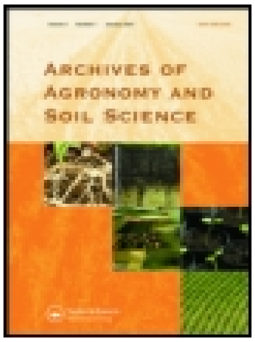

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Suitable management options to improve the productivity of rice cultivars under salinity stress

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ABSTRACT

Growing rice in saline soils by minimizing damage on growth and yield remains a challenge. We conducted field experiments in the Africa Rice research field located in the Senegal River delta (16° 11′ N, 16° 15′ W) to study the effects of three management options of fertilization e.g. (i) nitrogen, phosphorus, and potassium fertilization: NPK; (ii) NPK combined with zinc: NPK-Zn, and (iii) NPK combined with gypsum: NPK-gypsum on the soil salinity level, the nutrient uptake and the productivity of different rice cultivars. The whole objective of this study is to determine how zinc or gypsum associated to NPK fertilizer can improve the growth and productivity of rice crop in saline soil. Results showed that the initial soil salinity level was reduced rapidly in plots treated with gypsum. The leaf-K/Na ratio, agronomic nitrogen use efficiency (ANUE), and grain yield of rice cultivars under the salinity stress were improved by the NPK-gypsum and NPK-Zn options relatively to the NPK option, suggesting that NPK-gypsum and NPK-Zn are suitable management options in reducing adverse effect of low K/Na, low ANUE as well as to improve rice yield under salinity stress.

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Electrical conductivity (EC); K/Na-ratio; *Oryza sativa*; Sahel; Senegal

Introduction

Decreases in water resources due to climate change, extreme temperatures and soil salinity are serious problems in arid and semi-arid regions (Yu et al. 2010; Meena et al. 2016a). Soil salinity is a common abiotic constraint that affects crop productivity in these regions, especially those located in coastal zones (Meena et al. 2016b). It has been estimated that about 20% of the world's irrigated lands have been degraded by salt, causing a global economic losses of US$27.3 billion per year (Qadir et al. 2014). In the Senegal River Valley (SRV) for instance, an estimated area of 179,765 ha is affected by salinity, while the potential of irrigated land is estimated at 240,000 ha (Dumas et al. 2010). Irrigated rice cropping remains one of the main agricultural activities in this area, and may contribute to more than 50% of the domestic paddy rice production in the Senegal (MAER 2014). However, the rice yields in this region may be reduced significantly as a consequence of the salinity stress.

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Many efforts have been invested to develop salt-tolerant varieties as a means to improve rice production in salt-affected soils. Despite the yield gains of these improved varieties compared to susceptible varieties, the difference between the potential yields of these varieties under normal conditions and those obtained under stress conditions remains important (Awala et al. 2010). In addition, at a relatively high salinity levels, the tolerance level of these varieties becomes low (Gholizadeh and Navabpour 2011). Under this situation, there is a need to develop management practice that would help to improve rice productivity under salinity stress. Several strategies to reduce harmful impacts of salinity on crops have been developed. Aside from the leaching of salt by drainage water, the use of organic amendment and the phytoremediation techniques, promising management practices for reducing the harmful effects of salt stress include chemical remediation using Ca supplement source like gypsum and the supply of Zinc micronutrient in soil. The application of gypsum ($CaSO_4 \cdot 2H_2O$) can remediate the soil salinity by improving soil structure properties so that leaching can effectively remove salts from the root zone (Qadir et al. 2014). Besides, applying gypsum in salt affected soils can provide Ca^{2+} to replace excess Na^+ from the colloid's cation exchange positions and the leaching out of Na^+ from the root zone (Gharaibeh et al. 2012). The application of zinc (Zn) is also crucial with respect to various aspects of plant physiology. According to Amiri et al. (2016), Zinc supply could mitigate the adverse effects of salinity by reducing the uptake and accumulation of Na in plants. Furthermore, regardless of the tolerance level of cultivars and soil constraints, fertilizer recommendations for rice in the SRV are blanket, involving only N, P and K nutrients. Although the N-use efficiency in crop under salinity stress is reduced (Murtaza et al. 2016). Nitrogen fertilizer should be managed efficiently under salinity stress to ensure profitable yield. This research was based on the hypothesis that the management options combining the N, P, and K nutrients with gypsum (NPK-gypsum) or with Zinc micronutrient (NPK-Zn) can increase nutrient use efficiency and rice yields in salt-affected soils. In the present study, we analyze the variation of root zone salinity under these different management options, effects of these management options on the nitrogen use efficiency and the rice yield under salt stress. Some physiological aspect like the concentration of K and Na in rice tissue was assessed. The overall objective was to analyze the varietal responses to different management options and to determine how zinc and gypsum associated with NPK fertilization can improve rice growth and productivity under the salinity stress.

Materials and methods

Experimental site

Field experiment was conducted at Africa Rice Center (AfricaRice) research station located in the Ndiaye village (16° 11′ N, 16° 15′W) in the Senegal River Delta during three consecutive rice growing periods from March 2012 to August 2013. The Ndiaye village is located in a depression along one of the branches of the Senegal River (Haefele 2001). According to the FAO soil classification (FAO 2008), the soil is an Orthothionic Gleysol, with a clayey structure that contains 40–54% clay, composed of smectite and kaolinite (Haefele 2001). The average percolation rate of this soil is estimated at 2.8 mm d^{-1} (Haefele 2001). The climate is semi-arid, with a wet season (WS; July to November) receiving approximately 200 mm of rainfall; a cold, dry season (CDS) from November to February; and a hot dry season (HDS) from March to June. Variations of air humididy and air temperature in Ndiaye from the hot dry season 2012 to the hot dry season 2013 are presented in Figure 1. Typically, rice production occurs twice a year in the hot dry season (HDS) and the wet season (WS). The experimental site of AfricaRice covers an area of about 11 hectares which is surrounded by a protecting dike on the side of the river branch. The soil salinity mapping in this perimeter indicates a general heterogeneity of the salinity level which may be divided in three parts:

the non-saline part (EC < 1 dS m^{-1}), composed of land portions regularly cultivated which represent approximately 45% of the total area, the moderately saline part (1 dS m^{-1} < CE < 4 dS m^{-1}) with a relatively low frequency of cultivation compared the non-saline part representing about 20% of the total area, and the saline part (EC > 4 dS m^{-1}) which is less cultivated or often abandoned representing about 35% of the total area. Two adjacent trials were implemented in a saline land portion (saline site) and a non-saline land portion (non-saline site). The two sites were separated by a distance of about 120 meters.

