The interaction between pests, mixed-maize crop production and food security: a case study of smallholder farmers in Mwea West, Kenya

Kate L. Constantine¹*, Sean T. Murphy¹ and Corin F. Pratt¹

**Abstract:** Crop pests (weeds, insect pests and pathogens) are recognised worldwide as a serious challenge to agricultural production and threat to food security. Potential losses due to weeds, animal pests and pathogens have been reported at 34%, 18% and 16%, respectively. In monetary terms losses can be high, for example, annual smallholder losses due to just five invasive species in six African countries have been estimated at US$0.9–1.1 billion. Here, smallholder mixed maize farmers’ perceptions of the key constraints to their farming practices are considered. Semi-structured interviews with smallholder households, in addition to key informant interviews, reveal that farmers report insect pests, pathogens and weeds (collectively “pests”) as the main constraints to farm production. Farmers report yield losses experienced due to pests, together with control expenditure significantly affect net income whilst undermining other livelihood assets. Farmers in Mwea West are highly vulnerable to a range of pests including a number of invasive alien species. Importantly, the farmer perceptions in this study agree with major research studies and confirm the serious impacts of pests on smallholder livelihoods. In order to achieve positive livelihood outcomes there is an urgent need for

---

**ABOUT THE AUTHOR**

Kate L. Constantine works in the Invasive Species Management team at CABI on various weed biological control projects as well as becoming increasingly involved in socio-economic work related to invasive species. She has a strong interest in interdisciplinary approaches and the links between natural and social science stemming from her MSc research investigating smallholder farmers, invasive plants and resilience is interlinked social-ecological systems. Recent work has primarily been on various projects under CABI’s global Action on Invasives (AoI) programme which aims to protect and improve the livelihoods of rural communities through an environmentally sustainable, regional, and cross-sectoral approach to managing invasive species. This work, alongside the study reported here, includes an economic assessment of the cost of five key invasive species to six Sub-Saharan African countries, a study on smallholder farmer perceptions of biopesticides, and the development of a framework and methodology to assess a country’s responsiveness to invasive species.

---

**PUBLIC INTEREST STATEMENT**

“Pests” including insects, pathogens and weeds are a serious constraint to smallholder farming contributing to yield losses and increasing the need for external inputs and labour. This study illustrates the magnitude of the problem by showing pests, of which invasive species form a key component, as the main constraint to smallholder farmers in Mwea West, central Kenya. Considering the importance of invasive species in existing pest complexes, farmers are predicted to be highly vulnerable to the increased spread and establishment of novel invasive species, with climate change exacerbating the problem. The pest complex present on farms in this study affected both maize, as a key subsistence crop but sometimes sold at market, as well as other key crops grown with the aim of improving income. There is an urgent need for international support to improve smallholder food security which is especially important for countries with low gross domestic product.
support to improve smallholder food security; this is especially important for countries with low gross domestic product.

Subjects: Agriculture & Environmental Sciences; Entomology; Environment & Economics; Africa - Regional Development; Rural Development; Environment & the Developing World

Keywords: smallholder; livelihoods; perceptions; pests (weeds/insect pests and pathogens); invasive alien species

1. Introduction

In developing countries more than 70% of total poverty is found in rural areas (Dixon et al., 2001) where communities are heavily dependent on agriculture for their livelihoods. Therefore, understanding the drivers of poverty in rural agricultural communities is of key concern. In Kenya, agriculture is vital to the economy, engaging more than 70% of rural people with smallholders accounting for 75% of the country’s total agricultural output (FAO, 2014). However, over 10 million people remain food insecure, making food security a key objective for the agricultural sector (Kenya Agricultural Research Institute, 2012). Understanding rural farmer realities and perspectives on the key constraints to their livelihoods plays a crucial part in tackling food insecurity and for the development of effective interventions (Adesina et al. 1994; Midega et al., 2012).

