ATTRIBUTES OF IRRIGATED RICE AS AFFECTED BY SOIL SODICITY AND POTASSIC FERTILIZER APPLICATION[1]

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SUMMARY

Soils of the coastal plains of Rio Grande do Sul, Brazil, are affected by salinization, which can hamper the establishment and development of crops in general, including rice. The application of high doses of KCl may aggravate the crop damage, due to the high saline content of this fertilizer. This study aimed to evaluate the effect of K fertilizer management on some properties of rice plant, grown in soils with different sodicity levels, and determine which attribute is best related to yield. The field study was conducted in four Albaqualfs with exchangeable Na percentages of 5.6, 9.0, 21 and 32 %. The management of KCl fertilizer consisted of the application of 90 kg ha^{-1} K_2O broadcast, 90 kg ha^{-1} K_2O in the row and 45 kg ha^{-1} K_2O in the row + 45 kg ha^{-1} K_2O at panicle initiation (PI). Plant density, dry matter evolution, height, SPAD (Soil Plant Analysis Development value indicating relative chlorophyll contents) index, tiller mass, 1,000-grain weight, panicle length and grain yield were evaluated. The plant density was damaged by application of K fertilizer in the row, especially at full dose (90 kg ha^{-1}), at three sodicity levels, resulting in loss in biomass accumulation in later stages, affecting the crop yield, even at the lowest level of soil sodicity (5.6 %). All properties were correlated with yield; the highest positive correlation was found with plant density and shoot dry matter at full flowering, and a negative correlation with panicle length.

Index terms: sodium, potassium, *Oryza sativa* L., density, spikelet sterility, grain yield.

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RESUMO: *ATRIBUTOS DE ARROZ IRRIGADO ALTERADOS PELA SODICIDADE DO SOLO E PELO MANEJO DO FERTILIZANTE POTÁSSICO*

Os solos das planícies costeiras do Rio Grande do Sul estão sujeitos à salinização, o que pode prejudicar o estabelecimento e o desenvolvimento das culturas em geral, inclusive do arroz. A aplicação de altas doses de KCl pode agravar os danos às lavouras, devido ao elevado índice salino desse fertilizante. Este trabalho teve como objetivos avaliar o efeito do manejo do fertilizante potássico sobre alguns atributos de planta de arroz irrigado, cultivado em solos com diferentes níveis de sodicidade, e verificar qual dos atributos melhor se relaciona com o rendimento de grãos. O estudo foi realizado a campo, em Planossolos Háplicos com percentagens de Na trocável de 5,6, 9, 21 e 32 %. O manejo do fertilizante, na forma de KCl, consistiu da aplicação de 90 kg ha^{-1} de K_2O a lanço; 90 kg ha^{-1} de K_2O na linha de semeadura; e 45 kg ha^{-1} de K_2O na linha de semeadura + 45 kg ha^{-1} de K_2O na diferenciação do primórdio floral (DPF). Foram avaliados o estande, a evolução da massa seca da parte aérea, a estatura de planta, o índice SPAD, a massa de perfilhos, a massa de mil grãos, o comprimento de panículas e o rendimento de grãos. O estande de plantas foi prejudicado pela aplicação do fertilizante potássico na linha de semeadura, principalmente na dose integral (90 kg ha^{-1}), em três níveis de sodicidade do solo, resultando em prejuízo no acúmulo de biomassa em fases posteriores, comprometendo assim o rendimento da cultura até mesmo no menor nível de sodicidade do solo: 5,6 %. Todos os atributos avaliados correlacionaram-se com a produtividade de grãos; a maior correlação positiva foi verificada com o estande de plantas e a massa da parte aérea seca no florescimento pleno, e a negativa, com o comprimento de panículas.

Termos de indexação: sódio, potássio, Oryza sativa *L., estande, esterilidade de espiguetas, rendimento de grãos.*

INTRODUCTION

Coastal plains of Rio Grande do Sul, Brazil, have vast areas suitable for the cultivation of irrigated rice (*Oryza sativa* L.), mainly because of the large availability of water resources and favorable terrain. However, sodicity, both of soil and water, may be a limiting factor for cultivation in this region of the State, where the main source of irrigation is a lagoon called Laguna dos Patos. By being connected to the Atlantic Ocean on its southern end, this source is subject to intrusion of sea water, with negative effects on the content of salts and especially of Na in the water. The adjacent lands under rice are therefore subject to the deposition of Na salts in greater proportions, which could affect the establishment and development of crops in subsequent plantings. In addition to the sodium increase by irrigation water, salinization of arable land in the coastal plains of Rio Grande do Sul may occur due to the soil genesis, based on the deposition of sandy sediments of marine and fluvial-lacustrine origin (Villwock & Tomazelli, 1995).