Plant materials

Plant materials were composed of six rice cultivars: (1) IR31785-58–1-2–3-3 (henceforth IR31785), salt susceptible, (2) Sahel 108, moderately susceptible, (3) IR4630-22–2-5–1-3 (henceforth IR4630), salt tolerant, (4) IR59418-7B-21–3 (henceforth IR59418), salt tolerant, (5) IR76346-B-B-10–1–1-1(henceforth IR76346), salt tolerant, and (6) IR72593-B-3–2-3–8 (henceforth IR72593), salt tolerant. The Cultivars 1 and 3 originated from the Philippines (IRRI), were introduced in the Africa Rice Center several years ago and used as a susceptible check and tolerant check in trials, respectively. The Sahel 108 variety (2) has been released in Senegal since 2009 and is grown by more than 70% of farmers. The last three cultivars originated also from the Philippines (IRRI) were selected from participatory varietal selections between 2008 and 2010 in Gambia, Mali and Senegal. The six rice cultivars were pre-germinated and seeded at nursery on 12 March 2012 for the HDS 2012 trial, 31 July 2012 for the WS 2012 and 28 February 2013 for the HDS 2013 trial. The plots were harvested from 31 July 2012 to 9 August 2012 for the HDS 2012 trial, from 10 December 2012 to 15 December 2012 for the WS 2012 trial, and from 29 July 2013 to 5 August 2013 for the HDS 2013 trial.

Fertilizers treatments

Three fertilizer management options were evaluated: (i) NPK, (ii) NPK-Zn, and (iii) NPK-gypsum. These treatments combine the major nutrients provided by urea (46%N), triple super phosphate (45% P_2O_5) and potassium chloride (60% K_2O_5); alternatively, zinc sulfate (Zn) or gypsum was added. Uniform doses of P (26 kg ha^{-1}) and K (50 kg ha^{-1}) were applied for all fertilization treatments, while different levels of N (0, 60, 120 or 150 kg ha^{-1}) were tested to evaluate the profitable nitrogen rate. The doses of Zn and gypsum were 10 and 100 kg ha^{-1}, respectively. The Gypsum was incorporated into the soil during the land leveling one day before transplanting, while total P, K, and Zn were applied three weeks after transplanting. The Nitrogen (N) rates were applied in three splits: 40% at three weeks after transplanting together with total P, K and Zn; 40% at panicle initiation; and 20% at the booting stage.

Experimental design and crop management

A factorial design in a split-plot arrangement with fertilizer treatment as the whole plot and six rice cultivars as subplot treatments was used in three replications. The size of the main plots for fertilizer treatment was 74 m^2 (13.6 m × 5.4 m), while the subplot size for the rice cultivars was 8 m^2 (4 m × 2 m). All plots were irrigated with fresh water from the river branch. To avoid salt damage to newly transplanted seedlings, leaching of salt by surface drainage was performed three times per week for all plots until the first fertilizer application. Traditional materials for land leveling (shovel and rake) were used to incorporate gypsum at a 5 cm soil depth. Missing plants were replaced shortly before the first fertilizer application. After the first application of nitrogen, the plots were continuously irrigated at least twice weekly without drainage. A single herbicide application consisting of a mixture of 5 L ha^{-1} propanyl (360 g L^{-1} propanyl) and 1 L ha^{-1} Weedone (480 g l^{-1} 2, 4-D-amine) was performed three days before the first N application. Weeds were further controlled manually. Except the first three weeks of cultivation in the saline site, the same crop management operations were conducted on both the saline site and non-saline site.

Sampling, measurements and analyses

In each site, soil sampling was performed at five points (sub-samples) within each repetition in the two soil horizons (0–20 cm) and (20–40 cm). The sub-samples were mixed to get three composite soil samples corresponding to the three repetitions. These samples were air-dried during one week and stored. The procedures of analysis of samples are described in Pansu and Gautheyrou (2006). Analyses included pH using a 1:2.5 soil: water mixture and electrical conductivity (EC) using a 1:5 soil: water extract. Soil organic carbon (SOC) was determined through the wet digestion method, and available phosphorus was extracted by a combination of HCl and NH_4F and determined according to the Bray 1 test. Total N was quantified following the micro-Kjeldahl procedure, while both cation exchange capacity (CEC) and exchangeable Na and K were determined using the ammonium acetate method. The Zn was extracted by diluted HCl and titrated by atomic absorption spectrometry (AAS). The exchangeable sodium percentage (ESP) was obtained through the following formula:

$$ESP = \frac{(\text{exchangeableNa} \times 100)}{\text{CEC}} \tag{1}$$

In the aim to study the daily variation of the root zone EC in function of three management options, root zone-EC was measured directly in the field every day before irrigation by inserting a probe of the portable VWR EC meter into the soil at a depth of 0–15 cm. All cultivars did not have similar phenology thus at the panicle initiation stage for each cultivar, sampling was conducted on the three topmost fully expanded leaves from three hills per cultivar, fertilizer treatment and replication. These samples were oven-dried at 65°C, ground and analyzed by flame photometry for sodium and potassium concentration in leaves after extraction using 1 N HCl. An area of 4 m^2 per subplot was harvested, and grain yields were recorded. The yields obtained were adjusted to the standard of 14% grain moisture level. The yield reduction due to the salinity stress relative to the non-saline condition was calculated using the following equation:

$$\text{YR}(\%) = \frac{(\text{GY2} - \text{GY1})}{\text{GY2}} \times 100 \tag{2}$$

where YR is yield reduction in percent, GY2 is grain yield obtained in non-saline soil in tons per hectare and GY1 is grain yield obtained in saline soil in tons per hectare.