Smallholder farmers (households with land holdings of two hectares or less: FAO, 2015) face many constraints in the production of crops (Salami et al., 2010). For example, constraints may include access to credit, access to healthy seed, cost of fertilizers, unpredictable climatic conditions, access to markets and crop pests (defined here to include insects, pathogens and weeds). The last crop pests are recognized worldwide as a serious challenge to agricultural production (Oerke, 2006). Crop pests include weeds, animals and pathogens for which Oerke (2006) reports overall potential losses are highest for weeds (34%), and less important for animal pests (18%) and pathogens (16%) (although absolute losses and loss rates vary among crops). In Africa, where there is high dependence on agriculture, insect pests are cited as one of the major constraints to production (Abate et al., 2000). For instance, yield losses of up to 100% are observed, although the economic importance of the majority of pests is poorly reported (Abate et al., 2000). An increasingly important aspect of the pest threat to agriculture comes from invasive alien species (IAS); on many crops these species now form a significant part of pest complexes. An estimate of the annual economic impacts of five major invasive species on mixed-maize smallholders in six African countries was calculated at US$0.9–1.1 billion, with future annual losses estimated at US$1.0–1.2 billion (Pratt et al., 2017). Invasive alien species include some of the world’s most destructive species and are a large and globally growing problem, driven strongly by increasing trade, transport and travel (Early et al., 2016; Perrings, 2005).

However, most figures on crop yield losses due to pests, are for national or regional level losses and based on studies of major pest species assessed in isolation. Yet at the farm level, smallholders face multiple crop pest problems and there is a paucity of information on the total impact that they might have on farm crop yield and farm economics. Equally important is how farmers perceive or evaluate the magnitude of pest impact in relation to other constraints to crop production. For example, understanding farmer perceptions was important in determining the reasons behind poor cotton yields in western Kenya (Midega et al., 2012) and also for developing effective integrated pest management strategies for rice pests in the Ivory Coast (Adesina et al. 1994). Local ecological knowledge gained from small-scale farmers has also provided valuable information for invasive weed management (Bart, 2010). The case of mixed-maize farming, one of the most important cropping systems in sub-Saharan Africa (SSA), well illustrates the problems smallholders face with respect to pests. All farmers in the mixed-maize system grow maize (Zea mays L.), often alongside other cereals and staples, but frequently farmers able to do so also invest in cash crops. In this system, therefore, farmers may occur across a livelihood spectrum. For example, those farmers only
growing maize for subsistence and potentially selling any surplus; to others growing maize in addition to one cash crop; through to those investing in more than one and potentially several cash crops.

The objectives of this study were to determine smallholder farmers’ perceptions of the main constraints to their farming practices, their current practices for pest management and their estimates of the levels of yield loss experienced and the impact of pests on farm level economics. This study was conducted in a typical mixed-maize farming community in Mwea West, Central Kenya. The research questions that were explored included: (1) what are the key crops being grown, farmer demographics and farmer identified major constraints to production?; (2) what are farmers’ perceived crop losses due to the identified constraints and what impact do these constraints have on total farm annual net income in relation to livelihood type?; (3) what pest control methods are farmers currently using and how effective are they?; and (4) how vulnerable are farmers in the area to the pest complex already present and what risk do they face from additional pest invasions? In order to understand farmer perspectives, the use of qualitative, as well as quantitative, research methods is valuable and contributes to depth of understanding (Dooley, 2007). Collection of in-depth first-hand information provides an important snapshot of the situation on the ground for specific farming community, and although there are limitations in applying the findings at a larger scale, it provides an informative starting point to understand the range of issues smallholders are experiencing.

2. Materials and methods

2.1. Study area

Mwea Constituency, found within Kirinyaga county, is located approximately 112 km north east of Nairobi at the foothills of Mount Kenya (Figure 1(a)) with a population of approximately 187,399 (Ngugi, 2013). On average the temperature is 20°C, ranging between 12°C and 26°C, with annual precipitation of approximately 1,250 mm. There are two rainy seasons; the long rains from March-May and the short rains from October-December. Agriculture is the main economic activity in Mwea, where over 70% of people are small-scale farmers. The area benefits from the Mwea Irrigation Scheme established in 1954, with the most commonly grown crops including tea, coffee, rice, maize, beans, bananas and various fruits and vegetables (Kenya Information Guide, 2015; Kirinyaga County Government, n.d.; National Irrigation Board, 2016). Mwea has two administrative wards, Mwea East and Mwea West that are ecologically very similar. This study focused on Mwea West which consists of three wards, the main horticultural area is found within Kangai ward therefore this area was selected for the smallholder farmer interviews; the average (±SD) age of respondents was 49 (± 14) years. In Kangai farmers grow maize and a range of other crops for self-sufficiency, with some also growing up to three cash crops for sale (Figure 2).

