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Rice sensitivity to saline irrigation in Southern Spain

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ABSTRACT

Losses of productivity of flooded rice in Southern Spain may occur due to the use of saline water coming from the existent tidal regime in the marshes of Guadalquivir River, and the sensibility of the plants is variable according to its stage of development. The aim of this research was to evaluate the production of rice grains and its components, spikelet sterility and the phenological development of rice at different levels of salinity and in different periods of its cycle. In the conditions of the trial, the productive potential of rice based on the electrical conductivity (EC) of the irrigation water can be estimated by using the equation "*Percentage of grain yield* = 100 – 12.0 (*EC* – 0.92)". It was estimated that from 1.6–1.7 dS m^{-1} salt content affects rice grain yield. Salinity also had a negative impact on a number of yield components including panicles per surface unit, tillers and spikelets per plant; floret sterility; and even delayed heading. Individual grain size was scarcely affected by salinity increase. The vegetative and reproductive phases were significantly more sensitive to salinity than grain filling and maturation phase. Irrigation management practices should be adopted to minimize salinity during these critical growth stages.

1. Introduction

Rice (*Oryza sativa* L.) is a high-tolerant crop to submersion, but not highly tolerant to salinity (Aguilar, 2010). The electrical conductivity (EC) increases in direct proportion to the salt concentration in the water. EC of the soil and field water in lower river basins is significantly higher than in upper basins (Grattan et al., 2002).

Substantial loss in seedling establishment, leaf chlorosis, and final yield reduction were observed in salt-affected rice growing areas (Scardaci et al., 1996; Shannon et al., 1998). Salinity also implies a delay in earing and flowering stages (Khatun and Flowers, 1995). Studies in some Californian rice systems (Hanson et al., 1999; Maas and Grattan, 1999) showed significant rice yield reductions from a salinity concentration of 3.0 dS m^{-1}, increasing in a 12% for every extra EC unit. Zeng and Shannon (2000), also in California, established the yield loss threshold in as few 1.9 dS m^{-1}, according to this equation: % yield = 100 – 9.1 (EC – 1.9); but with less loss percentage for every extra EC unit. In both cases, panicle per square meter and number of full grains per panicle were the most affected yield components.

Rice response to salt stress varies according to growth stage. Rice is particularly sensitive to salinity during the stages of seedling with 3–4 leaves (at the end of the vegetative phase), panicle initiation and early booting (both during the reproductive phase), as reported by Pearson and Bernstein (1959), Kaddah (1963), Maas and Hoffman (1977), Flowers and Yeo (1981), Heenan et al. (1988), Cui et al. (1995), and Zeng et al. (2001). Instead, the plant is relatively salt tolerant during germination and during the filling and maturation grain phase (Heenan et al., 1988; Khan et al., 1997).

Therefore, differential sensitivity during growth stages is one of the major issues in the management of saline water for irrigation. This can be clearly shown when stages are well defined in the timing treatments and the stress is quantified at growth stages based on the same duration of salinization (Zeng et al., 2001).

The final stretch of the Guadalquivir River, which divides the Seville rice area, is subject to tidal influence. Their growing conditions are similar to those of the California rice systems. The salty sea water tends to penetrate upstream, while the fresh water of the river opposes this intrusion, forming a transition zone with variable salinity, where pumps for irrigation water are located. In addition, irrigation water is reused in many plots, which promotes the degradation of phytosanitary products but increases water salinity at

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Abbreviations: T1, non-saline irrigation; T2, saline irrigation at 2.22 dS m^{-1}; T3, alternating saline irrigation at 2.38 dS m^{-1}; T4, saline irrigation at 4.13 dS m^{-1}; C, never-saline irrigation; V, saline irrigation only during the vegetative phase; R, saline irrigation only during the reproductive phase; M, saline irrigation only during the grain filling and maturation phase; V-R-M, saline irrigation during the three phases.

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the same time. In years of moderate irrigation water restrictions, the average salt concentration in irrigation water is usually around 2.86 dS m^{-1}. In years with severe restrictions, although infrequent, salinity can reach 4.0 dS m^{-1} or more, resulting in substantial losses in grain yield (Aguilar, 2010).

The aim of this work was to study rice sensitivity to salinity in Southern Spain, determining the effects of different salt contents in irrigation water and duration of salt stress on grain yield and its components, as well as on other physiological characters (plant height and days to 50% of heading) and industrial quality (head rice yield). In this rice-growing region, these effects are little known and have not been studied to date.

2. Materials and methods

A controlled salinity study was conducted in 2013, 2014, and 2015 in experimental plots belonging to Rice, Corn and Cotton Department of IFAPA, in Alcalá del Río (Sevilla). Two experiments were carried out in order to know the sensitivity of rice to different salt concentrations and its agronomic response to saline irrigation at different growth phases. A total of 24 experimental plots (3 × 2 m) were used each year, 12 plots (4 treatments and 3 replications) per experiment.