The agronomic nitrogen use efficiency (ANUE), defined as the yield obtained per unit of N applied was calculated by the following equation:

$$\text{ANUE} = \frac{(Y_N - Y_0)}{A_N} \tag{3}$$

where Y_N and Y_0 refer to grain yields (kg ha^{-1}) in the treatment in which N fertilizer has been applied and not applied, respectively, and A_N is the amount of N fertilizer applied (kg N ha^{-1}).

Statistical analyses

The analysis of variance (ANOVA) was performed using the Generalized Linear Model procedure (proc GLM) of SAS software version 9.2 (SAS Institute Inc., Cary, NC, USA). The SNK test was used for multiple pairwise comparisons of means at significance levels of 1% and 5%.

Results

Soil initial conditions

The initial chemical characteristics of soil in both the saline site and non-saline site are shown in Table 1. In the saline site, the soil was neutral with a pH ranged between 6.92 and 7.01 at 20 cm and 40 cm depth, respectively, while in the non-saline site, soil was moderately acidic with a pH ranged between 5.79 and 6.07 respectively at 20 cm and 40 cm depth. The level of the SOC, available P and exchangeable K in the saline site was lower compared to the non-saline site (Table 1). The soil ESP was 11.86% and 5.56% in the saline site and the non-saline site respectively. The soil Zn level in saline site was ranged between 0.77 and 0.84 mg kg^{-1} respectively at 20 cm and 40 cm depth; while in the non-saline site it was ranged between 1.58 and 1.60 mg kg^{-1} respectively at 40 cm and 20 cm depth (Table 1). The soil EC in the non-saline site was below 1 dS m^{-1} during the three seasons of trials, while in the saline site the initial soil EC was 17.74 dS m^{-1} (Table 1) and varied in function of management during the three seasons of trials.

Variation of EC in function of management options

During the three seasons of experimentation, soil EC in the non-saline site remained below 0.5 dS m^{-1}, whereas in the saline site large variations in soil EC depending on treatment were observed. The box plot graphs were used to represent the daily amplitude of the EC variation in the saline site. EC trends through median values during seventy days after transplanting (DAT) in the HDS 2012, WS 2012 and HDS 2013 are shown in Figure 2. The soil EC was ranged from 1.5 dS m^{-1} to 18.2 dS m^{-1} in the HDS 2012, between 3.4 dS $m^{-1}$and 11.8 dS m^{-1} in the WS 2012, and between 1.5. dS m^{-1} and 9.3 dS m^{-1} in the HDS 2013 (Figure 2). At 20 DAT, EC decreased significantly in all plots regardless of management and increased thereafter. Under the NPK option, EC values increased daily by 0.44 dS m^{-1} and 0.33 dS m^{-1} in the HDS 2012 and the WS 2012, respectively, and decreased by 0.07 dS m^{-1} in the HDS 2013 (Figure 2(a)). Under the NPK-Zn option, EC increased daily by 0.22 dS m^{-1} and 0.09 dS m^{-1} in the HDS 2012 and WS 2012, respectively, while in the HDS 2013, a daily reduction in EC by 0.13 dS m^{-1} was recorded (Figure 2(b)). A regressive trend of EC in the three seasons was observed in plots amended with gypsum (option NPK-Gypsum). Under the NPK-Gypsum option, the EC level decreased daily by 0.44, 0.33 and 0.14 dS m^{-1} respectively in the HDS 2012, WS 2012 and HDS 2013 (Figure 2(c))

Leaf-K, leaf-Na and leaf-K/Na ratio in rice

Results of ANOVA of the Na and K concentration in leaves (leaf-Na and leaf-K) and their ratio (leaf-K/Na) are presented in Table 2. The leaf-Na was highly affected ($p < 0.01$) by salinity level, management option and cropping season, while no effect of nitrogen rate and cultivar was found. The average leaf-Na was 1.27 g kg^{-1} and 0.30 g kg^{-1} respectively in the saline site and the non-saline site (Table 3). The leaf-Na recorded under the NPK-Gypsum, NPK-Zn and NPK option was 0.67 g kg^{-1}, 0.81 g kg^{-1} and 0.85 g kg^{-1}, respectively. The average leaf-Na recorded in the HDS and WS was 0.57 g kg^{-1} and 1.20 g kg^{-1}, respectively. The leaf-K was highly affected ($p < 0.01$) by salinity level, management option, nitrogen rate, cultivar and cropping season (Table 2). The average leaf-K was 2.16 g kg^{-1} and 2.42 g kg^{-1} respectively in the saline site and the non-saline site (Table 3). The leaf-K recorded under the NPK-Gypsum, NPK-Zn and NPK option was 2.87 g kg^{-1}, 2.32 g kg^{-1} and 1.68 g kg^{-1}, respectively. The lowest leaf-K (1.45 g kg^{-1}) was recorded under 0 N kg ha^{-1}, while the highest leaf-K (2.73 g kg^{-1}) was recorded under 120 N kg ha^{-1}(Table 3). The leaf-K in the cultivars Sahel 108, IR4630, IR59418, IR76346, and IR72593 was higher than in the cultivar IR31785 (Table 3). The average leaf-K recorded in the HDS and WS was 2.02 g kg^{-1} and 2.83 g kg^{-1}, respectively.

Table 1. Initial chemical characteristics of soil in the saline and the non-saline sites. The values presented are the average of three repetitions in each site.