2.2. Smallholder farmer survey

Surveys involved individual semi-structured interviews with 32 randomly selected smallholder farmers during January-February 2016. The small sample size for this case study reflects the qualitative nature of the interviews, which take more time to complete than a response style tool such as a questionnaire, in order to ensure sufficient understanding of the situation from the participants’ perspective (Dooley, 2007; Sundaram et al., 2012).

The farmers included were all household owners who were farming areas of approximately one hectare (ha). A list of farmers in Mwea West was provided by agricultural extension staff working in the area attached to the global Plantwise programme (www.plantwise.org). The list consisted of farmers who were members of the Mitoini Irrigation Scheme and contained the names and contact details of almost 500 individuals. Although this sample selection is not ideal it was considered the most appropriate within the timeframe of the study (further interviews (see below) aimed to ensure views of non-members were also considered). After removing non-households, the list was split by gender and 25 farmers of each gender randomly selected. A higher number was selected than in the survey design to compensate for those who might be unavailable. If farmers could not be located the
next farmer on the list was selected. This procedure was followed until all farms selected for the survey had been exhausted. The interviews were conducted in English and/or Swahili and a GPS record of the location was taken at each household visited. Farmers were asked to provide information for each part of the questionnaire based on an average recent year. Photo cards of pest damage symptoms were used to assist discussion. All interviews were conducted at or near the farmers’ land to enable viewing of pest symptoms (where present) and visual confirmation of weed species. For the farm level economic analysis farmers were placed into the following livelihood categories: type a: no or one minor cash crop for sale; type b: maize plus one cash crop sold; and type c: maize plus two or three cash crops sold.

2.3 Key informant interviews
Five additional interviews were conducted with farmers within the wider study area. Three were selected at random distances from the Mitooini co-operative office within Kangai (but who were not members of the Mitooini Irrigation Scheme) and one randomly selected household in Kiago—
the nearest small town where the local market is held. A further interview was conducted with a female representative from the co-operative who was knowledgeable on the area and the issues farmers were experiencing. An interview was also conducted with the Agricultural Officer at the Department of Agriculture who was responsible for the Mwea West sub-county. A further two interviews were conducted with local agro-dealer input suppliers in Kagio.

2.4 Data analysis
Statistical analysis was carried out in R version 3.4.0 (R Core Team, 2017). Chi-squared tests were used to test for overall significance and between male and female responses (with Yates correction) for constraints to production. Generalised Linear Modelling (GLM) with Poisson errors and post hoc analysis using Tukey’s procedure were used to test for significant differences between the perceived effectiveness of control methods. ANOVA and post hoc analysis using Tukey’s procedure were used to compare the mean areas of different crops grown, as well as numbers of crops grown in relation to income, input and control costs, and farm area. Where data transformation was carried out, this is mentioned in the text.

3. Results

3.1. Demographic and farm data
The randomised sampling resulted in respondents from six sub-wards in Kangai participating in the surveys: Kimicha, Nyua, Kiambogo, Kagumaini, Nyaga and Wang’ata (Figure 1(b)). The number of male and female respondents was almost equal (47% and 53%, respectively). The average (±SD) age of respondents was 49 (± 14) years and the average household size was 6 (± 3). Most households (88%) owned livestock and all practiced zero grazing, with fodder collected off-farm and brought to animals. Maize was grown by all farmers, with banana (Musa spp.) and tomato (Solanum lycopersicum L.) the next most cultivated crops grown by 97% and 44% of farmers, respectively. The majority of respondents (88%) owned land of 2 ha or less. There was a significant difference (p < 0.001) in the average area for various crops grown. For example, the average area (±SE) planted to maize, the primary crop grown, was 0.54 (± 0.08) ha and for banana 0.13 (± 0.03) ha which, for both, was significantly higher than all other crops (Figure 2).
Of these crops, maize provides for subsistence, however may also be sold by some farmers to provide income. Farmers grew a range of other crops over smaller areas both for subsistence and in some instances for sale on local markets, but mostly on a casual basis and this frequently included banana. Some farmers actively invested in growing major cash crops to generate income; this included growing banana, and also tomato; not necessarily together. Some farmers also grew French beans for the same purpose but not to the same extent as the other two cash crops. Thus, for the analysis of the main pests affecting the main crops, focus was placed on the three most frequently grown crops: maize, banana and tomato.