Rice is considered moderately sensitive to salinity, and the critical level, expressed as electrical conductivity of saturation extract, can vary from 1.9 dS m^{-1} (Grattan et al., 2002) to 3.0 dS m^{-1} (Maas & Hoffman, 1977; Ayers & Westcot, 1999), according to the variety and soil texture. For sodicity, Fairhurst et al. (2007) determined the critical level according to the exchangeable Na percentage (ESP); soils with ESP > 20 % are considered harmful to the crop. According to Pearson & Bernstein (1959), salinity is critical to rice in the seedling and flowering stage, resulting, respectively, in plant density reduction (Oster et al., 1984; Shannon et al., 1998) and spikelet sterility (Ehler, 1960; Fraga et al., 2010), a property highly correlated to grain yield (Grattan et al., 2002).

The decrease of soil osmotic component, caused by excess of salts in the soil solution, restricts the plants´ capacity of water uptake, decreasing transpiration by stomatal closure and hence a minor assimilation of photosynthetic active radiation, resulting in lower biomass production, with consequent reduction of tillering (Ehler, 1960) and plant height (Singh et al, 2007). The bluish-green color of the thicker and waxy leaves are also typical symptoms of prolonged water stress (Ayers & Westcot, 1999).

Most studies on the effects of salinity and sodicity on rice in Rio Grande do Sul have been performed in controlled environments, such as pots or tanks (Machado et al., 1991; Marcolin & Macedo, 2001; Schoenfeld et al., 2007, Fraga et al., 2010), where the response of different plant properties, e.g., biomass and grain yield of genotypes under sodicity levels in irrigation water are evaluated. In these studies, however, Na is accumulated in the root zone, since water with excessive levels of this ion is continually added while on the other hand, leaching and deep water percolation do not occur, which are real field conditions, especially in sandy soils. This complicates the interpretation of experimental results, since the sodicity in the root zone is constantly increased, although the Na content in the water added is the same, unlike in the field, where the addition of good quality water tends to reduce sodicity. Moreover, in these studies soils free of significant amounts of sodium are generally used as substrate, which does not allow an evaluation of the initial damage caused by pre-existing soil sodicity, as verified in various regions of the coastal plains of Rio Grande do Sul (Carmona et al., 2011).

In this State, direct seeding is adopted in about 90 % of the areas (Oliveira, 2006), with flooding at tillering (stage V4, Counce et al., 2000). The short period prior to irrigation, from emergence to V4, can damage the crop in case of high salt concentrations in the root zone, especially in sandy soils with low water-holding capacity. Under these circumstances, salinity and sodicity can cause failure in the germination process, inhibited tiller emission and plant death.

The application of high doses of KCl in the rows can exacerbate the damage caused by sodicity due to fertilizer hygroscopicity. Accordingly, the broadcast application of KCl can mitigate the damage caused by both the soil and fertilizer in direct contact with the seeds, increasing plant density, and higher initial accumulation of biomass. Depending on the salinity and sodicity level, the better initial growth provided by broadcast fertilization can be reflected in improvements in subsequent phases, including grain yield.

This study aimed to evaluate the effects of sodicity and potassic fertilizer application on irrigated rice attributes.

MATERIAL AND METHODS

The study was carried out on the Fazenda Cavalhada, in Mostardas, in the rice region called Outer Coastal Plain (OCP), Rio Grande do Sul, Brazil. The area consists largely of Albaqualfs and the main water source is a lagoon called Lagoa do Casamento, connected to the North end of the Laguna dos Patos. The area is characterized by sparse sodicity patches, with variable degrees of damage to the crop. For the experiment, different areas with a history of damage caused by sodicity during rice germination and development were selected.

