes. The other studied indexes were also used by Akçura et al. (2011) to identify drought-tolerant bread wheat genotypes and were suggested as useful indicator for wheat breeding where the stress is severe. Aslam et al. (1989) reported that even if high salinity greatly affects rice plant growth, total biomass, and grain yield, proper fertilizer management improves crop prediction. Beakal et al. (2017) reported rice STI, SSI, YSI and YI using 15 rice genotypes grown under stress and non-stress conditions in Ethiopia and which ranges of 0-0.69; 0.49-1.40; 0-0.65; and 0-2.26, respectively. The adoption of the good agricultural practices including recommended fertilizer rate mostly nitrogen fertilizer and the use of the tested rice genotypes IR63275-B-1-1-3-3-2, WAS73-B-B-231-4, NERICA-L9, and IR29 should help reduce the impact of saline soil on rice yield in the Senegal River Delta.

Conclusion

Field experiments were conducted during four rice-growing seasons from July 2014 to July 2016 at Africa Rice Center research station at Ndiaye, Senegal to evaluate the performance of five rice genotypes under three salinity levels and two fertilizer management options. The results showed that fertilizer top dressing with nitrogen fertilizer application at the panicle initiation and at flowering significantly improved rice yield compared to the basal fertilizer application only. Rice yield was significantly affected by soil salinity and was 20% higher during the hot and dry seasons than during the wet seasons. IR63275-B-1-1-3-3-2 obtained the highest stress tolerant index and the highest yield stability index. The analysis of the combination of yield index, yield stability index, stress susceptibility index and the stress tolerant index indicated that the newly developed rice genotypes IR63275-B-1-1-3-3-2 and WAS73-B-B-231-4 constitute good candidates for adoption and the integrated resources management options could lead to sustainable rice production in the Senegal River Delta.

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