### 3.2 Constraints to crop production

The eight most frequent constraints identified by farmers and segregated by gender can be seen in Figure 3. A significant difference was found between the categories of constraints ($\chi^2 = 142.6; p < 0.001$). When each constraint was segregated by gender no significant difference was found between male and female responses for any category; although some trends in the data are apparent such as more females identifying hand weeding, and more males lack of market, within the top three constraints and reflects the typical gendered division of labour within these farming systems. Figure 3 shows that a high proportion of respondents ranked insect pests, pathogens and weeds (88%, 85% and 60% of farmers, respectively) within the top three constraints to production. Other important constraints identified included drought, lack of market and capital as well as the price of fertiliser with these constraints affecting male and female farmers differently, however, they were perceived by farmers to be of less importance than the impact of pests. The importance of pests was reflected in the following example farmer comments: “[insect pests] are the main problem; the rest we try to control and manage; we have to spray otherwise we would harvest nothing”; “[Maize Lethal Necrosis Disease (MLND)] is the worst problem, if plant during dry season affects 100% of crop, it never used to be there, last year and now this year too”; “[weeds] we have to control them and keep weeding ‘just do’; if we don't weed or spray it results in a poor crop; weeds are increasing”. The additional interviews confirmed the significant problems farmers were experiencing were pest issues and that the complaints from farmers are increasing on a yearly basis.
3.3 Insect pests and pathogens on the main crops

Table 1 details the most commonly reported insect pests and pathogens, or groups of the former where these have a similar feeding habit on a crop (e.g. stem borers) that farmers reported on the crops included in the study, the likely scientific name of the species, or species within a feeding group, and the status of the species—whether native or an IAS—although in some cases the area of origin of a pest is unclear and it is not possible to describe as an IAS. In addition, farmer reported presence and average annual yield loss (after control efforts) due to insect pests and pathogens for the three main crops is given. A number of important insect pests and pathogens occurring on the three main crops are IAS that have at some point been introduced to Kenya. Other symptoms and minor pests were reported by a few farmers but the impacts of these were only considered minor and are not presented.

Farmers reported a range of insect pests and pathogens contributing to maize yield losses. The majority of farmers reported low level yield losses (0–9%) due to maize insect pests however, medium level yield losses (10–50%) were reported by 27%, 20%, 15% and 11% of farmers due to cutworms, stem borers, weevils and armyworms, respectively. In terms of maize pathogens 42% and 7% of farmers reported medium yield losses (10–50%) and 6% and 3% high yield losses (51–100%) due to MLND and MSV, respectively, suggesting these pathogens affect yield considerably. A high proportion of farmers growing maize reported stem borer and weevil pests present on their farms (94% and 86%, respectively), both of which were dealt with using chemical pesticides—without these most farmers stated total yield loss would be experienced. Farmers reported MLND to be very common and one of the most serious problems in the area especially during the dry season; one farmer reported losing their entire crop to MLND last year; four farmers reported the pathogen to have arrived relatively recently (within the last 2–3 years) in accordance with the literature.

Farmers found yield losses for banana difficult to articulate since in most instances’ losses occur in terms of reduced fruit size rather than total losses. Although the banana weevil was present, the main problem farmers were concerned about was a yellowing disease, identified as Black Sigatoka, *Mycosphaerella fijiensis* (confirmed by Plantwise communication). Farmers who reported the disease present on their farm (74%) stated that it was a new problem. In terms of yield loss 29% of farmers reported the disease to contribute to low level losses (0–9%), 10% of farmers reported medium level losses (10–50%) and 6% reported the disease to contribute to high level losses (51–100%).

On tomato, farmers reported the leaf-miner, *Tuta absoluta*, as most problematic. The following farmer quote exemplifies the views of those growing tomatoes in Kangai: “[*T. absoluta*] starts on the leaves and moves to the fruit. Lose 100% if not sprayed which is very expensive and must be from the start of the crop. The pest is a new cry for farmers and very dangerous; we may be defeated to grow tomatoes here”. Farmers reported that without control, total crop loss would be experienced: “[*T. absoluta*] causes a lot of damage and you have to use different pesticides to control it due to resistance; if present and don’t spray lose all [of the tomato crop]”. Four farmers who had previously grown tomatoes have now ceased to grow them due to this pest. Nearly all affected respondents (90%) reported medium level losses (10–50%) due to *T. absoluta*, after control measures had been taken. The respondents in this study reported relying on chemical pesticides to control *T. absoluta* however the need for regular hand weeding was also mentioned. Since tomato is grown as a cash crop for sale, more farmers related losses to reduced income than they did for maize.