Depth (cm)	pH	EC (dS m^{-1})	SOC (g kg^{-1})	total N (g kg^{-1})	P Bray 1 (mg kg^{-1})	CEC (cmol kg^{-1})	K^+ (cmol kg^{-1})	Na^+ (cmol kg^{-1})	ESP (%)	Zn (mg kg^{-1})
Saline site 0–20	6.92 (0.74)	17.74 (0.52)	4.51 (1.40)	0.88 (0.15)	8.94 (2.17)	10.20 (1.30)	0.60 (0.11)	1.15 (0.42)	11.27 (1.33)	0.77 (0.25)
20–40	7.01 (0.86)	19.94 (2.90)	3.36 (1.01)	0.74 (0.10)	9.04 (2.03)	13.40 (2.10)	0.72 (0.18)	1.67 (0.36)	12.46 (1.62)	0.84 (0.15)
Non-saline site										
0–20	5.79 (0.49)	0.24 (0.10)	5.00 (1.04)	0.85 (0.21)	10.44 (1.58)	12.52 (0.87)	0.71 (0.20)	0.64 (0.13)	5.11 (0.39)	1.60 (0.21)
20–40	6.07 (0.57)	0.33 (0.19)	4.72 (0.97)	0.75 (0.12)	10.29 (2.06)	13.28 (1.60)	0.74 (0.13)	0.80 (0.24)	6.02 (0.41)	1.58 (0.10)

Standard deviations in the bracket

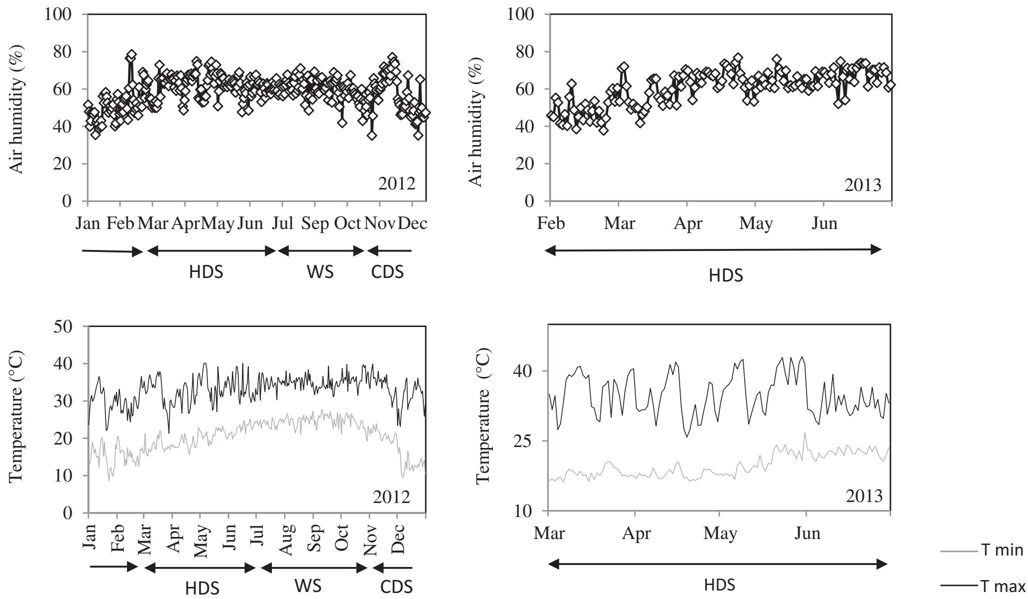

Figure 1. Mean air humidity and air temperature (maximum and minimum) in Ndiaye during the HDS 2012, WS 2012, CDS 2012 and HDS 2013.

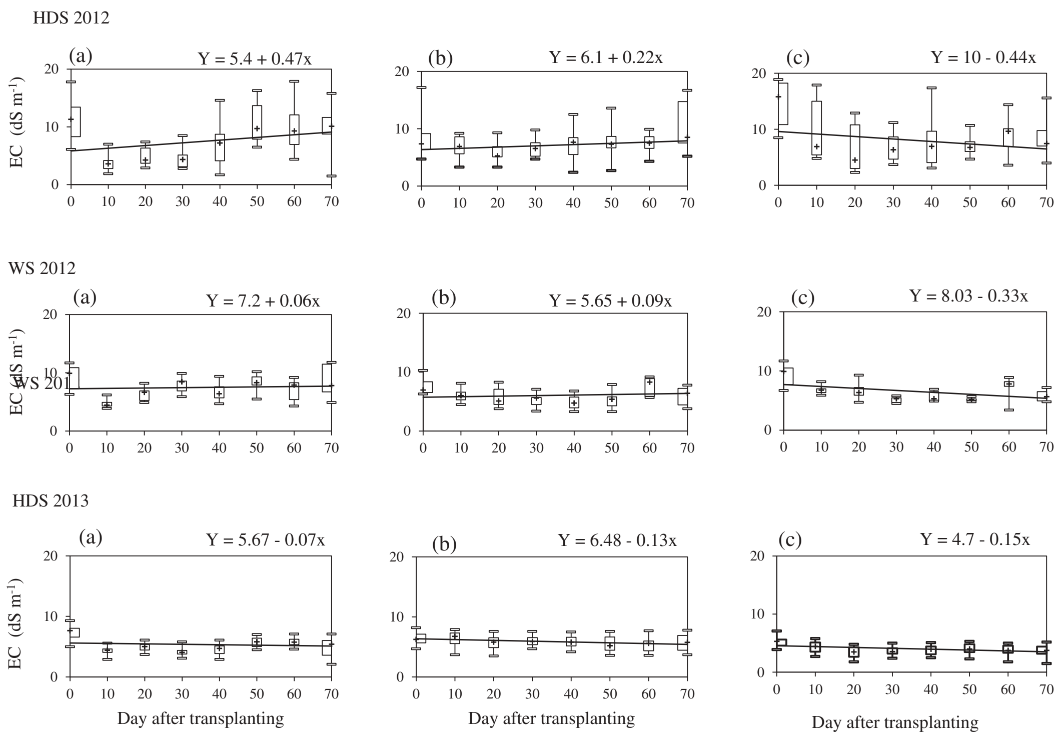

Figure 2. Trend of the root zone EC during seventy days after (WS 2012) and in the Hot Dry Season 2013 (HDS 2013) in function of the three management options (a): NPK, (b): NPK-Zn and (c): NPK-Gypsum.

