Agricultural Water Management 115 (2012) 156–166

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Genotypic trade-offs between water productivity and weed competition under the System of Rice Intensification in the Sahel

Timothy J. Krupnik[a,*], Jonne Rodenburg[b], Van Ryan Haden[c], Doudou Mbaye[d], Carol Shennan[e]

[a] International Maize and Wheat Improvement Center. House 9, Road 2/2 (Chairmanbari), Banani, Dhaka 1213, Bangladesh
[b] Africa Rice Center (AfricaRice), East and Southern Africa, P.O. Box 33581 Dar es Salaam, Tanzania
[c] Department of Land, Air and Water Resources, University of California, One Shields Avenue, Davis, CA 95616, USA
[d] Africa Rice Center (AfricaRice), Regional Sahel Station. BP 96, Saint Louis, Senegal
[e] Environmental Studies, University of California 1156 High St, Santa Cruz, CA 95064, USA

ARTICLE INFO

Article history:
Received 12 December 2011
Accepted 30 August 2012

Keywords:
SRI
Weed management
Alternate wetting and drying
NERICA
Oryza sativa
Oryza glaberrima

ABSTRACT

Yield, water productivity and weed-inflicted Relative Yield Losses (RYL) under Recommended Management Practices (RMP) were compared with the System of Rice Intensification (SRI) under double-cropping for two seasons and at two locations in the Senegal River Valley. Seven genotypes from *Oryza sativa* and *Oryza glaberrima* species and their interspecific crosses, were grown under weed-free conditions and in competition with weeds. Weed-free grain yields in SRI were never significantly different than those obtained with RMP. An average of 27% (range 18–46%) less water was applied to SRI than required for continuous flooding in RMP, resulting in consistently higher water productivity with SRI. However, when subjected to weed competition, mean SRI yields were significantly lower than RMP in three of four experimental iterations (an average of 28% less). Across experiments, weed-inflicted RYL was greater in SRI than RMP in 81% of observed cases. Weeds reduced the water productivity enhancing benefits of SRI by an average of 38% compared to weed-free treatments, resulting in significantly lower water productivity with SRI in three of four experiments. Rice genotypes Jaya and Sahel-202 were identified as relatively weed-competitive under each crop management system, however both have intermediate-length cycles and required more irrigation than shorter-duration genotypes. When weeds are carefully controlled, good yields and significant water savings can be achieved with SRI. However, this specific requirement of careful weed control might be difficult to meet by farmers coping with high weed infestations or with limited access to tools, inputs or labor to address them. Weed-competitive genotypes could help reduce weed-inflicted yield losses associated with SRI and other water-saving rice production systems, though future breeding efforts should address the trade-offs between weed competitive traits, water productivity and crop duration to meet the needs of farmers practicing double rice cropping.

1. Introduction

Consumer demand for rice is expanding more rapidly than for any other cereal in sub-Saharan Africa (FAOSTAT, 2011). The Sahel has the highest yield potential for irrigated rice (12 t ha^{-1}) in Africa (Seck et al., 2010). With the goal of exploiting both wet and dry season production, over 200,000 ha of irrigation facilities have been built across the Sahel since the 1980s (Balasubramanian et al., 2007 updated with FAOSTAT, 2011). But despite such efforts, Sahelian rice production has failed to meet growing consumer demands. The majority of consumed rice is consequently imported from Asia, which undermines food security and increases vulnerability to price shocks (Seck et al., 2010). High production costs, especially for irrigation, and poor governmental support for the domestic rice sector, are among the main causes for this failure (de Vries et al., 2010; Seck et al., 2010). Large quantities of water are required to counter the evaporative demand of the arid Sahelian climate (Raes et al., 1995). In the Senegal River Valley, electric or diesel pumps supply water to farmers' fields. Rising energy costs are driving up irrigation fees, which now comprise between 20 and 44% of farmers' total production costs (Krupnik et al., 2012a,b). Future competition for water is also expected to grow from increasing urban demand and anticipated climate change induced scarcity (Turral et al., 2011; Venema et al., 1997). High yielding crop management systems

* Corresponding author. Tel.: +880 2 989 6676; fax: +880 1 831 706 2652.
E-mail address: t.krupnik@cgiar.org (T.J. Krupnik).

0378-3774/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agwat.2012.08.016

that reduce irrigation requirements, thereby increasing field-level water productivity, should consequently be prioritized in the Sahel.

At the level of the farmer's field, notable water-saving rice management systems include aerobic rice, saturated soil culture, raised beds, alternate wetting and drying (AWD), and the System of Rice Intensification, or SRI (see Farooq et al., 2009). In these systems, water savings are obtained by manipulating tillage, crop establishment, and irrigation volume, frequency and/or timing to reduce the non-consumed fraction of water applied. However, these systems remain poorly tested and are not yet recommended anywhere in Africa (Krupnik et al., 2012b). The potential to conserve water without compromising yield is also complicated by numerous abiotic and biotic factors, of which weed management is a key concern. Weeds cause relative yield losses between 28 and 84% in transplanted lowland rice in sub-Saharan Africa (see Rodenburg and Johnson, 2009), and are a primary constraint in the Sahel (Demont et al., 2009; Diallo and Johnson, 1997). Traditionally, rice farmers practiced flooding to suppress weeds, as many species do not germinate under anaerobic conditions. Reductions in floodwater depth and duration could therefore result in profound changes in weed flora and competition (Rodenburg et al., 2011), with poorly understood implications for agricultural productivity.