Four sites (Figure 1) with different levels of soil sodicity (Richards, 1954) in the 0 - 20 cm layer (Table 1) were chosen. Sodicity was expressed as exchangeable Na percentage (ESP), according to equation 1. Ten sub-samples were collected at each site, constituting one sample per site.

$$ESP\ (\%) = [(Na^+/CEC_{pH\ 7})] \times 100 \qquad (1)$$

The Na saturation levels were 5.6 %, at the site called Casamento (30 ° 27 ' 08 " S, 44 ° 33 ' 43 " W), 9.0 % in Cavalhada (30 ° 29 ' 45 " S , 44 ° 34 ' 32 " W), 21 % in Banhado (30 ° 32 ' 09 " S, 44 ° 33 ' 38 " W), and 32 % in Sinval (30 ° 32 ' 33 " S, 44 ° 34 ' 35 " W). At three locations (Cavalhada, Banhado and Sinval), the variety IRGA 417 was used and IRGA 422 CL in Casamento, due to the high infestation of red rice. This variety, derived from five backcrosses, has IRGA 417 as direct parent (Lopes et al., 2003) and 97 % of its features. The different names given to the experimental sites refer to the farming plots considered in this study.

The plots had a size of 12 m² (4 x 3 m), and the borders 0.2 m. Thus, the evaluated area was 9.36 m² (3.6 x 2.6 m) and the total area at each of the four locations 203.5 m². Row seeding was carried out on different dates, depending on the dynamics of planting adopted on the property: Cavalhada on November 1, 2008; Banhado and Sinval on November 8, 2008 and Casamento, 17 November 2008. The seeding rate was 120 kg ha^{-1} and row spacing 0.2 m.

The soil chemical properties are shown in table 1. The treatments of KCl application consisted of: 1) 90 kg ha^{-1} K_2O broadcast; 2) 90 kg ha^{-1} K_2O in the row and 3) 45 kg ha^{-1} K_2O in the row + 45 kg ha^{-1} K_2O at panicle initiation (PI) (Counce et al., 2000). In the experimental plots, an amount equivalent to 60 kg ha^{-1} P_2O_5 (granular triple superphosphate – TSP), was also broadcast-applied immediately after sowing. When the plants reached stage V4, urea was applied at a rate of 120 kg ha^{-1} N, and immediately after, the plots were flooded. At PI, the second N rate of 30 kg ha^{-1} was applied, totaling 150 kg ha^{-1} N. For each sodicity level, there was a control treatment without KCl addition, but with 150 kg ha^{-1} N divided in V4 (120 kg ha^{-1}) and PI (30 kg ha^{-1}), and 60 kg ha^{-1}

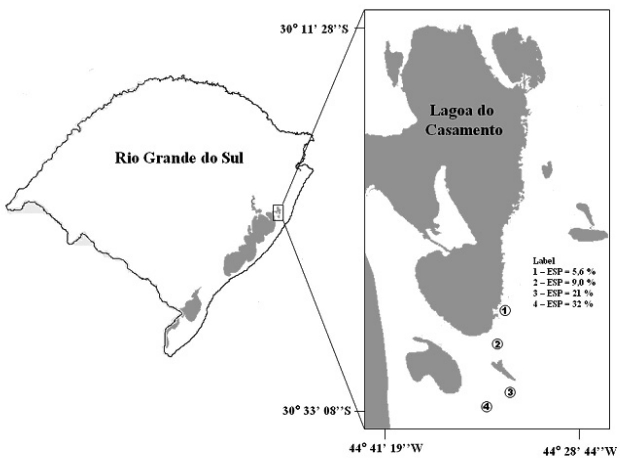

Figure 1. Location of the studied soils.

Table 1. Soil chemical properties and clay content in the 0 - 20 cm layer, at different sites

Site	pH(1)	Clay(2)	OM(3)	P(4)	K(5)	Na(5)	Ca(5)	Mg(5)	$CEC_{pH7.0}$	EC(6)	ESP(7)
	1:1	g kg^{-1}		mg dm^{-3}			$cmol_c$ dm^{-3}			dS m^{-1}	%
Casamento	4.4	140	18.9	32	42	106	2.33	1.45	8.4	1.96	5.6
Cavalhada	4.6	150	13.7	38	62	151	1.87	1.96	7.2	1.77	9.0
Banhado	4.9	140	14.1	26	83	376	2.05	1.77	7.7	6.04	21
Sinval	5.1	130	12.3	36	154	878	2.16	3.14	11.7	12.1	32

(1) pH in H_2O (Tedesco et al., 1995). (2) Pipette method (Tedesco et al., 1995). (3) Soil organic matter, wet combustion method (Tedesco et al., 1995). (4) Mehlich 1 (Tedesco et al., 1995). (5) Ammonium acetate extractant, 1,0 mol L^{-1} (Embrapa, 1997). (6) Electrical conductivity of saturated extract (Tedesco et al., 1995). (7) Exchangeable sodium percentage (Embrapa, 1997).