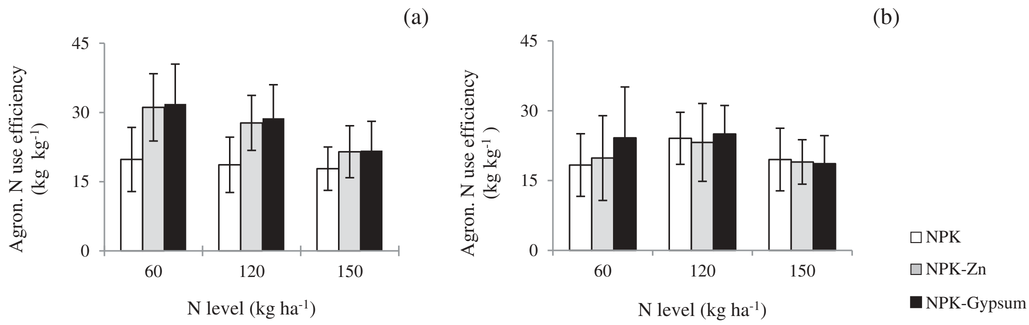

Figure 3. Average Agronomic Nitrogen Use Efficiency (ANUE) in function of management options NPK, NPK-Zn and NPK-Gypsum, and nitrogen levels in the saline site (a) and the non-saline site (b).

Table 2. Statistical significance of effects of fertilizer treatment (F), Cultivar (C), Season (S), and interaction between these three factors on leaf-Na, leaf-K, leaf-K/Na, grain yield (GY), yield reduction (YR) and agronomic nitrogen use efficiency (ANUE).

Source of variation	Leaf-Na	Leaf-K	Leaf-K/Na	GY	YR	ANUE
Salinity (S)	***	***	***	***	-	***
Management option (MO)	***	***	***	***	***	***
Nitrogen rate (NR)	ns	***	***	***	**	***
Cultivar (C)	ns	***	ns	***	**	ns
Cropping season (CS)	***	***	ns	***	***	***
S × MO × NR × C × CS	ns	ns	ns	ns	ns	ns
MO × NR × C × CS	ns	ns	ns	ns	ns	ns
S × NR × C × CS	ns	ns	ns	ns	ns	ns
S × MO × NR × C	ns	ns	ns	ns	ns	ns
S × MO × NR	ns	ns	ns	ns	ns	ns
NR × C × CS	ns	ns	ns	ns	ns	ns
MO × NR × C	ns	ns	ns	ns	ns	ns
S × NR × C	ns	ns	ns	ns	ns	ns
MO × NR	ns	ns	ns	ns	ns	ns
NR × CS	ns	ns	ns	ns	ns	ns
S × MO	ns	ns	ns	**	ns	ns
C × MO	ns	ns	ns	ns	ns	ns
C × CS	ns	ns	ns	ns	ns	ns
C × NR	ns	ns	ns	ns	ns	ns
S × NR	ns	ns	ns	ns	ns	**
S × C	ns	ns	ns	***	ns	ns

*** Significant effect at the probability of 0.01
** Significant effect at the probability of 0.05
ns Non-significance

The leaf-K/Na was also highly affected ($p < 0.01$) by salinity level, management option, nitrogen rate, while no effect of cultivar and season was found (Table 2). The average leaf-K/Na was 2.84 and 9.97 in the saline site and the non-saline site respectively (Table 3). The leaf-K/Na recorded under the NPK-Gypsum, NPK-Zn and NPK option was 8.58, 5.66 and 4.93 g kg^{-1}, respectively. The lowest leaf-K/Na (4.73) was recorded under 0 N kg ha^{-1}, while the highest leaf-K/Na (7.25) was recorded under 150 N kg ha^{-1} (Table 3).

Grain yield

The difference in grain yield (GY) among the saline site and the non-saline site was highly significant (Table 2). The GY was on average, 7.0 t ha^{-1} and 4.2 t ha^{-1} in the non-saline and saline sites, respectively (Table 4). The difference in GY among management options was highly significant (Table 2). The average GY under NPK-gypsum, NPK-Zn and NPK options was 5.7 t ha^{-1}, 5.5 t ha^{-1}, and 5.3 t ha^{-1}, respectively (Table 4). The effect of nitrogen rate on GY was

Table 3. Mean values of Leaf-Na, Leaf-K, and Leaf-K/Na in function of the different factors.

Factor	Treatments	Leaf-Na (g kg^{-1})	Leaf-K (g kg^{-1})	Leaf-K/Na
Salinity level	Non-saline site (EC< 1 dS m^{-1})	0.30 b	2.42 a	9.97 a
	Saline site (EC 4 dS m^{-1})	1.26 a	2.16 b	2.84 b
Cropping season	HDS	0.57 b	2.02 b	6.37 ns
	WS	1.20 a	2.83 a	6.42 ns
Management option	NPK-Gypsum	0.67 b	2.87 a	8.58 a
	NPK-Zn	0.81 a	2.32 b	5.66 b
	NPK	0.85 a	1.68 c	4.93 b
Nitrogen level	0 kg N ha^{-1}	0.80 ns	1.45 c	4.73 b
	60 kg N ha^{-1}	0.80 ns	2.62 ab	6.29 a
	120 kg N ha^{-1}	0.76 ns	2.73 a	7.03 a
	150 kg N ha^{-1}	0.76 ns	2.39 b	7.25 a
Cultivar	Sahel 108	0.84 ns	2.19 a	5.87 ns
	IR31785-58–1-2–3-3	0.88 ns	1.88 b	6.32 ns
	IR4630-22–2-5–1-3	0.79 ns	2.32 a	5.89 ns
	IR59418-7B-21–3	0.76 ns	2.50 a	6.78 ns
	IR76346-B-B-10–1-1–1	0.74 ns	2.49 a	7.10 ns
	IR72593-B-3–2-3–8	0.67 ns	2.35 a	6.32 ns

HDS: hot dry season; WS: wet season; In each column, means followed by the same letter per factor are not significantly different at the probability of 0.05; ns: non-significance

Table 4. Average grain yield in t ha^{-1} in the saline site (GY1) and the non-saline site (GY2) of the six rice cultivars under the different management option in the HDS 2012, WS 2012 and HDS 2013.

