Field Crops Research 162 (2014) 1–5

Contents lists available at ScienceDirect

Field Crops Research

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

Improving estimation of weed suppressive ability of upland rice varieties using substitute weeds

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ARTICLE INFO

Article history:
Received 20 December 2013
Received in revised form 9 March 2014
Accepted 10 March 2014
Available online 3 April 2014

Keywords:
Substitute weed
Breeding
Low-input system
Rice
Weeds

ABSTRACT

Ideal weed-competitive rice (*Oryza* sp.) varieties are high yielding under both weed-free and weedy conditions, and have strong weed-suppressive ability (WSA). WSA is the ability to suppress weed growth and reduce weed seed production, benefiting weed management in both the current and the subsequent growing seasons. WSA is determined by assessing weed biomass under weedy conditions. However, natural weed growth in field conditions is heterogeneous, resulting in high experimental error in phenotyping studies. Using crops as substitute weeds is one approach for improving the accuracy of estimation of WSA. Four upland-rice experiments were conducted using 14 diverse varieties in Benin between 2009 and 2011 to examine if the use of substitute weeds can improve estimation of WSA, and help identify varieties with strong WSA. Two rice varieties (Aus 257, which was also included in 14 varieties tested, and IR 1552, a purple-leaved rice) and cowpea (cv. KVx396-18) were tested as substitute weeds, and compared with natural weed infestation. At 50–62 days after rice sowing, weed biomass (weeds, rice or cowpea) were measured as an indicator of WSA. While WSA was more heritable in plots with substitute weeds than with natural weed infestation, there was no large difference in heritability among substitute weeds. In only one of the four experiments was the effect of variety on WSA not consistent between substitute weeds and natural weeds. But in this experiment, Aus 257 consistently showed strong WSA in both plots with substitute weeds and plots with natural weed infestation. Superior WSA of Aus 257 was also observed in the other experiments, and associated with higher biomass accumulation. These results indicate that the use of substitute weeds can offer an efficient selection approach for improving weed-suppressive ability of upland rice. Aus 257 can be used as donor for developing varieties with strong weed-suppressive ability.

1. Introduction

Weeds are one of the major biological constraints to rice (*Oryza* sp.) production, especially in low-input systems in Asia and Africa, where resource-poor farmers cannot afford to buy herbicides, and manual weeding, especially hand weeding, is still common for weed control (Becker and Johnson, 2001; Rodenburg and Johnson, 2009; Saito et al., 2010a). In such conditions, labor availability for weeding is often limited, resulting in high levels of yield reduction caused by weed infestation.

Rice is considered a weak competitor against weeds compared with taller crops such as maize (Dingkuhn et al., 1999; Saito et al., 2010a). However, development of superior weed-competitive rice varieties as a component of an integrated weed-management strategy may be an attractive option to increase or sustain rice productivity. Ideal weed-competitive rice varieties are high yielding under both weed-free and weedy conditions, and have strong weed-suppressive ability (WSA) rather than weed tolerance, or the ability to maintain high yield despite weed competition. This is because tolerance only benefits the current growing season and may result in increased weed pressure from unsuppressed weeds (Callaway, 1992). WSA is the ability to suppress weed growth and reduce weed seed production, benefiting weed management in both the current and the subsequent growing seasons. WSA is determined by assessing weed biomass under weedy conditions (Saito, 2010; Saito et al., 2010b).

Abbreviations: cv., cultivar; DAS, days after sowing; exp., experiment; H, broad-sense heritability; LSD, least significant difference; vs., versus; WSA, weed-suppressive ability.

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http://dx.doi.org/10.1016/j.fcr.2014.03.006
0378-4290/

Table 1
Description of experimental conditions in Benin, 2009–2011.

	Exp. 1	Exp. 2	Exp. 3	Exp. 4
Sowing date	28 Aug 2009	16 Mar 2010	29 Apr 2010	29 Apr 2011
Sampling time	62 DAS[a]	50 DAS	54 DAS	52, 53 DAS
Water management	Fully irrigated	Fully irrigated	Rainfed	Rainfed
Dominant weed species	*Celosia trigyna* L.	*Richardia brasiliensis* Gomez	*Cyperus sphacelatus* Rottb.	*Richardia brasiliensis* Gomez
	Amaranthus spinosus L.	*Gomphrena celosioides* Mart.	*Cyperus rotundus* L.	*Mollugo nudicaulis* Lam.
	Phyllanthus amarus Schumach. & Thonn.	*Eragrostis tenella* (L.) P. Beauv. ex Roem. & Schult.	*Eleusine indica* (L.) Gaertn.	*Cyperus rotundus* L.
	Cleome viscosa L.	*Phyllanthus amarus* Schumach. & Thonn.		*Boerhavia erecta* L.
Weed treatment	T1: Natural weed infestation Weeding at 19 DAS	T1: Natural weed infestation No weeding until sampling	T1: Natural weed infestation Weeding at 12 DAS	T1: Natural weed infestation No weeding until sampling
	T2: Cowpea (KVx396-18) sown at 6 DAS and cut at 10 cm level at 42 DAS	T2: Cowpea (KVx396-18) sown at 13 DAS	T2: Cowpea (KVx396-18) sown at 14 DAS	T2: Cowpea (KVx396-18) sown at 14 DAS
	T3: Rice (Aus 257) sown at 6 DAS	T3: Rice (Aus 257) sown at 6 DAS	T3: Rice (Aus 257) sown at 6 DAS	
			T4: Purple rice (IR 1552) sown at 0 DAS	T4: Purple rice (IR 1552) sown at 0 DAS