Of the particular pest problems reported by farmers, the foremost complaint made to both agro-dealers was of *T. absoluta* on tomatoes, followed MLND, and then weevils on maize, including the notorious invasive *P. truncatus*. Both agro-dealers stated that over time these pests have worsened with some previously effective pesticides now ineffective. The Agricultural Officer confirmed pest issues were the most significant constraint for farmers in the area and that MLND was particularly problematic.
Table 1. Main insect pests and pathogens reported on the main crops, most likely species present, IAS status and farmer reported presence and perceived yield loss

| Crop/pest                      | Most likely species present                                      | Species status                                                                 | % of farmers reporting yield loss |
|-------------------------------|-----------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------|
|                               |                                                                 |                                                                               | Low (0-9%) | Medium (10-50%) | High (51-100%) |
| **Maize insect pests**        |                                                                 |                                                                               |               |                |               |
| Stem borers                   | African maize stalk borer, Busseola fusca (Fuller); Spotted stem borer, Chilo partellus (Swinhoe) | B. fusca: indigenous to mainland Africa south of the Sahara. *C. partellus*: introduced and established in East Africa in 1950s subsequently spreading to southern and central Africa (i). | 94          | 80             | 20            | 0              |
| Weevils                       | Greater grain weevil, Sitophilus zeamais (Motschulsky); Larger grain borer, Prostephanus truncatus (Horn) | S. zeamais: indigenous to mainland Africa south of the Sahara. *P. truncatus*: introduced into Africa in the late 1970s subsequently spreading throughout the region (i). | 84          | 85             | 15            | 0              |
| Cutworms                      | Agratis spp. includes various species in the large moth family Noctuidae, *A. ipsilon* (Hufnagel) is one of the most widely distributed species in the cutworm complex | Widespread and serious pests in Africa occurring from the Cape to the Mediterranean coast with wide host ranges. | 47          | 73             | 27            | 0              |
| Armyworm                      | African black armyworm, Spodoptera exempta (Walker) (not the fall armyworm, Spodoptera frugiperda) | Widespread in Africa south of the Sahara. | 28          | 89             | 11            | 0              |
| **Maize pathogens**           |                                                                 |                                                                               |               |                |               |
| Common smut                   | Common smut of maize, Ustilago maydis (DC.) Corda | Widely distributed throughout the world. | 81          | 96             | 4             | 0              |
| Head smut                     | Head smut of maize, Sphacelotheca reiliana (J.G. Kühn) Clinton | Widely distributed throughout the world. | 59          | 100            | 0             | 0              |
| Yellowing diseases            | Maize Lethal Necrosis Disease (MLND) | Introduced to Kenya in 2011 subsequently spreading throughout the country (i). | 88          | 52             | 42            | 6              |
|                              | Maize Streak Virus (MSV) | Endemic throughout SSA; first reported in Kenya in 1936 and now widespread. | 91          | 90             | 7             | 3              |

(Continued)
Table 1. (Continued)

| Crop/pest | Most likely species present | Species status | % of farmers reporting as present |
|-----------|-----------------------------|----------------|----------------------------------|
|           |                             |                | Low (0-9%) | Medium (10-50%) | High (51-100%) |
| **Banana insect pests** |                             |                |            |                |                |
| Banana weevil | Banana weevil, *Cosmopolites sordidus* (Germar) | Pest present in all banana-growing countries of the world. | 32 | 13 | 0 | 0 |
| **Banana pathogen** |                             |                |            |                |                |
| Yellowing disease | Black Sigatoka, *Mycosphaerella fijiensis* M. Morelet | Present in all major banana-growing regions of the world. First reported in Kenya in 1988 (i). | 74 | 29 | 10 | 6 |
| **Tomato insect pests** |                             |                |            |                |                |
| Leaf miner | Tomato leaf miner, *Tuta absoluta* (Meyrick) | Introduced pest present and rapidly spreading throughout SSA. Identified as present in Kenya in 2014 (i). | 71 | 10 | 90 | 0 |
| **Tomato pathogens** |                             |                |            |                |                |
| Blight | Late blight, *Phytophthora infestans* (Mont.) de Bary; early blight, *Alternaria solani* Sorauer | Worldwide distribution and serious disease with high economic consequences; associated with Solanaceous crops. | 100 | 79 | 21 | 0 |
| Blossom end rot | Physiological disorder | | 73 | 64 | 36 | 0 |
| Bacterial speck | *Pseudomonas syringae* pv. Tomato | Diseases caused by bacteria; occur during rainy season. | 71 | 73 | 18 | 0 |
| Leaf curl | Tomato yellow leaf curl virus (TYLCV) | Globally important virus disease transmitted by the whitefly *Bemisia tabaci*. | 64 | 89 | 11 | 0 |