		IR 31785		Sahel 108		IR 4630		IR 59418-7B-21–3		IR 76346-B-B-10–1-1-1		IR 72593-B-3–2-3–8	
Season	Fertilizer treatment	GY1	GY2	GY1	GY2	GY1	GY2	GY1	GY2	GY1	GY2	GY1	GY2
HDS 2012	NPK	2.2 b	7.4 a	2.8 b	7.8 b	3.1 b	6.1 a	3.1 b	7.6 a	3.1 b	7.3 a	3.0 b	6.9 a
	NPK-Zinc	3.3 a	7.5 a	3.4 a	8.5 a	4.1 a	6.6 a	4.2 a	7.0 a	3.4 a	6.6 b	3.3 b	7.6 a
	NPK-Gypsum	3.8 a	7.9 a	3.7 a	8.5 a	3.9 a	6.6 a	4.1 a	7.6 a	3.9 a	8.1 a	3.8 a	7.3 a
	Mean	3.1	7.6	3.3	8.3	3.7	6.4	3.8	7.4	3.5	7.3	3.4	7.3
WS 2012	NPK	2.7 a	7.3 a	3.0 b	7.3 a	3.1 b	5.5 a	3.7 a	6.5 a	3.7 b	6.3 a	3.7 a	6.2 a
	NPK-Zinc	3.2 a	6.9 a	3.7 a	7.1 a	3.7 a	5.7 a	4.1 a	6.8 a	4.3 a	6.7 a	4.3 a	6.4 a
	NPK-Gypsum	3.0 a	7.2 a	3.6 a	7.5 a	3.8 a	5.5 a	4.2 a	6.8 a	4.8 a	6.5 a	3.9 a	6.0 a
	Mean	3.0	7.1	3.4	7.3	3.5	5.5	4.0	6.7	4.3	6.5	4.0	6.2
HDS 2013	NPK	5.7 a	6.9 a	5.5 a	7.3 a	5.1 a	5.7 a	5.6 a	7.1 a	5.6 a	7.3 a	6.5 a	7.5 a
	NPK-Zinc	5.8 a	6.8 a	5.9 a	7.4 a	5.1 a	5.7 a	5.5 a	7.2 a	5.3 a	6.7 a	6.1 a	7.0 a
	NPK-Gypsum	5.9 a	7.2 a	5.7 a	7.2 a	4.8 a	5.7 a	5.8 a	6.8 a	5.6 a	6.9 a	6.6 a	7.2 a
	Mean	5.8	7.0	5.7	7.3	5.0	5.7	5.6	7.0	5.5	7.0	6.4	7.2

HDS: hot dry season; WS: wet season; GY1: Grain yield in the saline condition; GY2: Grain yield in the non-saline condition
In each column, means followed by the same letter per season are not significantly different at the probability of 0.05

highly significant (Table 2). The GY recorded under 0, 60, 120, and 150 kg N ha^{-1} was 3.7 t ha^{-1}, 5.6 t ha^{-1}, 6.1 t ha^{-1}, and 6.7 t ha^{-1}, respectively. Significant differences were detected among cultivars for GY (Table 2). Independently of salinity factor, the cultivar IR72593 recorded the highest GY (6.0 t ha^{-1}), followed by IR59418 (5.8 t ha^{-1}) and IR31785 (5.8 t ha^{-1}), Sahel 108 (5.4 t ha^{-1}) and IR76346 (5.4 t ha^{-1}), and IR4630 (4.7 t ha^{-1}). The difference in GY among cropping season was also significant. The average GY recorded in the HDS and WS were 5.8 t ha^{-1} and 5.0 t ha^{-1} respectively (Table 4).

Two interactions, between salinity and management option, and between salinity and cultivar were found (Table 2). In the non-saline site, the difference in GY among fertilizer treatments was attributed solely to nitrogen level. The GY was 5.2 t ha^{-1}, 6.4 t ha^{-1}, 8.1 t ha^{-1} and 8.0 t ha^{-1} under 0, 60, 120, and 150 kg N ha^{-1}, respectively (Table 4). While in the saline site, the difference in grain yield among fertilizer treatments was attributed to both nitrogen level and the three management options. The GY in the saline site was 2.3 t ha^{-1}, 4.0 t ha^{-1}, 5.3 t ha^{-1}, and 5.4 t ha^{-1} under 0, 60, 120, and 150 kg N ha^{-1}, respectively (Table 4). In the saline site the highest GY (4.7 t ha^{-1}) was recorded under the NPK-gypsum option, while the lowest GY (3.8 t ha^{-1}) was recorded under the NPK option. When averaged across cultivars, mean GY was improved by 21%, 16%, and 8% in the HDS 2012, WS 2012, and HDS 2013, respectively, under the NPK-gypsum option in comparison to the NPK option (Table 4). Under the NPK-Zn option, mean GY was improved by 28%, 15%, and 2% in the HDS 2012, WS 2012, and HDS 2013, respectively, in comparison to the NPK option (Table 4). The Sahel 108 recorded the highest GY (7.7 t ha^{-1}), followed by IR31785 (7.3 t ha^{-1}), IR76346 (7.0 t ha^{-1}), IR72593 (7.0 t ha^{-1}), IR 59418 (6.9 t ha^{-1}) and IR4630 (5.9 t ha^{-1}) in the non-saline site. However, in the saline site, IR72593 recorded the highest GY (4.5 t ha^{-1}), followed by IR59418 (4.4 t ha^{-1}), IR76346 (4.3 t ha^{-1}), Sahel 108 (4.1 t ha^{-1}), IR4630 (4.1 t ha^{-1}) and IR31785 (3.8 t ha^{-1}).

Yield reduction

The effect of management option on the yield reduction (YR) was significant (Table 2). On the three season's basis, the YR recorded under the NPK-gypsum, NPK-Zn, and NPK options was 37%, 38% and 48%. There was a significant difference in YR among the four nitrogen rate (Table 2). The YR decreased with the increase levels of nitrogen. In the HDS 2012, the YR was 74%, 53%, 48% and 43% under 0N, 60N, 120N and 150 kg N ha^{-1}, respectively. In the WS 2012, the YR was 60%, 41%, 39%, 38% under 0N, 60N, 120N and 150 kg N ha^{-1}, respectively. In the HDS 2013, the YR was 28%, 16%, 11%, 15% under 0N, 60N, 120N and 150 kg N ha^{-1}, respectively (Table 5). Significant differences were detected among cultivars for YR. The cultivar IR31785 recorded the highest YR (50%), followed by Sahel 108 (45%), IR 76346 (39%), IR 59418 (37%), IR 72593 (35%) and IR4630 (33%). There was a significant difference in YR among cropping seasons. The YR recorded in the WS (48%) was higher than the HDS (26%).

