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Productivity of sodic soils can be enhanced through the use of salt tolerant rice varieties and proper agronomic practices

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ABSTRACT

Regaining the agricultural potential of sodic soils in the Indo-Gangetic plains necessitates the development of suitable salt tolerant rice varieties to provide an entry for other affordable agronomic and soil manipulation measures. Thus selection of high yielding rice varieties across a range of sodic soils is central. Evaluation of breeding lines through on-station and on-farm farmers' participatory varietal selection (FPVS) resulted in the identification of a short duration (110–115 days), high yielding and disease resistant salt-tolerant rice genotype 'CSR-89IR-8', which was later released as 'CSR43' in 2011. Several agronomic traits coupled with good grain quality and market value contributed to commercialization and quick adoption of this variety in the sodic areas of the Indo-Gangetic plains of eastern India. Management practices required for rice production in salt affected soils are evidently different from those in normal soils and practices for a short duration salt tolerant variety differ from those for medium to long duration varieties. Experiments were conducted at the Indian Council of Agricultural Research-Central Soil Salinity Research Institute (ICAR-CSSRI), Regional Research Station, Lucknow, Uttar Pradesh, India during 2011 and 2013 wet seasons, to test the hypothesis that combining matching management practices (Mmp) with an improved genotype would enhance productivity and profitability of rice in sodic soils. Mmp were developed on-station by optimizing existing best management practices (Bmp) recommended for the region to match the requirements of CSR43. The results revealed that transplanting 4 seedlings hill^{-1} at a spacing of 15×20 cm produced significantly higher yield over other treatments. The highest additional net gain was US$ 3.3 at 90 kg ha^{-1} N, and the lowest was US$ 0.4 at 150 kg ha^{-1} N. Above 150 kg ha^{-1}, the additional net gain became negative, indicating decreasing returns from additional N. Hence, 150 kg N ha^{-1} was considered the economic optimum N application rate for CSR43 in these sodic soils. Using 150–60–40–25 kg $N–P_2O_5–K_2O–ZnSO_4{\cdot}7H_2O$ ha^{-1} in farmers' fields grown to CSR43 produced an average of 5.5 t ha^{-1} grain. The results of on-farm evaluation trials of CSR43 showed that matching management practices (Mmp) increased yield by 8% over existing best management practices (Bmp) recommended by ICAR-CSSRI for sodic soils and by 16% over framers' management practices; however, combining Mmp with CSR43 resulted in 35% higher yields over farmers' current varieties and management.

This approach of combining cost effective crop and nutrient management options and a salt-tolerant variety can maximize the productivity and profitability of sodic soils in the alluvial Indo-Gangetic plains and in neighboring salt-affected areas of the Ganges mega delta in South Asia.

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1. Introduction

Salt affected lands are estimated at about 955 million ha worldwide (Szabolcs, 1994), afflicting 7% of the world's total arable land (Flowers et al., 1997). The Indo-Gangetic region in India (21° 55′–32° 39′N and 73° 45′–80° 25′E; Singh et al., 2010) has about 2.7 million ha of salt affected soils, consisting mostly of centuries-old barren sodic soils with no land use opportunities (NRSA and Associates, 1996). These soils have been regarded as unfit for agriculture due to high pH (>8.5) and concentrations of soluble salts that produce alkaline hydrolysis products such as Na_2CO_3 and $NaHCO_3$, together with sufficient exchangeable sodium to cause poor physical soil characteristics.

Grain yield of rice in salt affected soils is much lower because of its high sensitivity to salt stress (Flowers and Yeo, 1989; Gao et al., 2007; Ismail et al., 2007). Rice is exceptionally sensitive to salinity and sodicity at early seedling stage (Aslam et al., 1988, 1993) and high yield losses have been observed because of high mortality and poor crop establishment. Modern high yielding varieties require considerable investment to ameliorate these soils to ensure reasonable yields, but this investment is beyond the capabilities of the resource-limited small holder farmers living off these salt affected areas. Increasing and sustaining yields in these areas will require a system that integrates salt tolerant varieties with effective and affordable crop and nutrient management practices. Chowdhury et al. (1993) observed that the number of seedlings hill^{-1} and plant spacing were important factors determining plant population per unit area for optimum nutrient uptake and for accessing sufficient light for photosynthesis, which ultimately determine grain yield. Plant mortality in sodic soils is high when young seedlings are transplanted, adversely affecting plant establishment and growth (Dargan and Gaul, 1974). Older seedlings survive better and establish earlier, but they produce less tillers and exhibit poor growth (Mandal et al., 1994). The effects of seedling age become more noticeable in short duration varieties (Chandrakar and Chandravanshi, 1988).

