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Delayed or early sowing: Timing as parasitic weed control strategy in rice is species and ecosystem dependent

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ABSTRACT

Parasitic weeds are a severe problem in rain-fed rice production ecosystems in sub-Saharan Africa. In this study, effects of sowing time of rice on parasitic weed infection and crop yields were investigated. Field experiments were conducted in *Striga asiatica*-infested upland and *Rhamphicarpa fistulosa*-infested lowland systems from 2012 to 2014 in Kyela district, Tanzania. In each system, three rice varieties were planted at five sowing times, the first coinciding with the start of the rainy season and the four other ones followed each at two weeks' intervals. The chosen rice varieties were the late maturing local varieties Supa India (upland and lowland) and Mwangulu (upland) and earlier-maturing NERICA-14 (upland), NERICA-L-20 (lowland) and IR64 (lowland) as alternatives. A greenhouse pot-experiment was conducted in Wageningen, the Netherlands, combining staggered planting of rice at two weeks' intervals with introduction of either *S. asiatica* or *R. fistulosa* at one moment in time. In both field and pot experiments sowing time influenced parasite growth and rice grain yield, but the direction of these effects differed considerably between weed species and associated agro-ecosystems. In upland, *S. asiatica* number and biomass decreased with a delay in sowing time. It was postulated that with these delays an increasing share of the *S. asiatica* seed population would return to a state of dormancy from where they are unable to germinate. Under conditions of heavy infection (2013) rice yields were highest at later sowing dates. Under moderate *S. asiatica* infection levels (2012 and 2014) the positive effects of late sowing on rice yield were annihilated, due to increased chances of drought stress during kernel filling. This risk was mitigated by the use of an improved early-maturing variety (NERICA-14). In lowland, there was a significant increase in *R. fistulosa* biomass with delayed sowing times. Planting rice before optimum soil moisture conditions (i.e. saturation) for *R. fistulosa* seed germination are met, would result in partial escape from infection by this facultative parasite, and consequently higher rice grain yields. Manipulating rice-sowing time is a feasible control strategy to minimize parasitic weed infection, but the proper application and associated risk of this practice are strongly species and ecosystem dependent.

1. Introduction

Parasitic weeds are a severe problem in rain-fed rice production systems in sub-Saharan Africa (SSA) (Parker, 2013; Rodenburg et al., 2010). Infestations by parasitic weeds lead to considerable rice yield losses and even make farmers decide to abandon their fields (Houngbedji et al., 2014; N'Cho et al., 2014). In a recent study, the economic losses caused by parasitic weeds in rain-fed rice production systems in Africa were conservatively estimated at US $ 200 million per year (Rodenburg et al., 2016b). In rain-fed upland rice systems, the most important parasitic weed species are the Witchweeds, particularly *Striga asiatica* (L.) Kuntze, and *S. hermonthica* (Del.) Benth (Rodenburg and Johnson, 2009). *Striga* infestation in rice fields is accelerated by continuous cultivation of cereal crops without proper soil fertility replenishment (Spallek et al., 2013; Ayongwa et al., 2006). In addition, the use of crop seeds contaminated with *Striga* seeds (Berner et al., 1994) and rainfall variability are important causes contributing to high infestation levels (Mohamed et al., 1998). In rain-fed lowlands, Rice Vampireweed, *Rhamphicarpa fistulosa* (Hochst.) Benth, is an important parasitic weed species (Rodenburg et al., 2015b; Ouédraogo et al.,

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1999). *Rhamphicarpa fistulosa* was not regarded a major problem in lowland rice some two decades ago, but has increased in recent years (Houngbedji et al., 2014; Rodenburg et al., 2011) The main reason for this increase is probably that rice farmers are increasingly exploiting marginal wetlands, which can be natural habitats of this species (Kabiri et al., 2015). *Rhamphicarpa fistulosa* is most prominent in rice production systems characterized by poor soil fertility and poor water management (N'Cho et al., 2014). The weed is able to cause considerable yield reductions; average losses ranging from 24 to 73% have been reported depending on rice variety (Rodenburg et al., 2016b).

Parasitic weeds constitute a severe problem, mainly because potentially effective solutions are not affordable or not accessible for resource-poor subsistence farmers. Crop rotation, a commonly used option to deal with *Striga* (Kayeke et al., 2007) and soil-borne diseases (Conway, 1996), is often not an option due to scarcity of land and water while smallholder farmers need their land for growing their main subsistence crops (Rigg, 2006). In rain-fed lowlands, the lack of alternative crops that grow well under seasonally flooded conditions (Andriesse and Fresco, 1991) is another factor complicating the feasibility of crop rotation. Soil fertility management also bears potential as a control strategy. Particularly, *Striga* incidence is often associated with poor soil fertility (Kamara et al., 2014; Jamil et al., 2012). However, the lack of financial resources and limited access to credit supply often prevents farmers from using fertilizers (Tippe et al., 2017). The use of resistant or tolerant varieties is another promising track. Recently, several improved rice varieties with resistance and tolerance against *S. asiatica, S. hermonthica* and *R. fistulosa* have been identified (Rodenburg et al., 2017; Rodenburg et al., 2016a). Complex national variety release procedures and the absence of functional seed systems, however still hamper the use of this technology in many parts of Africa. Herbicides, a commonly used curative weed control measure in many parts of the world, are difficult to source and knowledge intensive (N'Cho et al., 2014; Rodenburg and Johnson, 2009). Herbicides are also poorly effective against *Striga* spp., as these species first attach to the roots of their host and already severely affect the crop before they emerge aboveground where they can be targeted (Hearne, 2009). Technologies like seed coating of herbicide-tolerant varieties, to address this technical shortcoming of herbicides, are not yet available for rice. As a consequence, the currently most used control strategy is hand weeding (Tippe et al., 2017; N'Cho et al., 2014). However, hand weeding is considered laborious, time consuming (Ogwuike et al., 2014) and therefore expensive, as extra labour needs to be deployed (Oswald, 2005). Additionally, similar to herbicides, this measure is not effective in controlling *Striga* spp., since most of the damage to the crop has already been done before emergence of the parasite (Spallek et al., 2013).