Nitrogen use efficiency

Significant difference for ANUE was noticed between the saline site and the non-saline site (Table 2). The average ANUE measured in the saline site was higher (25.3 kg kg^{-1}) than in the non-saline site (20.3 kg kg^{-1}) (Figure 3). Significant higher ANUEs were observed under NPK-gypsum and NPK-Zn options (37 kg kg^{-1}, and 30 kg kg^{-1}, respectively) as compared to NPK option (27.4 kg kg^{-1}). There was a significant difference in ANUE among the nitrogen rates (Table 2). The ANUE measured under 60 kg N ha^{-1} (24.5 kg kg^{-1}) and 120 kg N ha^{-1} (24.5 kg kg^{-1}) were higher than that measured under 150 kg N ha^{-1} (19.5 kg kg^{-1}). Higher ANUE was measured in the HDS as compared to the WS (e.g. 36.5 kg kg^{-1} against 23.0 kg kg^{-1}). No significant difference for ANUE was noticed among the six cultivars and no interactions between cultivars and the other factors were noticed. However, effect of nitrogen rate was significantly different in function of salinity level as the interaction of the nitrogen rate and salinity level was significant (Table 2). In the saline site, ANUE was higher under 60 kg N ha^{-1} and lower under 120 kg N ha^{-1} and 150 kg N ha^{-1} (Figure 3a). While in the non-saline site, ANUE was higher under 120 kg N ha^{-1} and lower under 60 kg N ha^{-1} and 150 kg N ha^{-1} (Figure 3b).

Discussion

Soil properties and variation of EC

The difference in soil fertility between the non-saline site and the saline site was mainly due to the high concentration of soluble Na and exchangeable Na in soil of the saline site compared to the non-saline site. The Zn level in soil of the saline site was below the critical soil limit of 0.83 mg kg^{-1} of West Africa's lowland showing a Zn deficiency in the saline site (Abe et al. 2010). To avoid salt damage to newly transplanted seedlings in the saline site, plots were flushed with fresh water at the frequency of four times per week during three weeks which may explain the drop of EC at 20 DAT. We stop surface drainage from 21 DAT to physiological maturity of rice in the aim to avoid the

Table 5. Yield reduction (YR) caused by the salinity stress of the six rice cultivars under the different fertilizer treatments in the HDS 2012 (YR1), WS 2012 (YR2) and HDS 2013 (YR3).

	IR 31785			Sahel 108			IR 4630			IR 59418-7B-21–3			IR 76346-B-B-10–1-1-1			IR 72593-B-3–2-3–8		
Fertilizer Treatment	YR1	YR2	YR3	YR1	YR2	YR3	YR1	YR2	YR3	YR1	YR2	YR3	YR1	YR2	YR3	YR1	YR2	YR3
NPK																		
0 N	91 a	77 a	14 c	75 a	64 ab	35 a	44 bc	51 a	4.0 b	68 ab	55 ab	16 ab	85 a	55 ab	39 a	69 a	57 a	4 b
60 N	67 ab	62 ab	15 c	59 ab	60 ab	18 b	46 bc	40 ab	5.3 ab	62 ab	51 ab	15 ab	60 b	40 ab	20 ab	59 ab	41 ab	13 ab
120 N	70 ab	64 ab	15 c	62 ab	60 ab	20 b	50 bc	48 ab	6.2 a	61 ab	46 ab	21 a	50 b	46 ab	9 c	59 ab	38 b	14 ab
150 N	60 b	52 b	23 bc	61 ab	53 b	28 ab	51 bc	38 ab	7.1 a	51 b	20 c	28 a	48 bc	26 b	26 ab	45 b	32 b	1 b
Mean	71	62	18	64	59	25	49	44	5.7	60	43	21	58	41	23	56	43	13
NPK-Zinc																		
0 N	83 ab	78 a	32 b	78 a	67 ab	40 a	70 a	56 a	3.5 b	71 a	62 a	30 a	78 a	62 a	35 a	77 a	49 ab	2 b
60 N	52 b	56 b	12 c	56 ab	49 b	26 ab	43 bc	30 b	5.1 ab	39 b	37 b	19 ab	48 bc	29 b	21 ab	54 ab	24 b	11 ab
120 N	43 c	51 b	1 d	58 ab	38 b	12 b	39 bc	31 b	7.0 a	20 c	27 c	21 a	45 bc	25 b	16 b	53 b	23 b	14 ab
150 N	52 b	38 b	16 c	52 ab	44 b	14 b	17 c	34 b	6.2 a	37 bc	37 b	27 a	33 c	32 b	15 b	47 b	38 b	23 a
Mean	56	54	14	60	48	21	42	36	5.7	40	39	24	48	36	21	56	35	14
NPK-Gypsum																		
0 N	80 ab	80 a	51 a	73 a	71 a	42 a	63 ab	44 ab	4.1 b	74 a	52 ab	23 a	79 a	39 b	44 a	66 ab	57 a	20 a
60 N	54 b	68 ab	10 c	62 ab	54 ab	32 ab	40 bc	15 c	5.5 ab	41 b	34 b	8 b	57 b	20 b	16 b	51 ab	29 b	13 ab
120 N	40 c	54 b	8 c	55 ab	43 b	6 c	39 bc	30 b	7.0 a	33 bc	33 b	6 b	54 b	24 b	7 c	42 b	29 b	2 b
150 N	47 c	43 b	10 c	40 b	48 b	12 b	29 c	37 b	6.1 a	47 b	42 ab	22 a	25 c	35 b	13 b	38 b	35 b	4 b
Mean	52	59	20	56	52	23	41	31	5.7	46	39	14	53	29	20	48	36	9

