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Determinants of parasitic weed infestation in rainfed lowland rice in Benin

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ABSTRACT

The parasitic weed *Rhamphicarpa fistulosa* is threatening rainfed lowland rice production in Benin. The aim of this study was to explore factors (such as biophysical characters of the rice growing environment, farmers' management practices, and socioeconomic characteristics) that affect the infestation of rainfed lowland rice fields by *R. fistulosa* and farmers' ability to cope with the problem. Data were collected from 231 rice plots located in 12 inland valleys infested by *Rhamphicarpa* in Benin. Data were analyzed using a double hurdle model, which analyses both the likelihood (of occurrence) and the severity of infestation. Results showed that 72% of the surveyed rice plots were infested by *R. fistulosa* and the average severity was 109 plants m^{-2}. The likelihood of infestation was higher on poorly fertile soils and fields located in the inland-valley bottom, and it decreases through timely use of herbicides and ploughing. Severity of infestation was higher on rice plots cultivated by female-headed households farmers and reduced through management practices such as late sowing, timely application of post-emergence herbicide, three hoe or hand weeding operations, medium-rate fertilizer application and prolonged fallow. Likelihood and severity of infestation were found to be negatively correlated. These findings suggest that farmers can reduce the likelihood and the severity of infestation of their plot as long as they are aware of factors causing the problem given their access to and management capacity of production resources.

1. Introduction

Since the 1960s, African demand for rice has increased at an average annual rate of 4.4%, twice as fast as the world-average, to reach a total consumption level of 20 million tons in 2009 (Rutsaert et al., 2013). In Sub-Saharan Africa (SSA), growth in rice consumption reached 4.6% per year between 2000 and 2010, nearly twice the 2.6% rate of population growth over that same period (USDA, 2012). Africa's rice sector has not been able to match this growth in demand, and as a result, it has become increasingly dependent on imports (Seck et al., 2010). In particular, domestic rice production is struggling with numerous biotic and abiotic constraints that undermine production efforts. Rice is produced in different rice growing environments (or ecosystems) through various production systems. The most prevalent rice growing environments are rainfed upland, rainfed lowland—also referred to as inland-valley systems—and irrigated agroecosystems. Across these ecosystems, weeds are the most important biotic constraint (Balasubramanian et al., 2007; Seck et al., 2012). Species belonging to the group of parasitic weeds, such as *Striga hermonthica*, *Striga asiatica* and *Rhamphicarpa fistulosa*, are among the most damaging local weeds (Rodenburg and Johnson, 2009; Rodenburg et al., 2010).

R. fistulosa was still considered of minor importance in the early nineties of the previous century (Raynal, 1994). However, recent literature review has revealed that it is found nowadays, in many countries in West Africa, Madagascar and South Africa (Rodenburg et al., 2010). *R. fistulosa* is a facultative hemiparasitic weed, which implies that it does not depend on the presence of a host to complete its life cycle (Ouédraogo et al., 1999). It is a wide-spread and common plant species in the natural vegetation of seasonally wet locations (Hansen, 1975; Ouédraogo et al., 1999; Staner, 1938). It is also commonly found in hydromorphic zones, and un-improved rainfed lowland rice fields (Rodenburg et al., 2010). While these inland valleys (IVs) have a huge production potential in SSA, they are largely untapped (Rodenburg et al., 2014;

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Sakurai, 2006). Following recent upward trends in rice consumption, it is expected that an increasing area of IVs in SSA is being put under rice production and consequently the already present *R. fistulosa* will become an increasingly common and constraining weed (Rodenburg et al., 2010).

In Benin, the boost in rice production necessary to meet increasing demand has to come for a large part from IVs; it has been estimated by Gruber et al. (2009) that about 194,800 ha of flood plains and inland valleys are exploitable for agricultural production. However, *R. fistulosa* is wide-spread in Benin (Gbehounou and Assigbe, 2003; Rodenburg et al., 2011). Hence, an increase in rice production, in this country, might be constrained by the presence of *R. fistulosa*. Weeding in un-mechanized rainfed rice systems in Africa is a labour-intensive and costly activity (Gianessi, 2009; Rodenburg and Johnson, 2009). The time and resources required for weeding might divert farmers from other (on- or off-farm) economic activities of the household. Consequently, the weeding requirement can reduce households' incomes both directly and indirectly, increase the risk of food insecurity and hence reduce their wellbeing. In addition to the costs incurred for weeding, the parasitic weed *R. fistulosa* causes substantial losses to rice production, thereby directly jeopardizing farm incomes and food security. According to farmers' perceptions and controlled pot experiments, grain yield losses of 60% or more are common (Rodenburg et al., 2011).

