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# Economic impacts of invasive alien species on African smallholder livelihoods

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ABSTRACT

In developing countries, invasive alien species (IAS) threaten smallholder farmer production and the food security of subsistence growers, but economic impacts are widely under-reported. Here, the economic impacts of IAS that threaten smallholder mixed maize farming in eastern Africa are presented. Maize is important for most smallholders and is commonly grown with horticultural crops and other cereals which collectively provide nutrition and income. These crops are also important for national economies. Estimates of the economic impacts of five major IAS: *Chilo partellus*, Maize Lethal Necrosis Disease, *Parthenium hysterophorus*, *Liriomyza* spp. and *Tuta absoluta* on mixed maize smallholders in six countries gave current combined annual losses of US$0.9–1.1 billion; and future annual losses (next 5–10 years) of US$1.0–1.2 billion.

## 1. Introduction

The diverse and vast scale of the negative impacts of many invasive alien species (IAS), namely a non-native organism causing economic or environmental harm or negatively affecting health (summarised from CBD, 2009), is increasingly well documented (Jackson, 2015; Mack et al., 2000; Nghiem et al., 2013; Pimentel, 2011). These species have largely become a global problem because of the accelerating rate of trade and transport, particularly since the end of the 20th century (Essl et al., 2011; Marini et al., 2011) and these factors are likely to drive further biological invasions (Levine and D'Antonio, 2003). Human enterprises and critical resources are affected, including trade, crop and livestock production, pastureland, forests, natural resources and biodiversity; as well as human and animal health (Mack et al., 2000; Mooney et al., 2005).

Despite the increasing knowledge of IAS impacts, most of the information to date is from studies of high-income countries with relatively little data available for developing countries (Nghiem et al., 2013; Peh, 2010). However, developing countries are particularly vulnerable to IAS impacts because the majority of people living in these countries are smallholders (land holdings of 2 ha or less) (Wiggins et al., 2010) and are almost totally dependent on agriculture and natural resources for their survival (Nghiem et al., 2013; Perrings, 2007; Wiggins et al., 2010), with IAS posing additional threats to nutrition and food security (Early et al., 2016). Smallholders typically grow a mixture of subsistence and cash crops and in some regions, households also harvest natural resources such as grasses and shrubs for animal fodder (Rai et al., 2012). In many developing regions, most crop production is by smallholders; small farms represent 80% of all farms in Sub-Saharan Africa (SSA) (approximately 33 million small farms) and in some countries contribute over 90% of national production (Livingston et al., 2011; Wiggins, 2009). Furthermore, almost 70% of the world's poor reside in rural areas (World Bank, 2015), with poverty now exacerbated by IAS which can affect many of the crops that they grow (Perrings, 2007).

An important dimension of impact, critical for policy and prioritization of actions, particularly for developing countries with limited resources, is that of economic costs associated with IAS. However, a major point arising from the unprecedented spread of IAS is that rural communities now face many IAS and yet the published studies to date on impacts on agriculture in developing countries are largely focussed on individual IAS; in addition, these studies relate more to impacts on yield rather than economic loss (Nghiem et al., 2013). Some authors have attempted to quantify IAS economic losses at a national or regional level but the studies are broad scale and mask the specific impacts on rural communities (e.g. Pimentel, 2011). Thus there is an urgent need to begin to address this gap in knowledge. One approach is to estimate economic impacts from existing published information detailing smallholder crop areas, production, values and distribution and yield losses from IAS in affected areas.

Here, a study is presented on the estimation of the economic losses caused by a representative group of damaging IAS that are currently known to be affecting smallholder agricultural production in mixed maize farming systems in six countries in eastern Africa: Ethiopia,

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Kenya, Malawi, Rwanda, Tanzania and Uganda. The mixed maize farming system is chosen because it is one of the most common agricultural systems in SSA, particularly in the eastern region (Garrity et al., 2012). Maize (*Zea mays*) is frequently grown with several other crops by smallholders, and in particular, farmers may grow horticultural crops to provide nutrition and as cash crops to provide income (Maertens et al., 2012). Many IAS, across a diverse range of taxa, are present in the eastern African region and are having detrimental impacts on agriculture, and pose a major threat to smallholder farms in mixed maize farming systems (Nyambo et al., 2011; Perrings, 2005; UNEP, 2006). Five IAS that affect pre-harvest production are included in the study: three insects, one pathogen and a plant. These species were selected because they are spreading in the region – rapidly in some cases – causing serious damage to crops and were considered to be representative of the collective IAS problems that a typical maize farmer now faces in a growing season.

National economic loss figures are derived to illustrate the magnitude of the impacts on mixed maize smallholder production, but a case study of each of the IAS included is presented in the Supplementary information to provide specific distribution and impact information for each species. The estimates are for the current time and are based upon the latest available distribution data for the five species, with extrapolation where data is lacking. Estimates of the economic impacts for the 5–10 years following this, based on current rates of spread, are also included. This type of projection is rarely included in economic impact studies (Born et al., 2005), but is valuable for assessment of future risks. IAS management approaches were found to be highly variable and poorly reported with costs rarely quantified and as such were excluded from the main study, however, weeding of crop fields was universal in the study area and a representative example of the costs of weeding an IAS is given for *Parthenium hysterophorus*. In addition, the use of classical biological control to manage IAS is an approach that can benefit smallholders on a large scale, offering yield savings without direct costs to farmers. As an example, biological control savings in maize brought about by the release of the parasitoid *Cotesia flavipes* against the spotted stem borer, *Chilo partellus* were calculated.