[a] DAS, days after sowing of the 14 rice varieties that were evaluated for weed-suppressive ability.

Varietal differences in WSA have been previously reported in rice (e.g. Rodenburg et al., 2009; Saito, 2010; Touré et al., 2011). Most studies have determined WSA late in the rice growth cycle (i.e. 80 days after sowing or later), or at harvest (Saito, 2010). In general, experimental error is high and heritability (*H*) is low, largely due to the heterogeneity of natural weed growth. Zhao et al. (2006a) and our calculation based on data from Saito et al. (2010b) gave *H* estimates of 0.38 and 0.25 for natural weed biomass estimated for one experiment with three replications, respectively. These esimates were much lower than those for yield under weedy conditions. This makes it difficult to select varieties with superior WSA. One approach for improving heritability could be to sow weeds or crops as substitute weeds to simulate natural weed infestation (Kawano et al., 1974; Bastiaans et al., 1997; Dingkuhn et al., 1999; Haefele et al., 2004; Saito et al., 2010a). Sowing crops as substitute weeds is simple and easier for breeders or agronomists than sowing weeds, as collecting weed seeds is laborious, seeds are not always readily available, and managing density of sown seeds at the same level in all the plots is difficult and requires high labor input (Johnson et al., 1998). However, no studies have compared this approach with natural weed infestation to test the hypotheses that WSA is consistent between the two, and that the use of substitute weeds reduces experimental error and improves the precision of WSA determination. Once these hypotheses are validated, selection for superior WSA in breeding programs could be done indirectly using substitute weeds.

In the upland-rice breeding program of Africa Rice Center (AfricaRice), *Oryza glaberrima* varieties have been extensively used for improving WSA of *Oryza sativa* tropical *japonica* varieties, which are commonly grown in West Africa (Saito and Futakuchi, 2009). Meanwhile, in Asia, several *O. sativa* upland *indica* varieties have been identified as weed-suppressive (Caton et al., 2003; Zhao et al., 2006a). Thus, it is essential to test a wide range of germplasm groups for evaluating WSA to identify donors with superior WSA.

Therefore, the objectives of the research reported in this paper were to examine if the use of substitute weeds can improve estimation of WSA, and identify varieties with superior WSA.

2. Material and methods

2.1. Description of the study site and rice varieties

Four upland rice experiments were conducted over 3 years (2009–2011) at the AfricaRice experimental farm in Cotonou, Benin (2°20′E, 6°25′N) (Table 1). Four experiments were conducted in different fields. This site is located in the southern Guinea savanna zone (Windmeijer and Andriesse, 1993).

Fourteen varieties, selected from different germplasm groups and for their variation in agronomic traits (days to heading, plant height and number of panicles), were used for all four experiments (Table 2). Entries comprised one *O. glaberrima* variety, one temperate *japonica* variety, three tropical *japonica* varieties, three interspecific progenies from the cross between *O. sativa* and *O. glaberrima* (NERICA varieties; Saito and Futakuchi, 2009; Saito et al., 2012), and six *indica* varieties (Asai et al., 2009). CG 14 and Aus 257 are traditional varieties, while all the others are improved ones.

2.2. Experimental design, crop management and data collection

Before each sowing, the fields were tilled manually or by tractor. Rice was then sown by placing about four seeds into holes 1–2 cm deep, spaced at 0.2 m × 0.2 m. After emergence, plants were thinned to two plants per hill. All crop management was carried out uniformly for the entire site, and manual weeding was done when required. In experiments (exp.) 1 and 2, the crop was not limited by moisture as supplemental irrigation was applied by restoring soil moisture to field capacity manually once or twice a day as necessary. Basal fertilizer at a rate of 30–30–30 kg N–P_2O_5–K_2O/ha was applied at the time of sowing, except in exp. 4, where the fertilizer at a rate was 20–40–40 kg N–P_2O_5–K_2O/ha. A further dose of N fertilizer (2 g/m^2) was applied at 30–32 days after sowing (DAS).

Each of the four experiments consisted of three or four weed treatments including natural weed infestation and substitute weeds (Table 1). Two rice varieties (Aus 257 and IR 1552) and cowpea were used as substitute weeds. They were highly adapted to field conditions in this campus. Also, we assumed that rice varieties could mimic glass weeds and cowpea could do broadleaf ones.