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Bird, weed and interaction effects on yield of irrigated lowland rice

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Weeds and grain feeding birds are the two main biological causes of yield losses in irrigated rice in Africa. To quantify the single and combined effect of these biological constraints on rice yields, and to investigate whether weeds attract birds and thereby contribute to increased bird damage, a three-year factorial experiment was set-up in the Senegal River Valley. We tested two management factors (bird and weed management), each with two levels ('complete' and 'absent'), and one crop cycle factor also with two levels (Sahel 202, a medium-cycle and Sahel 108, a short-cycle rice cultivar). Season-long competition from weeds resulted in high but predictable yield losses ranging from 50% to 75%, with lower yield losses for the medium-cycle cultivar Sahel 202 in two of the three seasons. Due to the nature of the pest, season-long exposure to birds resulted in less predictable yield losses ranging from 13% to as high as 94%, with high seasonal variation. In two seasons, much lower bird-inflicted yield losses were observed in the short-cycle cultivar Sahel 108, whereas in one season the medium-cycle cultivar Sahel 202 was much less damaged. When rice was exposed to both weeds and birds, the relative yield losses ranged from 80 to 99%. The yield reducing effect of weeds and birds was never additive. Bird visits to a weedy crop were more frequent compared to a weed-free crop at least in the early rice grain filling stages. This attraction of birds by weeds resulted in an additional yield loss in five of the six cases, ranging from 2 to 62%. Bird-inflicted yield losses in irrigated rice may be reduced by keeping the crop, as much as possible, free from weeds.

1. Introduction

Rice is a crop of increasing importance for sub-Saharan Africa (SSA). Regional rice production has increased with 170% over the past three decades (Seck et al., 2010). In this region, the main rice ecosystems are the rain-fed upland rice systems on plateaus and hydromorphic slopes (comprising 32% of the total area under rice), rain-fed lowland rice in valley bottoms and floodplains (38%), and irrigated rice in lowlands and highlands (26%), with the remaining 4% of area used for the production of deep-water floating rice along major rivers and mangrove-swamp rice in lagoons and deltas (Diagne et al., 2013a). Estimated average rice yields in SSA range from 1.2 t ha^{-1} in rain-fed rice ecosystems to 2.2 t ha^{-1} in irrigated rice (Diagne et al., 2013a). These relatively low yields are the result of a myriad of production, post-harvest, socio-economic and institutional constraints. Across ecosystems, the two major and overarching biotic production constraints to rice production in the region are weeds and granivorous birds (Adesina et al., 1994; Seck et al., 2012; Diagne et al., 2013b). Weed inflicted yield losses in rice in SSA, despite control, range from 15 to 23% and are conservatively estimated to add up to 2.2 million tons per year, equating to approximately half the current total imports of rice to this region (Rodenburg and Johnson, 2009). A recent review suggests that bird damage on cereal crops is in the order of magnitude of 15–20% of production (de Mey et al., 2012; de Mey and Demont, 2013) which could therefore result in similar economic losses as those suffered due to weed competition. The extent of bird damage to rice is however highly variable between years and locations, determined by biophysical conditions, and further depends on crop management practices (e.g. Elliott, 1979; Bruggers and Ruelle, 1981; Manikowski, 1984; Treca, 1987; Avery et al., 2005; Cheke et al., 2007).

An area where both weed and bird problems are prominent is the Senegal River Valley (SRV), with extensive irrigated rice production systems that are representative of the wider West African Sahel zone. The average yield in irrigated rice in the Sahel was estimated at 3.9 t ha^{-1} leaving an estimated yield gap (difference

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from potential yield) of 5.9 t ha^{-1} (Becker et al., 2003). Inadequate weed management could explain 17% of this yield gap, and 14% was due to sub-optimal nitrogen management. Diagne et al. (2013) similarly attributed efficiency gaps in irrigated rice production in the SRV to sub-optimal weed and fertilizer management, but further identified biotic (granivorous birds), technological, organizational and institutional constraints as major factors preventing SRV farmers from achieving optimal productivity and efficiency levels. An earlier econometric study on the same panel dataset of SRV rice farmers estimated mean rice yield losses due to bird attack at 13%, which was very consistent with farmers' perceptions, who assessed the damage to be on average 15% (de Mey et al., 2012). Finally, a continent wide survey among irrigated rice farmers provided a perceived yield loss estimate from bird and rodent attacks at 19% (Diagne et al., 2013b).

The dominant bird species feeding on rice in the Sahel is the Red-billed quelea (*Quelea quelea* L., subspecies *quelea*). This is a gregarious, granivorous bird adapted to semi-arid habitats (typically *Acacia* savannas of SSA) (Elliott, 2006). They typically gather in large flocks (up to several million) and breed in colonies covering vast areas (sometimes > 100 ha, with about 30,000 nests per hectare). The species *Q. quelea* primarily feeds on seeds of cereal crops, grasses in field margins and weedy crop fields but also on insects (Elliott, 1979). They prefer seeds of grasses in general and that of *Echinochloa* spp. in particular. Most noxious weeds in irrigated rice in the Sahel are the grasses *Oryza barthii* A. Chev. and *Oryza longistaminata* A. Chev. & Roehr (wild rice), *Echinochloa colona* (L.) Link, *Ischaemum rugosum* Salisb. and *Leersia hexandra* Sw., the sedges *Cyperus difformis* L., *Cyperus esculentus* L., *Schoenoplectus senegalensis* (S.) Raynal, and *Bolboschoenus maritimus* (L.) Palla (syn. *Scirpus maritimus* L.) and the broad-leaved *Sphenoclea zeylanica* Gaertner, *Ludwigia erecta* (L.) H. Hara, *Ludwigia hyssopifolia* (G. Don) Exell, *Eclipta prostrata* (L.) L. and *Ammania auriculata* Willd. (e.g. Diallo and Johnson, 1997; Johnson et al., 2004; Krupnik et al., 2012). In the SRV most farmers rely on chemical weed control, using a combination of propanil and 2,4-D, followed by hand weeding (e.g. Haefele et al., 2002a). Against birds, seasonal chemical control is often routinely executed by the Senegalese Crop Protection Directorate near important bird roosts. This involves the use of large quantities of non-selective avicides, often organophosphate insecticides like cyanophos and fenthion, that are toxic to many bird species, including non-seed eaters, as well as reptile and fish species, posing serious environmental hazards (Mullié et al., 1999; McWilliam and Cheke, 2004; Cheke et al., 2012, 2013). Alternative methods include the use of bird repellents, based on chemicals or natural plant extracts (Avery et al., 1996; Avery and Mason, 1997; Avery et al., 1998, 2005; Werner et al., 2005), repellents based on sound or by netting the crop and by better crop sowing timing and synchronization (Elliott, 1979; Treca, 1985).