In discussions with farmers, sowing time of rice was often mentioned as a factor influencing parasitic weed infection levels (Tippe et al., 2017). Farmers indicated that delayed sowing reduced *Striga* infection levels in uplands. Hence, sowing time may constitute a potential component of an integrated parasitic weed management strategy in rice. Whether the response to sowing time is consistent and whether it is identical for *S. asiatica* and *R. fistulosa* is, however, not yet known. Changing the sowing time may also imply risks. Delayed sowing is more likely to result in drought stress during grain filling, particularly for the traditional late-maturing rice varieties under upland conditions (Pantuwan et al., 2002). To mitigate such risks, potentially the strategy could benefit from the introduction of an early-maturing rice variety.

The objectives of the current study were therefore to investigate (i) the effects of sowing time on parasitic weed infection and rice yield levels, (ii) whether this effect differed between parasitic weed species and (iii) the extent to which these sowing time effects on rice yields can be modified by using varieties with different growth durations. Field experiments were supplemented by a greenhouse experiment, in which the effects of rice sowing time on dry matter production of rice were compared under parasite-free and parasite-infested conditions.

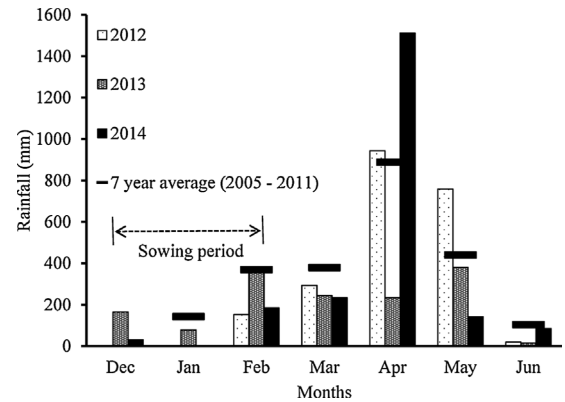

Fig. 1. Cumulative monthly rainfall (mm) as recorded in the experimental fields in Kyela district, Tanzania from December to June, during the three years of experimentation. Additional data for the past 7 years prior to this experimentation was received from Kyela District Agriculture and Livestock Office.

2. Material and methods

2.1. Field experiments

2.1.1. Site characterization

Field experiments were conducted in three consecutive years (2012–2014) at Kilasilo and Mbako village in Kyela district, South West Tanzania (09°35′08" S − 33°48′43" E and 9°37′30" S − 33°52′30" E, respectively). The fields are situated in an endemic *S. asiatica* and *R. fistulosa* infested rice-growing area. Two fields were selected: (1) a *Striga asiatica*-infested upland field and (2) a *Rhamphicarpa fistulosa*-infested lowland field. Fields were not inoculated by supplemental parasitic weed seed and an experimental design with blocks was used to control for the inherent heterogeneity of the original infestation. The two fields were 900 m apart from each other and are located at around 529 and 520 m above sea level (upland and lowland, respectively), with monthly average temperatures ranging from 19 to 23 °C in the months of May to October and from 29 to 31 °C in November to April. The sites have a unimodal rainfall regime with an average seasonal rainfall of around 2300 mm (Fig. 1). In 2011/2012, the rainy season commenced relatively late, whereas in 2012/2013, the amount was considerably lower than in the other two seasons and the reference period.

Prior to the sowing, soil samples from both sites were collected at 0–20 cm depth. The soil in both upland and lowland sites was characterized as a strongly acidic (pH = 4.8) sandy clay loam, with estimated sand:silt:clay ratios of 63.1:11.6:25.2 in the upland field and 50.2:17.6:32.1 in the lowland field. Extraction according to Mehlich (1984) showed that the available phosphorous (P) ranged from high to medium in upland and lowland sites (5.24 ppm and 3.6 ppm, respectively), while exchangeable potassium (K) was 230 ppm in upland and 127 ppm in lowland. Soil organic matter content (Colometric; Walkley and Black, 1934) was 2.09% (upland) and 1.27% (lowland) and total nitrogen (Kjeldahl; Bremner and Mulvaney, 1982) was 0.11% (upland) and 0.06% (lowland). Soil cation exchange capacity (CEC) and electric conductivity (EC) were relatively low (7.9 cmol(+) kg^{-1} and 95.7 $uScm^{-1}$, respectively).

2.1.2. Experimental set-up

In both fields, a split-plot experimental design with five replications was used, with rice variety at the main plot and sowing time at the subplot level. The experimental treatments included three rice varieties, each with different growth duration. For the upland field experiment, the local rice varieties Mwangulu (late maturing; 152 days), Supa India (medium maturing; 144 days) and upland NERICA-14 (early maturing; 131 days) were selected. The rice cultivars are all susceptible to *S. asiatica* infection, although Supa India is more susceptible than the