P_2O_5. Each experiment (site) was performed with three replications per treatment, in a randomized block design. Weeds were controlled with specific herbicides (Penoxulam + Clomazone for IRGA 417 and Imazethapyr + Imazapic for IRGA 422 CL) applied at stage V3 - V4 (Counce et al., 2000) prior to flooding. The electrical conductivity of irrigation water ranged from 0.25 to 0.33 dS m^{-1}.

When plants of the control treatment at each site reached the V4 stage, stand density was evaluated in all treatments of each site. In each plot, the number of emerged plants in two 1.0 m long rows (Foloni et al., 1997) was counted. To assess the shoot dry matter, plant samples were collected in four periods of rice development: V4, 21 days after flooding (DAF), 42 DAF and at full flowering (FF). The plants in 1.0 m long rows were collected, except in V4, when 2.0 m long rows were harvested. The plants were dried in a forced-air oven for 72 h to determine dry matter. In view of the uneven stand density in Sinval, due to the high salinity and sodicity (Table 1), plants were sampled only once, at full flowering, so as not to hamper the subsequent evaluations. Additionally, 42 DAF plant height was measured as well as the indirect N content in the youngest leaf, using a chlorophyll meter SPAD-502® (Minolta, 1989), for all sites and treatments.

At maturation, prior to harvest, two 50 cm long rows of plants were collected from each site and treatment. After counting the number of tillers, the material was dried in a forced-air oven for 72 hours to determine tiller mass and panicle length. Then the spikelets were removed and manually separated from the panicles, to determine 1,000 grain weight. Grain was harvested from an area of 5 m^2 per plot. The material was threshed with a stationary thresher and the grain cleaned by sieving, weighed and the grain mass corrected to 13 % moisture.

The data of plant attributes of each sodicity level were subjected to ANOVA to verify the statistical significance ($p < 0.05$) of the effects of different potassic fertilizer application. Then the, means were compared by the LSD test ($p < 0.05$). Additionally, all properties were related, regardless of potassium application, with the grain yields of IRGA 417. These relations were performed only (ESP of 9.0, 21 and 32 %).

RESULTS AND DISCUSSION

Plant attributes in relation to potassic fertilizer application

The ANOVA summary regarding plant density at different sodicity levels (Table 2) showed a significant effect of K fertilizer management in soils with ESP of 5.6 % ($p < 0.01$), 21 % ($p < 0.05$) and 32 % ($p < 0.05$). The application of 90 kg ha^{-1} of K_2O in the row decreased ($p < 0.05$) seedling emergence compared to the control (without addition of K_2O), to the broadcast application of 90 kg ha^{-1} K_2O and to the split application of K_2O (45 kg ha^{-1} in the row and 45 kg ha^{-1} at PI) in soils with ESP of 5.6, and 21 % (Figure 2a). The plant density on soil with ESP of 32 % was very low, which should be mainly attributed to the high salinity and sodicity (Table 1). At this site, the negative effect of K fertilizer on density compared to control ($p < 0.05$) was independent of the application form (Figure 2a). In this case, the hygroscopicity of the fertilizer seems to have had a negative influence when applied broadcast. The splitting of KCl application proved to be an effective alternative to mitigate the effects of direct seed-fertilizer contact; at the ESP level of 21 %, there was no difference ($p > 0.05$) from the control and broadcast treatments, but in soil with ESP of 5.6 %, this practice resulted in lower density ($p < 0.05$), compared to the control and broadcast application.

The application of high K rates in the row is therefore detrimental to plant establishment, by reducing the osmotic potential around the root system, as well as by the specific effect of Cl on the crop, which is moderately sensitive to salinity. Oster et al. (1984) have suggested the need for management practices that prevent a direct contact of the seeds in adversely saline substrates, aiming at more uniform seedling emergence. In this sense, Carmona et al. (2009) observed a delay in the seedling development of rice cultivar IRGA 417, grown on small plots with ESP levels of 0.7, 5.0, 10 and 20 %. In this study, it was found that the initial seedling growth was more stimulated by broadcast application of K fertilizer than by application in the row and that the effects were most significant at the highest sodicity levels. In the coastal plains of Rio Grande do Sul, some farmers have been applying K fertilizer broadcast in advance to obtain better crop establishment. This practice increases the lifetime of sowing machines and the efficiency of manpower, besides facilitating sowing on the recommended dates, especially on large attributes, or with restricted availability of equipment.