(i) IAS as described in the literature. References: CABI Crop Protection Compendium, 2017; CABI Invasive Species Compendium, 2017; Infonet biovision, 2017.
3.4 Weeds present on farms

A high number of weeds (18 species) were present and identified by farmers as problematic on their farms. Table 2 lists the most frequently reported species together with farmer perceived impact on crop yield, after any control measures had been taken. The remaining weed species were reported as present by a lower percentage of farmers and as such are not included in Table 2, but some are mentioned in the text below as their incidence was higher than the minor insect pests and pathogens. Weeds impact at the farm level because most weeds are not crop specific.

| Weed species (Latin/common name) | % of farmers reporting as present | % of affected farmers reporting yield loss |
|---------------------------------|----------------------------------|------------------------------------------|
|                                 | Low (0–9%) | Medium (10–50%) | High (51–100%) |
| Commelina benghalensis, wandering jew | 94 | 83 | 10 | 7 |
| Bidens pilosa, blackjack(ii) | 91 | 83 | 14 | 3 |
| Ageratum conyzoides, billy goat weed(ii) | 88 | 89 | 7 | 4 |
| Tagetes minuta, stinking Roger(ii) | 66 | 95 | 5 | 0 |
| Sida acuta, sidai(ii) | 47 | 93 | 7 | 0 |
| Xanthium strumarium, common cocklebur(ii) | 41 | 100 | 0 | 0 |
| Datura stramonium, common thorn apple(ii) | 38 | 92 | 8 | 0 |
| Parthenium hysterophorus, parthenium(ii) | 38 | 100 | 0 | 0 |

ii: IAS as described in the literature. References: BioNET-EAFRINET, Keys and Fact Sheets, 2011; CABI Invasive Species Compendium, 2017; Global Invasive Species Database, 2019; Witt et al., 2018.

The three most prevalent weeds across farmers’ land included C. benghalensis, B. pilosa and A. conyzoides. In general farmers rated yield losses attributed to weeds as low but for some species, yield losses were rated as medium to high by a small percent of farmers—for example, for the three most prevalent weeds. Despite most farmers rating yield losses as low, overall a high proportion of farmers felt they were losing yield annually as result of infestation by each of these weeds. Thus, in many cases there was a high weeding effort, mainly in the form of hand weeding, and in some cases the use of herbicides with the associated gender implications for these practices (i.e. women mainly responsible for hand weeding and the application of herbicides amale activity). In addition, a high proportion of farmers felt that quality of production was being compromised. For example, one farmer stated: “[B. pilosa] if not weeded will cover the entire land with 80% losses and if in grassland prevent some of the grasses cattle feed on from growing.”

A number of farmers reported an increase in the rate of spread of weeds in recent years and that whilst they may have previously weeded once per a season this has now increased to three or four times. Exemplified by the following farmer quote: “All weeds are gradually increasing as the years go by, they didn’t use to spray as they do these days.”

