Agriculture, Ecosystems and Environment 235 (2016) 306–317

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Parasitic weed incidence and related economic losses in rice in Africa

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ARTICLE INFO

Article history:
Received 10 June 2016
Received in revised form 20 October 2016
Accepted 21 October 2016
Available online xxx

Keywords:
Rain-fed rice
Africa
Striga
Rhamphicarpa
Oryza sativa
Parasitic weeds
Geographic distribution
Stochastic impact assessment

ABSTRACT

Parasitic weeds pose increasing threats to rain-fed rice production in Africa. Most important species are *Striga asiatica*, *S. aspera* and *S. hermonthica* in rain-fed uplands, and *Rhamphicarpa fistulosa* in rain-fed lowlands. Information on the regional spread and economic importance of parasitic weeds in cereal production systems is scant. This article presents the first multi-species, multi-country, single-crop impact assessment of parasitic weeds in Africa. A systematic search of public international and national herbaria and the scientific literature was conducted to collect all available data on the regional distribution, incidences and related yield losses of the most important parasitic weeds in rice. Herbaria specimens were geo-referenced and these coordinates were overlapped with rain-fed rice areas. Probabilistic diffusion waves of parasitic weeds were generated to derive most likely incidence values. Estimates from this spatial analysis were then combined with secondary data from the literature into a stochastic impact assessment model to generate a confidence interval of the likely economic impact per country and for sub-Saharan Africa as a whole. *Rhamphicarpa fistulosa* occurs in at least 36 African countries, 28 of which produce rice in rain-fed lowlands where this species thrives. *Striga hermonthica* is found in at least 32 countries, *Striga asiatica* in at least 44 and *S. aspera* in at least 17. A total of 50 countries have at least one of these three species of *Striga*, 31 of which produce rice in the rain-fed uplands where these species can be encountered. An estimated 1.34 million ha of rain-fed rice is infested with at least one species of a parasitic weed in Africa. Our stochastic model estimates that annual economic losses inflicted by all parasitic weeds exceeds, with 95% certainty, a minimum value of US $111 million and most likely reaches roughly US $200 million and increases by US $30 million annually. To reverse this trend and support small-holder rice farmers in Africa with effective, sustainable and affordable solutions for control, targeted investments in research, development and capacity building are required. The top-10 priority countries where such investments would probably have the highest return are Nigeria, Guinea, Mali, Côte d'Ivoire, Cameroon, Tanzania, Madagascar, Uganda, Sierra Leone and Burkina Faso.

1. Introduction

Parasitic plants depend on other plants for part or all of their nutrition (Heide-Jørgensen, 2008). They parasitize by making a xylem-to-xylem connection with the host plant using a specialized organ called haustorium. Through this connection the parasite extracts water, nutrients and metabolites and alters the plant growth regulators of the host, resulting in stunted growth and losses in reproductive output of the host plant (Westwood, 2013).

Parasitic plants feature in 20 plant families (Heide-Jørgensen, 2013), with eight families harboring species of economic importance. They are economically important when they are weedy and constrain crop production. This may happen when they shift from the natural vegetation, where they spontaneously occur, to cultivated fields with agricultural crops (Raynal Roques, 1994). In sub-Saharan Africa (SSA), the Orobanchaceae family contains the vast majority of species that have turned into parasitic weeds and from that family, *Striga* is without any doubt the most important genus in terms of economic impact in this region (Mohamed et al., 2006). *Striga* Lour., is a vast genus with 28 species and 6 sub-species in Africa, 22 of which are endemic to this continent (Mohamed et al., 2001). Other *Orobanchaceae* genera with economically important parasitic weed species in SSA are

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http://dx.doi.org/10.1016/j.agee.2016.10.020

Orobanche, *Alectra,* and *Rhamphicarpa*. The most important parasitic plant species that have developed into parasitic weeds in cereal production systems in SSA, are the Witchweeds, *Striga asiatica* (L.) Kuntze, *S. aspera* (Willd.) Benth. and *S. hermonthica* Benth., and Rice Vampireweed, *Rhamphicarpa fistulosa* (Hochst.) Benth. (Parker, 2012). All of these species may be found in rice fields, with *Striga* spp. in rain-fed uplands and *R. fistulosa* predominantly in rain-fed lowlands and moist uplands (Kabiri et al., 2015). Rain-fed rice growing environments are entirely depending on rainfall and groundwater flows for water supply. The description 'rain-fed upland' refers to free-draining soils, often positioned in pluvial landscape zones – i.e. crests, upper slopes and middle slopes, while 'rain-fed lowland' refers to hydromorphic and water-logged soils, in phreatic and fluxial zones – i.e. lower slopes and valley bottoms (Windmeijer and Andriesse, 1993).

Known hot-spots of parasitic weed infestation in rice are northern Côte d'Ivoire (Johnson et al., 1997; Kouakou et al., 2015) and northeast Nigeria (Gworgwor et al., 2001; Dugje et al., 2006) for *Striga aspera* and *S. hermonthica*, the Middle West of Madagascar (Fujisaka, 1990; Elliot et al., 1993), Comoros (Reneaud, 1980) and southern Tanzania (Kabiri et al., 2015) for *Striga asiatica*, and central and northern Benin (Rodenburg et al., 2011c; N'cho et al., 2014), northern Togo (Houngbedji et al., 2014), southern Mali and central Burkina Faso (Ouédraogo et al., 1999), eastern Uganda (Rodenburg et al., 2015a) and southern Tanzania (Kabiri et al., 2015) for *R. fistulosa*. The areas affected by parasitic weeds accommodate some of the world's poorest farmers and are reported to increase (Dugje et al., 2006; Rodenburg et al., 2011b; Kouakou et al., 2015). Within this category of farmers, parasitic weeds seem to predominantly affect women as they are often working on the most marginal and parasitic weed infested plots (Houngbedji et al., 2014; N'cho et al., 2014).