The different K fertilizer management affected the shoot dry matter in V4 in the soil with ESP of 5.6 % ($p < 0.01$); 21 DAF in the soil with ESP of 21 % ($p < 0.05$); 42 DAF, again in the soil with ESP of 5.6 % ($p < 0.05$); and at full flowering in the soil with ESP of 32 % ($p < 0.05$) (Table 2). The K fertilizer applied in the row, both as full dose and split, reduced ($p < 0.05$) biomass production. At this site, this effect was observed again 42 DAF (Figure 2d). However, only the application of 90 kg ha^{-1} K_2O in the row affected ($p < 0.05$) biomass production. Twenty-one DAF, the fertilizer management was effective only in soil with ESP of 21 % (Figure 2c), where, as verified at 5.6 % (Figure 2b,d), the application of the full fertilizer dose in the row decreased ($p < 0.05$) biomass production, compared to the control and broadcast application. At full flowering, there was a very low production of biomass in soil with ESP of 32 % (Figure 2e), as a result of the lowest plant establishment at this site (Figure 2a), as also observed by Shannon et al. (1998).

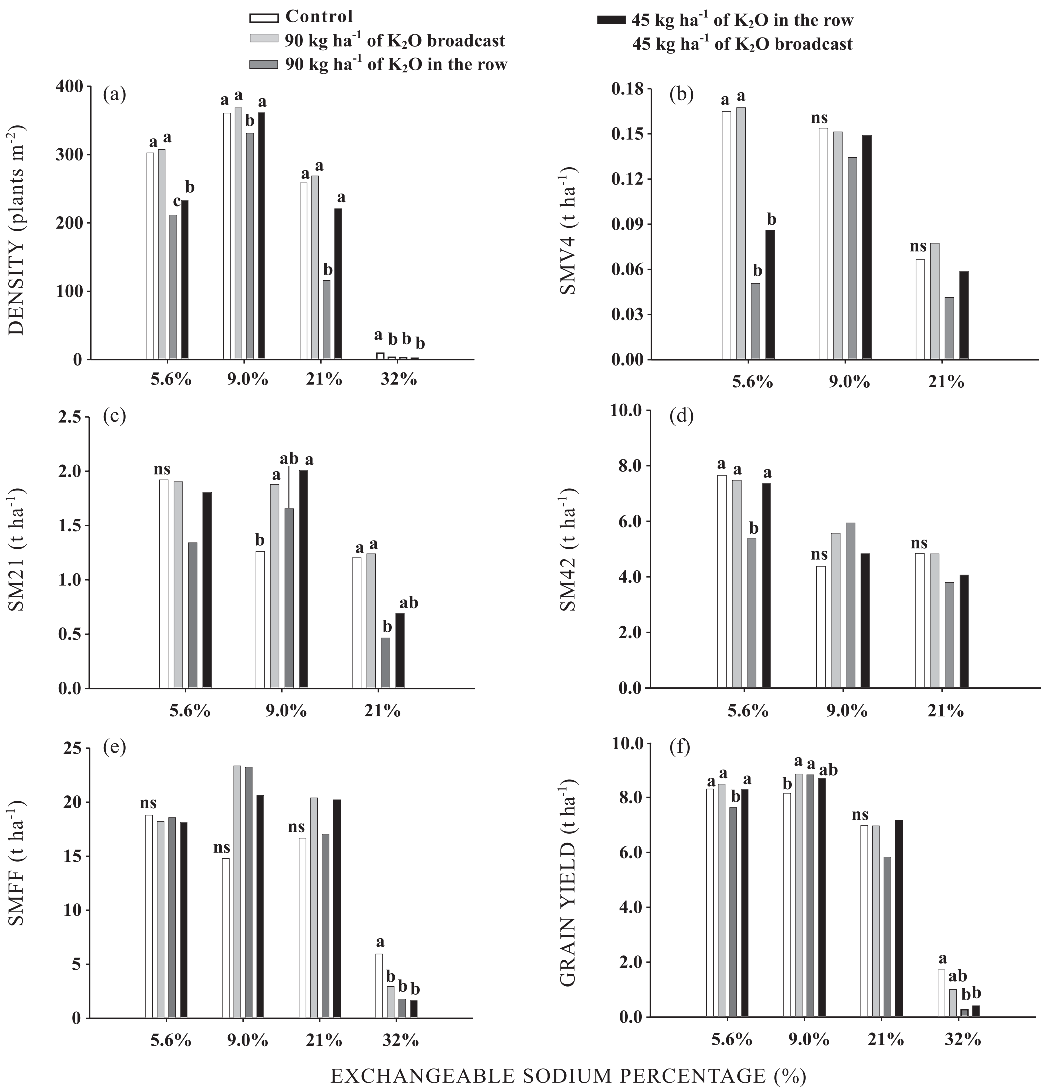

Figure 2. Density (a), shoot mass in V4 (b), shoot mass 21 DAF (c), shoot mass 42 DAF (d), shoot mass at full flowering (e) and grain yield (f) of irrigated rice plants according to potassic fertilizer management and soil sodicity level. Means followed by the same letter, between the sodicity levels do not differ by LSD test at 5 %.

Table 2. Summary of analysis of variance for density, shoot mass in V4 (SMV4), shoot mass 21 days after flooding (SM21), shoot mass 42 days after flooding (SM42) shoot mass at full flowering (SMFF), plant height, chlorophyll meter reading (SPAD index), mass of tillers (MT), 1,000-grain weight (1.000 GW), panicle length (PL) and grain yield (GY) in soils with different exchangeable sodium percentage (ESP)

Source of variation	DF	Mean square										
		Density x 10	SMV4 x 10^5	SM21 x 10^2	SM42 x 10^2	SMFF x 10	Height x 10	SPAD x 10	MT x 10^2	1,000 GW x 10^2	PL x 10	GY x 10^2
						ESP 5.6 %						
Blocks	2	16.1	9.79	54.4	1.30	45.2	14.7	2.26	44.6	25.3	136	6.11