Of the main weeds identified by farmers (Table 2) C. benghalensis has a wide distribution in tropical and subtropical areas (West Africa, East Africa, Central, Southern and in South-East Asia extending as far as Japan, the Philippines and Australia (CABI Invasive Species Compendium, 2017)), indeed this creeping weed is reported to be present and troublesome in most arable crops in East Africa. However, the remainder of species identified as problematic by farmers are IAS. For example, B. pilosa is reported as a pantropical weed occurring in high level infestations in eastern Africa and reported as invasive in Kenya; A. conyzoides although naturalised throughout...
Africa is invasive in Kenya; *T. minuta* is an alien weed first recorded in Kenya in the 1920s; *S. acuta* is a widespread invasive in Kenya; *X. strumarium* is also widely naturalised but invasive in parts of Kenya; *D. stramonium* is invasive in parts of Kenya; and *P. hysterophorus* is invasive and spreading fast in Kenya (BioNET-EAFRINET, Keys and Fact Sheets, 2011; CABI Invasive Species Compendium, 2017; Global Invasive Species Database, 2019). In addition, a number of weeds reported present by farmers (but not included in Table 2) are also IAS, namely *Lantana camara* (widespread and invasive in large parts of Kenya), *Acanthospermum hispidum* (first reported in Kenya in 1945 and now a widespread invasive in Kenya), *Mimosa pigra* and *Tithonia diversifolia*; both reported as invasive in parts of Kenya. Another introduced ruderal weed species present in Kangai but reported by fewer farmers was *Richardia scabra* (rough Mexican clover) termed locally “AIDS weed” due to its rapid spread and high impacts (East African Plants, A photo guide, 2011).

### 3.5 Type and effectiveness of control methods used

The control methods used by farmers included hand weeding and application of chemical pesticides and herbicides. There was no significant difference between genders for any of the control methods used in this study. All farmers in the study hand weeded their farms themselves and the majority (84%) also hired labourers to assist with this task. Significantly more respondents found hand weeding to be poorly effective ($p < 0.05$) than any of the other effectiveness ratings, mainly due to the need to keep repeating this approach. Chemical pesticides were used for the control of insect pests by a number of farmers (72%). Although there was no significant difference between responses for effectiveness most farmers using pesticides found them to be very effective. Half of the farmers interviewed used herbicides to control weeds, and again, although no significant difference was found between effectiveness categories most of those using this control method reported herbicides to be very effective (Figure 4).

![Figure 4. Farmer assessment of the effectiveness of their control methods.](image)

### 3.6 Impact of pests on farm level economics

A preliminary analysis showed there was no significant relation between farm area and livelihood type (data log transformed) or net income in this study, thus this factor was not controlled in the design. The mean annual gross income (including income from crops but not from livestock or other non-farm activities) was found to rise significantly in relation to the number of cash crops grown ($p < 0.001$) (data transformed—cube root) (Figure 5); a pairwise analysis showed significant differences in income between livelihood type a and livelihood type b ($p = 0.01$) and between livelihood type a and livelihood type c ($p < 0.001$); and between livelihood type b and c ($p = 0.03$).
The cost of total other inputs (i.e. not including control costs) was also found to rise significantly in relation to livelihood type ($p = 0.02$) but a pairwise analysis only showed significance between livelihood type a compared with types b ($p = 0.03$) and c ($p = 0.03$), but not between types b and c (Figure 5). In fact, total input costs remain similar once maize for sale is grown with one or more cash crops for sale.

The trend of control costs (pesticide and herbicide product costs in addition to the cost of labourers if hired to apply them, or the cost where labourers were hired for hand weeding) in relation to livelihood type mirrored that found for total other input costs [livelihood type a was significantly different to type b ($p = 0.006$) and type c ($p = 0.007$)] (data transformed—cube root). Control costs rose once one major cash crop was grown with maize, but did not increase significantly with additional cash crops. However, for those farmers growing cash crops, control costs did become an important proportion of other input costs (approximately 30%). However, the analysis did mask a trend that a few farmers growing two major cash crops with maize were sometimes spending more on chemical pesticides than those just growing one major cash crop with maize.

Net income differed significantly across livelihood types ($p < 0.001$) (data transformed—cube root) (Figure 5) with a significant rise between livelihood type a and c ($p = 0.004$) and b and c ($p = 0.002$) but not between a and b. As other inputs, plus control costs form a significant proportion of annual farm budgets, net income only became positive when, on average, farmers grew two or more cash crops with maize for sale as well (Figure 5).

Figure 5. Mean annual income, net income, total input costs and control costs in relation to livelihood type (±SE bars) (trend in data indicated by lines).

