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Combined effects of cover crops, mulch, zero-tillage and resistant varieties on *Striga asiatica* (L.) Kuntze in rice-maize rotation systems

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ABSTRACT

In low-input rice-maize rotation systems in the hills of central Madagascar, farmers deal with erratic rainfall, poor soils, high soil erosion risks and infestation by the parasitic weed *Striga asiatica* (L.) Kuntze. Practices combining zero-tillage with permanent soil cover by intercropped legumes and crop residue mulches — known as Conservation Agriculture (CA)— are proposed as remedy against soil and climatic constraints. Implications of these practices for *S. asiatica* are unknown. A 4-season factorial experiment compared the current farmer practice of rice − maize rotation, involving seasonal tillage and crop residue removal (CONV), with three rice − maize rotation systems following CA with different cover crops, i.e. *Vigna unguiculata* (cowpea) and *Mucuna pruriens* (CACM), *Vigna umbellata* (ricebean) (CARB), and *Stylosanthes guianensis* (CAST). Performance of two rice varieties, NERICA-4 and −9, with partial *S. asiatica* resistance, were compared with the locally popular B22. Parasite emergence time, numbers, and seed bank sizes were recorded.

In all CA practices *S. asiatica* infection was significantly reduced. Best results were obtained with *Stylosanthes guianensis* (CAST). This species also suppressed ordinary weeds much better than other cover crops. With CAST, average parasite emergence was delayed by 7.5 days (in rice) and 6.3 days (in maize) and infection levels were reduced by 79% (in rice) and 92% (in maize) compared to the conventional farmer practice (CONV). NERICA varieties delayed *S. asiatica* emergence by 5.7 days (NERICA-9) and 9.7 days (NERICA-4) and reduced infection levels by 57% (NERICA-9) and 91% (NERICA-4) compared to B22. In maize the residual effect of resistance of NERICA-4 resulted in a delay of 7.5 days in *S. asiatica* emergence and a reduction of 60% in parasite numbers. The best combinations delay *S. asiatica* emergence by 17.8 days (CAST + NERICA-9) and 19.1 days (CARB + NERICA-4) and reduce the parasite infection levels by 96% (CAST + NERICA-9 or −4) to 98% (CARB + NERICA-4) in rice, compared to CONV + B22. After two full rice-maize rotation cycles *S. asiatica* seed numbers in the soil (0–10 cm) were 76% (CACM), 78% (CAST) and 86% (CARB) lower than under CONV. Even the combination of zero-tillage, crop residue mulching, cover crops and resistant rice varieties does not entirely prevent *S. asiatica* parasitism and seed bank increase. Additional measures, targeted to escaping weeds, would be required for fully effective and long-term control.

1. Introduction

Maize (*Zea mays* L.) and rice (*Oryza sativa* L and *O. glaberrima* Steud.) are two of the most important food crops in sub-Saharan Africa (Shiferaw et al., 2011; Seck et al., 2012). Rice varieties adapted to free-draining upland soils can be grown under similar conditions as maize and both crops are therefore often grown by the same farmers, either intercropped or in rotation (Balasubramanian et al., 2007; Shiferaw et al., 2011). These farmers however face a number of —related or mutually reinforcing— production constraints, like drought, sub-optimal soil fertility and weed infestation (Balasubramanian et al., 2007; Cairns et al., 2012). *Striga* spp., are important weeds in both crops (e.g. Johnson et al., 1997). The two most important *Striga* species are *S. asiatica* (L.) Kuntze, with weedy forms predominantly found in Eastern and Southern Africa, and *S. hermonthica* (Del.) Benth., mostly found in sub-Saharan Africa north of the equator (Mohamed et al., 2001).

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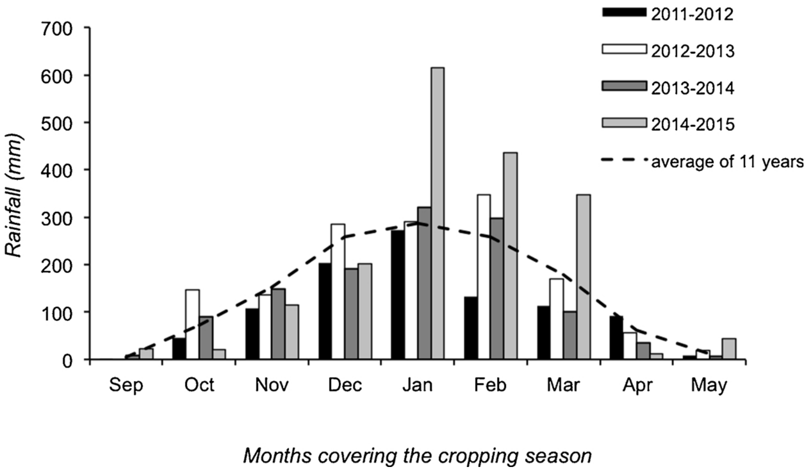

Fig. 1. Monthly rainfall (mm) per season, during the four cropping seasons from 2011–2012 (S1) to 2014–2015 (S4), and the 11-year average.