HDS: hot dry season; WS: wet season

Means followed by the same letter per column are not significantly different at the probability of 0.05

leaching of applied fertilizers. Despite the interruption of drainage at 21 DAT, the continued decline in EC level in plots treated with gypsum was observed and this was probably due to the improvement of the soil structure e.g. porosity, permeability and infiltration rate, thus allowing effective leaching of salts (Gharaibeh et al. 2012). This process may explain the reduction of root zone EC from 21 DAT to 70 DAT under the NPK-gypsum option for the three seasons. However, in plots not treated with gypsum (NPK or NPK-Zn options), the drainage was probably not sufficient to wash excess salts after 20 DAT, and the high evaporation may have induced the capillary rise of salt from the shallow saline water table, hence the increase of root zone EC from 21 DAT to 70 DAT in these plots in the HDS 2012 and WS 2012. In the HDS 2013, the EC level has been drastically reduced regardless of management option, showing the positive effect of the intensity of cropping on the reclamation of saline soil (Ceuppens and Wopereis 1999).

Leaf-K, leaf-Na and leaf-K/Na ratio in rice

Leaf-Na was observed to be higher in the saline site than in the non-saline site, and the reverse trend was observed for leaf-K. However, gypsum and Zn supplies into saline soil improved the K uptake to the detriment of Na uptake resulting in the improvement of leaf-K/Na. Similar results have also been reported by Abd-Elrahman et al. (2012) in wheat and Saleh and Maftoun (2008) in rice. Furthermore, the increasing doses of nitrogen allowed an increase in leaf-K and leaf-K/Na. The findings in our study were in line with (Fageria and Oliveira 2014) who reported a positive interaction between N and K and a synergism effect in absorption of these two nutrients. The significant difference in leaf-K among cultivars was noticed, suggesting that some cultivars may absorb higher amounts of K than others. This K selectivity among cultivars could be a useful criterion in screening for salt tolerance. The seasonal differences in leaf-K and leaf-Na (e.g. both were higher in the WS than the HDS) are probably related to differences in climatic conditions, with particular reference to air humidity, as it is recognized as one of the key factors governing transpiration and therefore the uptake of nutrients (Lemoine et al. 2013). Generally in the WS, air humidity was relatively high, hence reducing the transpiration volume flow and the salt uptake. However, in the present study, because of time constraints due to long duration to maturity in the first season of trial (HDS 2012), the sowing in the WS 2012 trial was delayed. The booting stage, at which leaf sampling was performed, coincided with the early cold dry season (CDS), then with the high transpiration period. Asch and Wopereis (2001) reported the same results when they deliberately delayed sowing in their trial to study varietal responses to seasonal salinity.

Effects of management options on GY, YR and ANUE

Zn and gypsum supplies were more effective in the saline site as compared to the non-saline site. This could be due on the one hand to the alleviation of Zn deficiency in the saline site, and a possible role of Zn in protecting crops against Na toxicity reported by Amiri et al. (2016) on the other hand this could be due to the reduction of initial level of salinity by gypsum application in the saline site. As a result, grain yields in the saline site were improved considerably, and the yield reduction caused by the salinity stress was significantly reduced under NPK-Zn and NPK-gypsum management options. In the Sahelian zone, there were a small number of cultivars achieving a YR less than 40% caused by the salinity stress, thus rice cultivars having a YR less than 40% have been classified as salt tolerant (Asch et al. 2000). Based on the behaviour of the six cultivars in the present study, the cultivar IR72593, followed by the cultivar IR59418 and IR76346 should be recommended at first for cropping in saline soil; because the YR caused by the salinity stress of these cultivars was ranged from 35 to 39%. Economically, the NPK-gypsum option could generate more profits compared to the NPK-Zn option because gypsum is cheaper than zinc micronutrient in the local market. However, in the case of Zn deficiency in addition to the salinity stress, the recommendation of NPK-Zn option should be adopted in priority. Zn and gypsum supplies were also effective in improvement of ANUE under salinity stress. According to Rehman et al. (2012), Zn micronutrient plays an important nutritional role by enhancing N uptake. Also Suriyan et al. (2011) reported that the gypsum treatment combined with nitrogen fertilizer may reduce nitrogen loss and consequently may increase the nitrogen use efficiency under salinity stress. The ANUE is linearly correlated to the value: cost ratio, which is an important profitability index of crop production (Bado et al. 2015). Our study revealed that the nitrogen rate of 60 kg ha^{-1} which provided highest ANUE in the saline site should be recommended in the saline soil. In the non-saline site, the profitable nitrogen rate was 120 kg N ha^{-1} and yield trend remains relatively stable over seasons under this recommended level of N combined with P and K nutrients which is in accordance with the results of Bado et al. (2010) in a long-term fertility trial in the Senegal River Valley.

Conclusion

Our study showed that gypsum amendment combined with NPK fertilizer (NPK-Ggypsum) and Zn micronutrient combined with NPK fertilizer (NPK-Zn) are suitable management options in irrigated rice cropping under the salinity stress. The impacts of these two management options were more pronounced in the two first cropping seasons as the level of soil salinity was high. The associated profitable rate of nitrogen was 60 kg N ha^{-1}. The cultivar IR72593 was the best performing with a grain yield of 4.5 t ha^{-1}. Finally, we recommend the application of 60 kg N, 26 kg P, 50 kg K ha^{-1} and 100 kg gypsum ha^{-1} in the first two seasons of irrigated rice cropping under the salinity stress. In the case of Zn-deficiency in addition to the salinity stress, the recommendation should be 60 kg N, 26 kg P, 50 kg K ha^{-1} and 10 kg Zn ha^{-1}. Both fertilizer management options should increase production and profit of farmers. From the third season of cropping, we recommend that farmers revert to the normal fertilizer recommendation (e.g. 120 kg N, 26 kg P, and 50 kg K ha^{-1} in the Senegal River Valley) as the salinity level of soil is expected to decrease significantly.

Disclosure statement

No potential conflict of interest was reported by the authors.

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