Sodic soils are inherently low in organic matter (<0.1%), and available N, and are more responsive to N application. These soils are more prone to N losses due to higher N volatilization caused by high pH, further aggravating N deficiency. Microbial activity, which influences N mineralization, is restricted by salt stress (Abrol et al., 1988; Liu and Kang, 2014; Wong et al., 2010). Therefore, the requirement of added N in sodic soils is higher than in normal soils and salt tolerant varieties appear to respond better to higher N application than sensitive varieties (Dixit and Patro, 1994; Meena et al., 2003).

Apparently, the lack of high yielding salt tolerant rice varieties, together with good management strategies specific for sodic soils are the main reasons for low and unstable productivity. High yielding salt tolerant varieties, like CSR10, CSR13, CSR23, CSR27, CSR36, Narendra Usar dhan3, which can tolerate sodicity of up to pH 9.8, were developed through conventional plant breeding and have made good impacts in salt-affected areas of India (Mishra et al., 1992). However, these varieties are of medium to long duration (130–140 days) and often do not fit well in the rice–wheat system predominating the Indo-Gangetic plains. Integrating farmers' participatory varietal selection approach (FPVS) within the evaluation process during breeding strengthens and accelerates the selection of varieties with characteristics desired by farmers and expedites their adoption when released. Using this approach, field evaluation of salt-tolerant breeding lines was conducted through the network of the "Stress Tolerant Rice for Africa and South Asia (STRASA)" project for five years under varying sodic soil conditions in Uttar Pradesh, India, culminating in the release of the salt tolerant variety "CSR43" in 2011 (Singh et al., 2013, 2014).

Suitable management practices for salt affected soils are obviously different than in normal soils. Moreover, any management option for sodic soils developed using medium to long duration salt-tolerant varieties might not be suitable for a short duration variety like CSR43. This study reports on the evaluation and release of CSR43 and on developing suitable crop and nutrient management practices to ensure better establishment and higher productivity of this variety, with the hypothesis that this combination will help to improve productivity and profitability of rice in the sodic soils of the eastern Indo-Gangetic plains.

2. Materials and methods

2.1. Germplasm evaluation through participatory varietal selection

A set of 126 geographically and genetically diverse rice genotypes was screened through researchers' managed on-station and on-farm trials during 2001. This set includes local genotypes, advanced salt tolerant breeding lines and salt tolerant high yielding varieties. From 2002 to 2005, FPVS (Paris et al., 2011) was employed during evaluation, and a set of 6 genotypes was selected from on-farm trials (Table 1). These genotypes were further evaluated, taking into account traits desired by men and women farmers, including grain yield and quality. A scale of 1–10 (1 being least preferred, 10 most preferred) was used to score and rank important traits. Preference scores for each genotype were calculated by subtracting the total negative votes from total positive votes, then dividing by the total votes. Through this process, the genotype CSR-89IR-8 consistently ranked first based on both farmers' preference ranking and grain yield. From 2006 to 2008, the performance of this genotype was further evaluated in farmers' managed trials and compared with popular high yielding varieties, then released as CSR43 (Singh et al., 2013, 2014) (Table 1).

2.2. Development of management practices for CSR43 through on-station trials

2.2.1. Site characterization

Field experiments were conducted from 2011 to 2013 at the experimental farm of ICAR-CSSRI, Regional Research Station, Uttar Pradesh, India (26° 47′ 58″N, 80° 46′ 24″E, 120 m above MSL). The study site is representative of large areas of abandoned alkali soils in the Indo-Gangetic plains. The soil is Typic Natrustalfs, with surface soil (0–15 cm) pH (1:2 soil:water) of 8.9 and sub-surface (>15 cm) pH of >9.4. The soil presents physical and nutritional constraints to plant growth due to poor soil water and soil air characteristics caused by high bulk density (>1.5 g cm^{-3}) and low infiltration rate (<2 mm day^{-1}) (Sharma et al., 2006). Poor soil aeration in sodic soils restricts root development, respiration and soil microbial activities resulting in poor crop growth and productivity. Before the experiment, soil samples were collected from the 0–120 cm soil profile of the experimental field. The samples were air dried, ground in a Wiley mill and passed through a 2.0 mm sieve. The pH and EC of the soil were determined using digital pH and conductivity meters (Jackson, 1967). The pH and EC of surface soil (0–15 cm) were 9.2 and 0.61 dS m^{-1}, respectively. Organic carbon was determined using the rapid titration method of Walkley and Black, modified by Walkley (1947) and was 0.29%. The concentration of Ca^{2+} + Mg^{2+}, measured with an Inductivity Coupled Plasma (ICP) Analyzer (PerkinElmer), was 2.60 me l^{-1}. Na^+ and K^+ concentrations were determined using a Flame Photometer (Richards, 1954) and were 4.50 and 0.06 me l^{-1}. Carbonate and bicarbonate concentrations were determined by titration with 0.01 N H_2SO_4 using phenolphthalein and methyl orange as indicators and chlo-