Farmer surveys in the SRV revealed however that rice producers know of little affordable and effective control measures against birds other than bird scaring, often carried out by children. The surveys did however expose the general farmers' perception that bird attacks were lower when their rice fields were weeded, compared to still weedy fields; 80% of rice farmers were aware of this interaction, and 57% planned their weeding efforts in relation to bird pressure (De Mey, 2009). Evidence on the interaction between weeds and birds in the literature is largely anecdotal. Luder (1985) observed that weedy patches in wheat fields are clearly associated with greater bird damage and several studies on rice cite the same interaction (e.g. Bruggers, 1979; Treca, 1985). However, to the best of our knowledge, no study has ever formally tested the hypothesis that weedy fields attract granivorous birds. A better understanding of this interaction may help to shape agronomists' and extension agents' crop management recommendations and assist farmers in their struggle to implement the often ambitious national rice development strategies (Demont, 2013). Therefore, the current study aimed at testing this hypothesis by studying the interaction between birds and weeds. The objective was to investigate single and combined yield reducing effects of weeds and birds in irrigated rice and how this is affected by rice cultivar choice. To this end, three years of multi-factorial experiments were carried out in the SRV, an area representative for irrigated rice production in the Sahel where *Q. quelea* has its main area of distribution.

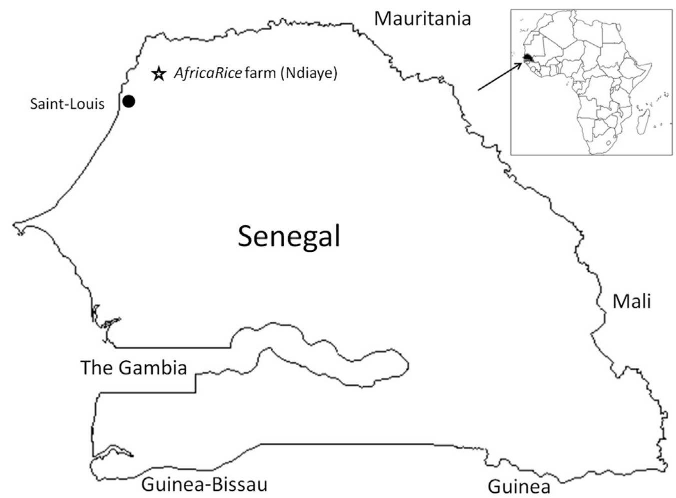

Fig. 1. Schematic geographical position of the experiments at the experimental farm of AfricaRice in Ndiaye, Senegal, indicating the nearest town (Saint-Louis), the position of neighbouring countries and the position of Senegal in Africa (see map in upper-right hand corner).

2. Materials and methods

2.1. Season and site description

As bird damage to irrigated rice is most important during the dry season when birds do not have many alternative food sources (Bruggers and Ruelle, 1981), the field experiments were carried out in this season. Experiments were conducted in 2009 (30 March – 21 August), 2010 (18 March – 2 August) and 2011 (18 March – 18 August) on the experimental farm of the Africa Rice Center (AfricaRice) at Ndiaye (16°14′N, 16°14′W, 1 m a.s.l.) in the delta of the Senegal River Valley, 35 km inland (Fig. 1; Table 1).

The site is characterized by a typical Sahelian climate with a nine-month dry period followed by a short wet season. During the hot dry season, which runs from February to June, the temperature ranges from a minimum of 10 in the early season to maxima of 40 °C in the late season (Dingkuhn et al., 1995). Actual mean monthly minimum and maximum temperatures ranged from 17 to 37 °C and total monthly rainfall amounts never exceeded 64 mm

Table 1
Overview of the experiments conducted in the dry seasons (DS) of 2009, 2010 and 2011 at the experimental farm of AfricaRice, Ndiaye, Senegal.

Season	Sowing method	Sowing date		Maturity date	DAS[a]	Harvest date	DAS
DS 2009	Broad-casting	30-03-09	Sahel 108	20-07-09	112	04-08-09	127
			Sahel 202	12-08-09	135	21-08-09	144
DS 2010	Dibbling at 20 × 20	18-03-10	Sahel 108	25-06-10	99	13-07-2010	117
			Sahel 202	20-7-10	124	02-08-210	137
DS 2011	Dibbling at 20 × 20	18-03-11	Sahel 108	15-07-11	119	11-08-11	146
			Sahel 202	02-08-11	137	18-08-11	153

[a] Days after sowing.