Treatments	3	705**	1.020**	22.2	3.44*	2.87	58.9	10.2	8.3	7.19	679	42.2*
Residue	6	9.57	54.2	11.1	67.3	44.5	24.9	18	18.1	13.8	971	7.33
CV (%)		3.71	19.9	19.2	11.8	11.4	2.10	4.21	25.5	1.46	4.38	3.31
						ESP 9,0 %						
Blocks	2	2.51	30.3	15.9	66.8	3.60	88.7	92.6	41 6	0.33	181	40.7
Treatments	3	81.4	23.1	32.2	148	4.82	7.21	9.26	122	30.2	116	31.8
Residue	6	21.5	30.2	8.62	62.4	2.18	23.9	26.6	115	31.9	390	9.28
CV (%)		4.12	11.8	17.3	15.2	22.8	2.46	5.31	9.13	2.37	2.94	3.53
						ESP 21 %						
Blocks	2	714	75.8	43.9	182	1.81	18.3	18.5	281	7.75	10.4	29
Treatments	3	1466*	68.9	43.9*	86	1.2	35	28.4	204	28.8	14.7	111
Residue	6	264	67.7	9.07	49.3	0.59	11.9	38.7	123	38.2	3.43	59.3
CV (%)		23.8	42.7	33.5	16.0	13.1	1.66	5.68	7.96	2.53	2.61	11.45
						ESP 32 %						
Blocks	2	52.5	n/e	n/e	n/e	2.94	48.4	8.28	107	222	1.040	22.8
Treatments	3	360*	n/e	n/e	n/e	120*	101	14.2	15.9	29.6	101	132
Residue	6	54.7	n/e	n/e	n/e	19.5	55.1	10.9	38.5	48.5	364	30.3
CV (%)		52.0	n/e	n/e	n/e	45.5	4.42	2.68	29.4	3.05	2.41	64.9

*, **: significant at 5 and 1 %, respectively. n/e: not evaluated.

In general, the most pronounced effect of K fertilizer management on plant attributes was observed in soil with ESP of 5.6 % (Table 2), where the damage caused by the application of full dose of KCl in the row on establishment, biomass accumulation and grain yield was confirmed (Figure 2a,b,d,f). It was expected, however, that the significance of fertilizer management would be proportional to the increase in soil sodicity, due to the sum of unfavorable factors for cultivation, which was not the case. In this sense, the lower rainfall that had occurred since the establishment of the experiment at this site, compared to the others (data not shown) should be taken into account because the seeding was nine days later than on the soils with ESP of 21 and 32 %; and 16 days compared to ESP of 9.0 %. The reduced rainfall may have boosted the hygroscopic effect of KCl (which was reflected until grain harvest - Figure 2f), since the soils studied have low clay and organic matter contents (Table 1) and therefore, low water-retention capacity.