A long-B grain size and early maturation cultivar, *Puntal*, was used. This *Indica*-type variety, which is cultivated in 80% of Southern Spain rice area, has been rated as medium sensitive to salinity.

Seeds were sown directly in experimental plots at a rate of 180 kg per hectare, as the common practice in the region. The final mean plant density was calculated using the number of panicles per m^2 and the tillering index in each treatment. This mean plant density was finally established at about 85 plants per m^2.

Irrigation with different salt concentrations was applied from the phenologic stage of three leaves by a 25,000 L-tank specially designed for this purpose. The system consisted of a small initial 1000 L-tank where irrigation water was mixed with appropriate sea salt amounts, due to the high difficulty of adding salt directly to the large tank, which was too high. From the small tank, the resulting mixture was pumped to each plot and diluted with fresh water from the larger tank until the desired final concentration was reached. The original characteristics of the irrigation (fresh) water are listed in Table 1. In order to check and control the salinity in each treatment, determinations of salt content in the irrigation water were carried out every two days, using a conductivity meter, from a water sample taken at the surface of each experimental plot. The following estimative relation between salt content (expressed in grams per liter) and electrical conductivity (expressed in deciSiemens per meter) can be established (Aguilar, 2010):

$$\text{Salt content}\ \ (\text{g}\ \ \text{L}^{-1}) = 0.63\,EC\ \ (\text{dS}\ \ \text{m}^{-1})$$

Irrigation water was conducted through a system of pipes to each experimental plot. Each plot had a saline water entrance from the small tank and a fresh water entrance from the large one, whose flow rates could be adjusted at will. The pipes from the two tanks were not connected, so water mixing occurred at the plot. Each experimental plot also had adjustable surface and drainage water outputs. An irrigation regulator controlling the time of the different irrigation periods according to each treatment was used. Continuous flooding was the irrigation system used, similar to that used in the rice fields of the Guadalquivir Marshes. Experimental plots were filled with soil from this rice-growing area (Table 1), existing, by proximity, also similar weather conditions (Fig. 1).

All data analyses were performed with the software "Statistix 9.0". A two-way ANOVA, with Randomized Complete Blocks design and three replications, was used to test the significance of differences among treatments and years for each measured variable. Means were compared using the Fisher's Least Significant Difference (LSD). Statistically significant effects and the coefficient of determination (R^2) were assumed for $p < 0.05$.

2.1. Agronomic response to different concentrations of saline water

Rice was grown in experimental plots that were flooded using prepared irrigation waters that varied in salinity, with targeted values of:

T1: 0.63 dS m^{-1}. Control/grower fresh water.
T2: 2.22 dS m^{-1}.
T3: 0.63–4.13 dS m^{-1}. Alternating the two salt concentrations every 6 h, trying to simulate the tidal influence and daily pumping of water with different salt concentrations existing in Southern Spain rice-growing area.
T4: 4.13 dS m^{-1}. Water directly coming from the small tank.

These average concentrations were recorded in the surface water of the experimental plots, with maximum fluctuations along the irrigation season of 0.31 dS m^{-1} for T2, T3 and T4, and 0.16 dS m^{-1} for T1.

The four salinity treatments were replicated three times in a randomized block design.

Recorded variables by elemental plot were:

- Days to 50% of heading. Visual estimation.
- Number of panicles per square meter. Calculation from three 0.5 m^2 ring throws.
- Number of filled grains per panicle. 40 panicles were considered.
- Thousand grain weight. From the average of three samples.
- Grain yield (at 14% relative moisture). The entire plot was harvested and weighed.
- Head rice yield. From a sample of dry paddy rice using a Satake (Satake Corporation, Japan) milling apparatus, type THU35B, with a Toshiba motor of 1900 rpm.

Table 1
Soil conditions in experimental rice plots and analysis of fresh water for irrigation. Alcalá del Río, 2013.

Analyzed variable	Units	Analysis result
Soil conditions		
Cation exchange capacity	meq 100 g^{-1}	18.2
Exchangeable sodium percentage	%	17.1
Electrical conductivity. Ext. 1:5	dS m^{-1}	2.1
pH		8.2
Oxidable organic matter	% P/P	1.92
Available phosphorus	mg kg^{-1}	15.6
Available potassium	mg kg^{-1}	407
Clay	%	44
Silt	%	42.2
Sand	%	13.8
Texture classification	Silty clay	
Fresh water for irrigation		
pH		8.1
Electrical conductivity	dS m^{-1}	0.6
N-Nitrate	meq L^{-1}	0.366
N-Ammonium	mg L^{-1}	0.057
Sodium	meq L^{-1}	2.33
Potassium	meq L^{-1}	0.252
Calcium	meq L^{-1}	7.01
P-Phosphate	meq L^{-1}	<0.001
Hardness	°H	62.6