Infestation by *Striga* is one of the main biotic production constraints in maize in Africa (Shiferaw et al., 2011; Cairns et al., 2012), with a conservatively estimated incidence of 14% across the continent (De Groote et al., 2008). For rice the importance is less generally acknowledged (Schut et al., 2015) but the average incidence of *Striga* in rice is recently estimated at a conservative 12% (Rodenburg et al., 2016). Reported *Striga*-inflicted yield losses range from 21 to 74% in maize (De Groote et al., 2008) and from 35 to 80% in rice (Rodenburg et al., 2016).

In the mid-west of Madagascar, upland rice-maize rotations are often practiced on poorly textured and poorly fertile soils on sloping land and under conditions of erratic rainfall, with droughts alternated by intense rainfall events (e.g. Bruelle et al., 2015). Soil erosion by runoff therefore occurs frequently in this area (Dusserre et al., 2012). This further impoverishes the soils (Smaling et al., 1996), and facilitates weed seed dispersal (Burton et al., 2005). *Striga asiatica* is one of the most dominant weed species in these rice-maize rotation systems in Madagascar (Geiger et al., 1996). This, in turn, is no surprise as the presence of *Striga* species is often associated with poor soil fertility and erratic rainfall conditions (Kamara et al., 2014).

One of the possible strategies to address the above-described climate and soil-related problems in cereal cropping systems is to replace the practice of seasonal soil tillage and clearance, by an intercropping, zero-tillage system with permanent —living or dead—vegetative soil cover, commonly referred to as Conservation Agriculture (Thierfelder and Wall, 2009, 2012). In mid-west Madagascar, where rice-maize rotation is the predominant system, Conservation Agriculture (CA) practices have been tested with variable outcomes, as socio-cultural and economic benefits and suitability lagged behind agronomic and environmental merits (Sester et al., 2015). Positive effects of CA were reported on rice blast (Sester et al., 2014) and white grub, a soil-dwelling Scarab beetle larvae (Ratnadass et al., 2013). It is not known whether the proposed CA strategies also reduce *S. asiatica* infestation, but individual components proved successful. Intercropping may reduce *Striga* when the intercropped non-host species can cause seed of the parasite to germinate without supporting parasitism, a principle called 'suicidal germination' (e.g. Khan et al., 2010). The intercrop canopy can also reduce *Striga* by increased shading and humidity and decreased temperatures (Oswald et al., 2002). Mulching has also been shown to suppress *Striga* parasitism (Midega et al., 2013), probably partly through similar mechanisms, while zero-tillage may prevent newly produced *Striga* seed to enter the soil deep enough to encounter suitable host roots in subsequent cropping seasons (van Ast et al., 2005).

In the current study, effects of a combination of these measures on *S. asiatica* were tested in an infested farmer's field in the rice-maize production zone of mid-west Madagascar. The practices were tested with rice varieties differing in resistance level. The use of resistant varieties has often been suggested as an ideal component of an integrated *Striga* management strategy (e.g. Yoder and Scholes, 2010), but broad-based evidence for this is still scarce. The locally predominant farmer practice of rice-maize rotation with seasonal tillage and crop residue removal is treated as the reference. The objectives were to (1) find leads for improvements of this rice-maize rotation system that could benefit smallholder farmers, (2) quantify effects of different rice varieties, management practices and combinations of varieties and practices on *S. asiatica* control and (3) discuss possible factors explaining such effects.

2. Materials and methods

2.1. Study site

During four cropping seasons — in the period from December 2011 to April 2015— a factorial experiment was conducted at a farmer's field in Ivory, in mid-west Madagascar. The field was located at 19°33′26″S and 46°24′55″E. The elevation at this site is 930 m above sea level.

The study area is characterized by a tropical climate of medium altitude with two well-defined seasons: the hot rainy season from November to April and the cold dry season from May to October. Temperature, radiation and rainfall data were recorded daily by an automatic meteorological station (ENERCO 404 Series, Cimel, France) at 835 m from the experiment. During the experiment (September to May) average monthly radiation ranged from 17 to 28 $\mathrm{MJ\,m^{-2}}$, and temperatures ranged from 17.2 °C (night) to 30.7 °C (day), with monthly averages between 21 and 25 °C, and similar monthly fluctuations across seasons. The cumulative rainfall during the experiment was 976 mm in Season 1, 1452 mm in Season 2, 1194 mm in Season 3 and 1814 mm in Season 4 (Fig. 1). The long-term annual mean rainfall is 1307 mm.

The soil is characterized as clay-loam Oxisol (USDA) with a clay-silt-sand composition of 34–39-27% in the top layers (0–10 cm). The soil was generally moderately deficient in nutrient and organic matter content, with 17.2 $\mathrm{g\,kg^{-1}}$ of C, 1.4 $\mathrm{g\,kg^{-1}}$of N (total) and 2.5 $\mathrm{mg\,kg^{-1}}$ of available P (Olsen). Soil pH (H_2O) was 5.3. Nutrient content of applied cattle manure was 0.93% N, 11.9% C, 0.14% P, 0.94% K, 0.50% Ca, and 0.20% Mg. The field was positioned on a moderate slope (0 to 5%). Experimental replicates were laid out along this gradient with Replicate 1 on the top and Replicate 6 at the bottom of the slope.

2.2. Experimental treatments and plant material

The locally predominant farmer practice of rice-maize rotation with seasonal tillage and removal of crop residues (henceforward referred to as conventional practice, or CONV) is compared with three rice-maize rotation systems following conservation agriculture (CA) principles.