Relationship between grain yield and other plant attributes at different sodicity levels

Yield losses due to salinity can occur due to a number of causes, such as reduction of photosynthetic capacity (Sultana et al., 1999), decrease in assimilate accumulation in the grain (Asch et al., 2000) and reduction in grain filling by insufficient carbohydrate supply of panicles (Khatun & Flowers, 1995). Since the effects of K fertilizer management in some plant properties (especially yield components) were not verified by ANOVA, a regression study was performed (Figure 3) in an attempt to verify which plant properties contributed most to the yield losses.

All evaluated plant properties were significantly related with grain yield. Among the measurements taken during plant growth, density had the highest regression coefficient (Figure 3a). The shoot dry matter in V4 showed greater adjustment (Figure 3b) than shoot dry matter 21 DAF (Figure 3c) and shoot dry matter 42 DAF (Figure 3d). Of all biomass assessments, however, the shoot dry matter at full flowering correlated best with yield (Figure 3e). The literature reports that different rice cultivars are inhibited in biomass production with increasing salinity of the medium, as presented by Zeng et al. (2001), Grattan et al. (2002) and Fraga et al. (2010). The decrease in osmotic potential of soil solution induces the accumulation of abscisic acid in plants (Chazen et al., 1995), decreasing stomatal conductance and intercellular CO_2 concentration. In this case, stomatal closure leads to a reduction of water and osmotic potential of leaves and the synthesis of biochemical constituents, reducing the accumulation of assimilates and, consequently, biomass production (Sultana et al., 1999).

These results demonstrate the importance of a good initial crop establishment, to favor a proper shoot development, which includes, in addition to tillering, plant height, as requirement for a satisfactory grain yield. The data presented here are consistent with those obtained by Zeng & Shannon (2000), who found a positive relationship between the number of tillers under salinity stress and productivity.

Plant height was also strongly related with yield (Figure 3f). In this case, the lower dry matter production (Figure 2e) may have been the result of low stand (Figure 1a) and reduced leaf emission, since the production of tillers tends to be lower at high sodicity levels, which is reflected in shorter height. Moreover, the leaf length tends to be shorter (Singh et al., 2007). Another property highly related to yield was 1,000-grain weight (Figure 3i). The lower grain mass, due to sodicity, can be attributed to the decrease in grain size. However, the redistribution of carbohydrates within the spikelets after reduction in the number of spikelets under stress, can partially compensate losses in grain yield by increasing fertility