Rice is perhaps not the first crop one would associate with parasitic weed problems. The problem is more generally known to occur in maize and sorghum, crops that suffer mainly from *Striga asiatica* in southern Africa and from *S. hermonthica* in West, Central and East Africa (Parker, 2013). Rice can be grown under permanently flooded conditions where parasitic weeds do not thrive. However, while irrigated rice may be the most popularly known rice production system, in SSA it is not the most important one in terms of area. Sixty-six percent of the land area under rice in SSA is characterized as rain-fed (Diagne et al., 2013), and these are precisely the environments where parasitic weeds are found as well. Rice is one of the major food crops in Africa, and is subject to a rapidly increasing consumer demand (Seck et al., 2012). The regional annual growth rate of rice consumption is 4.5% while the regional production growth rate is only 3.2% (Seck et al., 2010). As a result, rice import dependency has increased by 2.2% annually since the 1960s (Demont, 2013). Apart from increasing imports, part of the gap will be closed by area expansion for rice production (van Oort et al., 2015). Such expansion results from new exploitations, mainly in the rain-fed lowlands, i.e. the inland valleys (Rodenburg et al., 2014), and conversions of fallow, maize and sorghum fields into (rain-fed upland) rice fields (Kijima et al., 2008). The natural vegetation of African inland valleys harbors *Rhamphicarpa fistulosa* (Hansen, 1975), and the fallow, maize or sorghum fields in this region are often highly infested by *Striga* spp. (Samake et al., 2006; Kamara et al., 2014). Hence the increase of area under rain-fed rice is likely to be associated with increasing parasitic weed problems and this is expected to be aggravated by climate change (Rodenburg et al., 2011a).

Parasitic weed inflicted yield losses in rice are a function of the parasite species, infestation and virulence level of the local ecotype (or morphotype) and the extent of resistance and tolerance of the crop variety (Rodenburg et al., 2015b, 2016). Estimates of the extent of the economic losses caused by parasitic weeds in crops in sub-Saharan Africa are however inaccurate and outdated (Parker, 2009). For rice, economic loss assessments have even never been undertaken. In parasitic weed affected countries there is a general lack of attention for this type of weed problems among agricultural extension and crop protection services, policy and decision makers and research portfolio and training curricula, particularly for rice production systems (Schut et al., 2015). As this is partly due to suboptimal awareness, a thorough assessment of the extent of the problem would be a first essential step to effectively address it. The objectives of this study are therefore to acquire estimates on the incidence and present the first multi-species, multi-country, single-crop impact assessment of parasitic weeds in Africa. Estimating economic losses inflicted by parasitic weeds, however, is severely constrained by data scarcity. Moreover, according to De Groote (2007), a major constraint is the lack of integration of social sciences in research on parasitic weeds. He proposes the following seven steps in the economic analysis: (i) estimating the extent and (ii) intensity of the problem, (iii) trials and (iv) appropriate economic analysis of new control methods, (v) farmer evaluation of these methods, (vi) modeling of the weed × crop × environment interactions, and (vii) impact assessment.

The current study purely relies on secondary data. Through an elegant combination of data mining, spatial analysis and stochastic impact assessment, we aim at obtaining a confidence interval of the minimum and most likely economic losses inflicted by parasitic weeds in rice in Africa and identifying the major drivers for these losses. This is expected to shed light on the current and likely future situation of this production constraint in rain-fed rice producing areas, which in turn should contribute to better targeted policy making, research and development endeavors and investments in the region.

2. Materials and methods

Our methodology consists of a combination of data mining, spatial analysis and stochastic impact assessment. This section is organized as follows. In Section 2.1, we develop a model for estimating the impact of parasitic weeds in production systems. From this model, we derive our data requirements. Through data mining, we then exploit the scarcely available data to the maximum extent possible. This involves collecting secondary data from literature and conducting an exhaustive herbarium study followed by geo-referencing (Section 2.2). In Section 2.3, we then combine these data with spatial data on rain-fed rice growing areas, and in Section 2.4, we incorporate uncertainty into our model by assigning stochastic distributions to our parameters, which enables us to obtain a confidence interval and a most likely value for our model outcomes.

2.1. Model

Total monetary losses, C (US$), and annual incremental change in monetary losses, ΔC (US$), inflicted by parasitic weeds in Africa can be estimated as follows:

$$C = \sum_{j=1}^{n} A_j \mu_j p_j \sum_{i=1}^{w} \phi_{ij} \Delta y_{ij} \tag{1}$$

$$\Delta C = \sum_{j=1}^{n} A_j \mu_j p_j \sum_{i=1}^{w} \Delta \phi_{ij} \Delta y_{ij} \tag{2}$$

with A_j the total rice area in country j ($j = 1, 2, \ldots, n$), μ_j the average milling recovery rate in country j (share in weight of milled