### 1.1. The study farming system and the major invasive alien species

Maize is the most important staple crop for smallholder families in many countries in eastern Africa, and may also be sold in markets by these families to generate extra income (Salami et al., 2010; Smale et al., 2011). An estimated 22 million households rely on this crop across the six selected countries alone, with annual production exceeding 24.5 million tonnes in 2014 (FAO, 2015; plus see Table A in Supplementary information for production data). Mixed maize covers 10% of the land area of SSA and has a vast agricultural population estimated at 60 million (Livingston et al., 2011). The mixed maize farming system has high potential to contribute to food security and rural growth, but has more poverty than any other farming system in Africa (Garrity et al., 2012).

Other crops grown with maize include the common bean (='dry') (*Phaseolus vulgaris*) which is an essential subsistence crop and source of protein, important when there is a seasonally variable food supply, particularly for the poor, for whom it plays a strategic role in poverty alleviation (Katungi et al., 2009). However, many smallholders are now supplementing their incomes by engaging in broader horticultural activities where fruit and vegetables are grown for both domestic and export markets (English et al., 2004). These crops include pea (*Pisum sativum*) and French bean (a cultivar of the common bean and also known as green beans), both of which are high value, and tomato (*Solanum lycopersicum*) which is commonly traded on local markets.

The IAS assessed on maize were: *Chilo partellus*, the spotted stem borer, Maize Lethal Necrosis Disease (MLND) and *Parthenium hysterophorus*, parthenium. The IAS assessed on horticultural crops were: *Liriomyza* spp., vegetable leafminers on dry beans/peas as subsistence crops and green beans/peas as horticultural crops, and *Tuta absoluta*, the South American tomato leaf miner on tomatoes. Some key information on these species is included in Table 1 is no longer below, with full case studies provided in the Supplementary infromation. Images of the IAS can be found on the Invasive Species Compendium (www.cabi.org/isc).

## 2. Methods

Current economic impacts were estimated from published data on the present ranges and yield losses caused by the five species (see Supplementary information for further details) and from data on average crop production and farm gate prices taken from published sources and major databases for the period 2009–2013; after this period key datasets become incomplete (FAO, 2015). Projected economic impacts were also estimated for a 5–10 year period following 2016 to account for likely range expansions for each of the five species. For some of the species, expansion and economic impact into new countries where they are not currently recorded as present were also considered (see case studies in Supplementary information).

Economic impacts were estimated using the following relation:

$$YL_C = p_{IAS} \cdot p_{SH} \cdot yl_{IAS} \cdot P_C \cdot V_C$$

where $\boldsymbol{YL_C}$ is the annual economic value of smallholder yield losses in crop $C$ to an IAS; $\boldsymbol{p_{IAS}}$ is the proportion of national crop production affected by an IAS; $\boldsymbol{p_{SH}}$ is the proportion of crop production affected by an IAS that is grown by smallholders; $\boldsymbol{yl_{IAS}}$ is the proportion of yield lost to an IAS in affected production areas; $\boldsymbol{P_C}$ is gross (pre loss to an IAS) national average annual production of crop $C$ (tonnes); and $\boldsymbol{V_C}$ is the average value of crop $C$ (US$ per tonne).

The major databases used for crop production and prices included FAOSTAT, the World Bank and Famine Early Warning Systems Network (FEWS NET). Where producer prices were absent from the FAOSTAT database, estimates were provided by the Prices Group, FAO Statistics Division.

For yield loss estimates, the need was to derive a typical representative level of loss that would occur as a result of the impact of each of the IAS across a country and year by year. However, for the IAS included in the study, reported yield losses tend to range from very low to very high values with fluctuations by season, area and year; this is generally a feature of many major IAS. Thus to achieve a representative estimate, first peer-reviewed data sources on yield loss for each IAS were prioritised to reduce bias from un-validated and extreme outlying data sources. Second, to illustrate the inherent variation that does occur in yield loss data, the most frequent values of yield loss in the data set were used, to generate a range with upper and lower bound figures. The values of these figures provide the typical range of losses and are used in this study to estimate "lower" and "upper" loss values for each of the IAS included.

The costs of weeding *P. hysterophorus* in maize were calculated by estimating the amount of time spent by smallholders carrying out this task at a standard labour rate per country. Biological control savings in maize brought about by the release of the parasitoid *C. flavipes* against *C. partellus* were calculated by comparing pre- and post-release yield loss estimates (please see Supplementary information for further details).

Where data were lacking for a country or region, extrapolations were made from published information from comparable regions; details are provided in the case studies (see Supplementary information). The estimated smallholder economic crop losses were also assessed in relation to the national agricultural gross domestic product (GDP) for each of the affected countries; GDP figures were obtained from the World Bank website (World Bank, 2016a, 2016b).