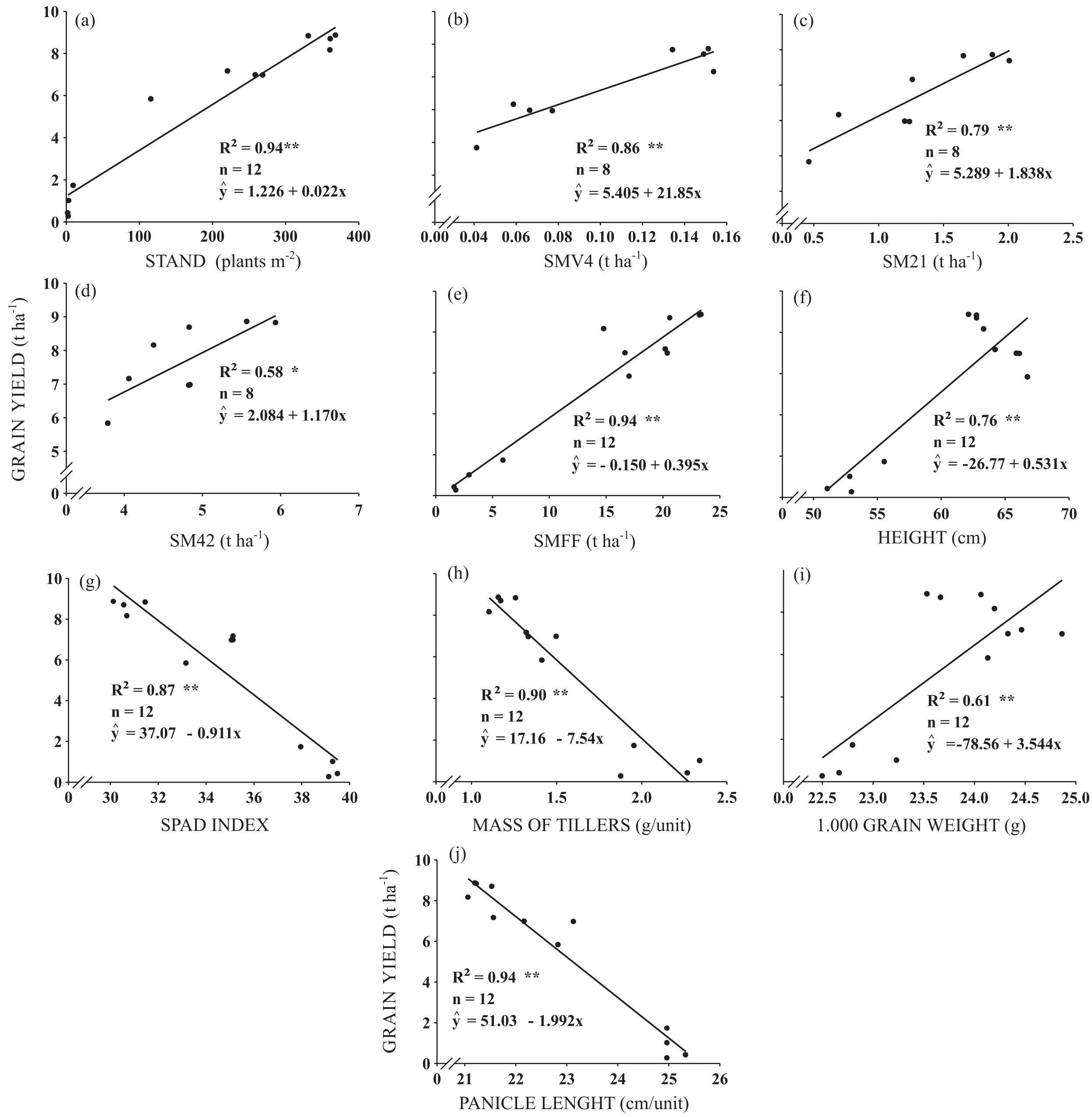

Figure 3. Relationship between density (a), shoot mass in V4 (b), shoot mass 21 DAF (c), shoot mass 42 DAF (d), shoot mass at full flowering (e), height (f), SPAD index (g), mass of tillers (h), 1,000-grain weight (i) and panicle lenght (j) with grain yield of the variety IRGA 417, grown in soils with different sodicity levels and under different potassic fertilizer management, *, **: p < 0,05, < 0,01, respectively.

of the remaining spikelets (Zeng & Shannon, 2000), which was not observed in this study.

Among the properties negatively related to yield, panicle length stands out (Figure 3j), followed by tiller dry matter (Figure 3h) and the SPAD index (Figure 3g). Although sodicity caused major damage to the shoot dry matter at full flowering (Figure 2e) precisely at ESP of 32 %, the remaining tillers became thicker, due to the greater spacing caused by low density (Figure 2a), which contributed to an increase in mass per tiller. The same was observed for panicle length, which was on average higher in ESP of 32 % (25.1 cm), than ESP of 21 % (22.4 cm) and ESP of 9.0 % (21.3 cm).

The highest SPAD index observed at ESP of 32 % may be related to a greater accumulation of ammonium in the leaves, as reported by Nguyen et al. (2005), in rice seedlings grown in a 100 mmol L^{-1} NaCl solution, where the increase in proteolytic activity and decreased protein synthesis caused accumulation of free amino acids, which may indirectly lead to excessive accumulation of ammonium in the leaves (Hoai et al., 2003). The bluish-green color, reported by Ayers & Westcot (1999) as one of the symptoms related to salinity in rice may therefore be related to high foliar N levels. Thus, the SPAD index may come to be used as a fast and efficient indicator of sodicity stress.

CONCLUSIONS

1. The application of high doses of K fertilizer in the row damages rice establishment, affecting biomass accumulation in subsequent phases.

2. The damage to plant density caused by local application of K fertilizer (contact with seeds) is reflected in rice yield losses, even at low soil sodicity levels.

3. The plant properties that are most strongly correlated with yield under different conditions of sodicity stress are density and shoot dry matter at full flowering (positively), and panicle length (negatively).

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