Despite the increasing threat of parasitic weeds in SSA, little information is currently available on key factors influencing infestation of rice crops by parasitic weeds such as *R. fistulosa*. The few previously conducted studies on *R. fistulosa* in rice (e.g. Ouédraogo et al., 1999; Gbehounou and Assigbe, 2003; Gbehounou, 2006; Rodenburg et al., 2011) only explored agronomic, ecological and biological factors to explain *R. fistulosa* infestation and proliferation. Several studies have identified factors affecting the infestation of crops by other parasitic weeds such as *Striga spp* (e.g. Dugje et al., 2008; Van Mourik et al., 2008; Vissoh et al., 2008). These studies have identified a range of agronomic and biophysical factors that play a key role in farms' infestation by parasitic weeds and subsequent yield losses. These factors can be grouped into farmers' agricultural practices and the agro-climatic environment in which farmers operate (see Dugje et al., 2008; Ogborn, 1987; Weber et al., 1995). Most studies have identified low soil fertility as one of the key factors affecting parasitic weeds infestation (Parker, 2012; Parker, 2009). They are more prevalent in production systems characterized by degraded soils and suboptimal water control (Rodenburg et al., 2010). Reducing fallow length, limited application of nitrogen and low soil fertility are the main causes of *Striga* infestation in West and Central Africa (e.g. Dugje et al., 2006). While few established control options are available yet against *Rhamphicarpa* (Parker, 2012), fertilizer application has been shown to reduce significantly *R. fistulosa* plant counts and rice grain weight loss under infested conditions (Rodenburg et al., 2011). However, factors like agroecological zone, topographical location of the rice field in the IV (upper/medium/lower slope or bottom), soil texture (clay, loamy, sandy) and socio-economic characteristics of the rice farmer remain to be investigated. Better knowledge of factors explaining infestation and farmers' ability to control the infestation will contribute to priority setting of research for development. It will also help to develop appropriate and effective control strategies, and to provide relevant recommendations to (agricultural) policy makers, extension agents and other stakeholders.

Therefore, this paper aims to explore factors such as the biophysical characters of the rice growing environment (agroecological zone, topographical location, soil fertility status), farmers' management practices (fertilizer and herbicide use, fallow practice, timing of sowing, land preparation methods, weeding frequencies) and socioeconomic characteristics that affect the infestation of rainfed lowland rice fields by *R. fistulosa* and farmers' ability to cope with this relatively new parasitic weed. This was done by analysing the infestation of rice plots in two stages (the occurrence and the severity of infestation) using a double hurdle model.

2. Data and methods

2.1. Study area and sample selection

In this study, a multistage sampling approach was used for sample selection. At country level, we have selected three regions: Collines in Central Benin, Alibori in North East and Atacora in North West. The presence of *R. fistulosa* in rainfed lowland rice has been reported in those three regions since 1997 (Gbehounou and Assigbe, 2003; Rodenburg et al., 2011). They accounted for 80% of the rice area and 85% of domestic production (DPP/MAEP, 2009).

In order to inform the sampling strategy, an exploratory visit was conducted within the country to identify IVs where *R. fistulosa* was present. After this tour, we have selected five districts (region level) where *R. fistulosa* was found in rice fields. The districts selected were Glazoué and Dassa in Collines, Kandi in Alibori, and Boukoumbe and Tanguieta in Atacora region. These districts encompass three out of the eight agroecological zones of the country. Dassa and Glazoué are located in the agroecological "cotton zone" (Sudan-Guinea zone), Kandi in the "cotton zone of North Benin" (Sudan savannah), and Boukoumbe and Tanguieta in the "Atacora West mountain" agroecological zone (Sudan–Sahelian savannah). In those districts (district level), 12 most cropped and infested IVs were selected. In those IVs (IV level), we made a census of rice farmers. From the census, a total of 182 rice farmers were selected randomly to minimize sampling errors and selection bias. The sampled farmers cropped a total of 231 rice plots. This subsample of rice plots included both infested and non-infested plots. Non-sampling errors like non-response and measurement errors were minimized by pre-testing the questionnaires to check for consistency. The efficient sampling method developed by Whitley and Ball (2002) for optimal allocation of resources was used to determine the sample size and minimize sampling variance.

2.2. Description of data

We analyzed the likelihood of infestation of *R. fistulosa* and the severity of infestation using data from field and farmer surveys conducted in Benin from September 2011 through January 2012. The field survey was conducted during the cropping season and the producer survey after harvesting. The field survey captured the following rice plot characteristics: spatial coordinates, plot size, *R. fistulosa* infestation status, the severity of the *R. fistulosa* infestation, rice variety used and paddy yield. The producer survey captured both rice plot and socio-economic characteristics. Plot data collected were: soil type, soil fertility status (based on farmer perception), field history, cropping techniques, use of chemical inputs and the sources of rice seed used. Farmers' socio-economic data collected were: age, gender, household size, education, labour endowment and access to chemical inputs. Farmers' weed management practices were also collected. In order to correctly match field and farmer survey data, during the field data collection phase, all farmers' plots were given an identification number.

In this study, "likelihood of infestation" was defined as the likelihood of observing *R. fistulosa* plants in a rice plot; the coverage score was defined as the proportion of the rice plot covered by *R. fistulosa* and visually estimated. We used the emerged *Rhamphicarpa* plants count to assess parasitic weed density following methods outlined by Dugje et al. (2008) and Ogborn (1987). The "severity of