Of the water-saving systems described above, SRI has received the most attention in the Sahel (Ceesay, 2010; Styger et al., 2010; Krupnik et al., 2012a,b). SRI is comprised of six components, including line transplanting of single, young seedlings at wide spacing, mechanical weeding, the integration of organic soil fertility management, and AWD. SRI was initially controversial due to extremely high yield claims (e.g., Sheehy et al., 2004), though it has since been shown to yield similarly to 'best management practices' (McDonald et al., 2006). SRI's attractiveness as a water-saving system nonetheless continues to engender support by institutions as diverse as the World Bank, NGOs, and farmers' organizations, with SRI promotional efforts ongoing in 50 countries (CIIFAD, 2012).

However, SRI can also be described as "risk-prone" because aspects of the system render it weakly weed competitive (Haden et al., 2007). Transplanting single seedlings at reduced densities, for instance, could delay early season canopy closure, a characteristic essential for weed competitiveness (Zhao et al., 2006a). AWD as practiced in SRI entails periods of no standing water, which could also increase weed germination (Rodenburg and Johnson, 2009). SRI could therefore stimulate weed growth and increase weeding labor demand (Krupnik et al., 2012a; Latif et al., 2009), potentially offsetting the economic advantages gained from reduced water and thus energy consumption. Haden et al. (2007) therefore suggested that SRI should be combined with weed competitive genotypes. Weed competitiveness is composed of weed suppressive ability, the capability to reduce weed growth, and weed tolerance, the ability to maintain high yields under weed competition (Zhao et al., 2006b). Competitive genotypes are thought to be tall, have high specific leaf area, rapid early growth, and longer durations to compensate for early season weed competition (Haefele et al., 2004a; Rodenburg et al., 2009; Saito et al., 2010). However, several of these traits may entail trade-offs with water productivity.

The objectives of this study were to determine if SRI could save water relative to regionally Recommended Management Practices (RMP) using flood irrigation, without reducing yield under weed-free and weedy conditions, and to test if genotypes could be chosen to minimize the expected trade-offs between yield, field-level water-savings, and weed competitiveness in SRI. We therefore compared the performance of seven genotypes under SRI, with AWD irrigation, to RMP with continuous flood irrigation. Genotypes were grown under both weed-free and weedy conditions at two locations in the Senegal River Valley, during the wet and dry seasons.

2. Materials and methods

2.1. Site descriptions

Experiments were conducted on the experimental farms of the Africa Rice Center in the Senegal River Valley, at the villages of Ndiaye (16°11′N, 16°15′W, 26 km inland from the Atlantic Ocean, hereafter referred to as "Delta"), and Fanaye (16°32′N, 15°11′W, 150 km further inland, hereafter "Middle Valley") during the 2008 dry season (Delta and Middle Valley), and 2008 (Delta) and 2009 wet seasons (Middle Valley). The Senegal River Delta site has a cooler climate mediated by the ocean, and is a former back-swamp. The Middle Valley site lies on a floodplain typical for farms in the region, and has larger temperature extremes. The soils of the Delta and Middle Valley sites are an Orhithionic Gleysol and Eutric Vertisol, respectively (FAO, 2006). Percolation rates in the Delta are lower than in the Middle Valley (Samba Diène, 1998). Soils in the Delta and Middle Valley were characterized by low N and C content (1.1 and 0.5, and 8.0 and 6.0 g kg^{-1}, respectively), low available P (P-Bray 5.9 and 7.3 mg kg^{-1}), medium-to-high exchangeable K (0.46 and 0.36 cmol kg^{-1}), moderate pH (5.9 and 6.5), and low EC (0.38 and 0.09 dS m^{-1}). Climatic data were collected in cropped rice fields at each site (Fig. 1).

2.2. Experimental design

Experiments were laid out according to a split–split–plot design. Main treatments (plot size: 287 m^2) included two crop management systems, Recommended Management Practices (RMP), and the System of Rice Intensification (SRI). The sub-plot level (plot size: 38 m^2) represented two weed management treatments (weedy and weed-free), while seven genotypes were tested on the sub-sub-plot level (plot size: 19 m^2). Bunds were constructed around all main- and sub-plots, and plastic sheeting was installed over bunds and to 0.4 m depth to reduce water movement between plots. An additional 4 m space was maintained between main-plots. Irrigation was applied to main-plots and distributed equally to all sub-sub-plots after passage through V-notched weirs, though following harvest of early maturing genotypes, irrigation was redirected only to sub-plots containing intermediate duration genotypes.

2.2.1. Main plot treatment details

In RMP, pre-germinated seeds were sown in a nursery at a rate of 40 kg seeds ha^{-1}. After field preparation with a power-tiller and land leveling, 23–24 and 27–28 days old seedlings were transplanted during the wet and dry seasons, respectively, at 20 cm × 20 cm, with three plants per hill, into main-plots containing a 2–4 cm floodwater layer. Seedling age differences correspond to recommendations to adjust transplant timing to reflect cool temperatures in the early dry season. Diammonium phosphate (21.5 kg N and 19.3 kg P ha^{-1}) was applied at transplanting. Urea was top-dressed in 40%, 40% and 20% splits (early tillering, panicle initiation, heading), at a total rate of 101.3 kg N ha^{-1}. Fertilizer K is not recommended in the Senegal River Valley because of high soil K reserves (Haefele et al., 2004b), and was therefore not applied. A continuous floodwater layer was maintained in RMP until two weeks before harvest.

In SRI, seeds were sown at 12 kg ha^{-1} in a nursery maintained without standing water. Compost or manures are recommended for SRI, though most SRI farmers mix organic and chemical fertilizers (Uphoff et al., 2010). However, these materials are scarce in the study region, and when available, they are allocated to higher-value horticultural crops. We therefore adapted this component of SRI by utilizing the most readily available organic material – rice straw residues – incorporated at a rate of 5 t ha^{-1}, 14 days before transplanting, after which fields were leveled. Chemical