4. Discussion
At a farm level, smallholder mixed-maize farmers in Kangai, Mwea West, on average ranked pests (insects, pathogens and weeds) as the greatest constraint to crop production with this finding
confirmed by the key informant interviews. Although other important constraints were identified such as lack of market and capital, which will affect the different livelihood types in different ways, for this particular community these constraints were not perceived to be a major factor influencing the number of cash crops grown. However, the likely most important of these additional constraints is lack of capital to purchase seeds to grow cash crops. Nonetheless, what farmers reported agrees with major research studies that pests such as cereal stem borers (Kipkoech et al., 2006) and pathogens such as MLND (De Groote et al., 2016) are serious threats to food security. Pests are clearly undermining rural livelihoods in Kangai and contribute to preventing farmers moving out of poverty, with IAS forming a significant and growing part of this pest complex, for example, MLND on maize (introduced to Kenya in 2011) and T. absoluta on Solanaceous crops (introduced in 2014), threatening smallholder livelihoods and ultimately food security. Increasing trade is cited as a key driver of invasions in low human-development index countries such as those found in SSA, which were considered the most at-risk countries in research considering total invasion cost (Paini et al., 2016).

Farmers in Kangai were found to be highly vulnerable as their livelihoods are being undermined by a number of significant pest problems resulting in reduced yields of subsistence crops, crops grown for sale, and fodder availability for livestock, and the increasing need to control pests subsequently reducing limited financial resources. Furthermore, high reliance on chemical pesticides detrimentally affects natural resources (such as native parasitoids) and potentially human capital due to detrimental health effects if training in application is not received and protective equipment not worn. Furthermore, severe detrimental health effects can occur when hand weeding noxious weeds such as P. hysterophorus, which also threatens livestock health. It has been demonstrated that farmers in Kangai have limited resources available to input into their farms and the increasing need for inputs to control the suite of pests limits farmers’ ability to move out of poverty. In Kangai some farmers were investing in high value crops which were promoted as a route out of poverty via income generation through export horticulture (English et al., 2004). However, farmers growing these crops are confronted by a range of limitations including that these crops are costly to produce with the need for pesticides and fertilizers, additional labour, irrigation and transport costs, in addition to marketing issues (Tschirley et al., 2012) which, in Kangai, were compounded by particularly troublesome pests including highly damaging IAS, resulting in this strategy becoming a potentially risky livelihood option. Various support structures were identified in Kangai including the co-operative which plays a strong role for members, in addition to extension agents and agro-dealers who advise farmers on pest issues. All of these support groups are identified as important links for any future interventions.

In the case of maize production, on average over a series of crop growing seasons, farmers experience continuous low to medium level losses from a range of pests which exert a burden on farming activities. However, in any one-year, individual farmers may lose their entire crop through the impact of one highly damaging pest. The recent arrival of MLND which is difficult to control and is spreading throughout Kenya presents a significant threat to production. Total maize losses to this pathogen in Kenya have been estimated at 0.5 million tons per year with an estimated value of US$180 million, with further spread expected to increase losses (De Groote et al., 2016). Furthermore, if farmers manage to store maize, treatment with a chemical pesticide was reported as essential, or they risk losing stored grain to the larger grain borer, P. truncatus. Cultural control and sanitary measures such as good store hygiene and integrated pest management are also highly important in managing the threat caused by this pest. This is important in the context of maize as a subsistence crop. Farmers with limited resources may grow solely maize, or maize with only a few other crops, for subsistence (and potentially sale in the case of any surplus); however, the losses caused by these pests can result in these smallholders losing any extra potential income and place families at risk of food insecurity.

Banana was important in the study area and was highlighted by some farmers as a good investment crop with high potential if better markets were created. However, Black Sigatoka
(M. fijensis) could significantly impact on the potential of banana as a cash crop. The disease is a major constraint to banana production where it occurs and worryingly can reach epidemic levels in just a few years (CABI Invasive Species Compendium, 2017).

Tomato was grown by 44% of farmers in this study and is considered a high value crop. Indeed, 71.6% of respondents in another study in Mwea West reported tomato as the most important income generating crop in the area (Mwangi et al., 2015). In our study farmers reported significant average losses to pests, in particular, with the recent arrival of T. absoluta, which threatens all tomato production in the area. All of the respondents who reported being affected by this pest regularly use chemical pesticides stating that without spraying they would lose most of, if not their entire crop. T. absoluta spreads extremely rapidly, with outbreaks likely to increase the economic, environmental and health costs of farming, with more neurotoxic insecticide use likely for those who can afford it. This finding is consistent with other studies where tomato farmers demonstrate an over-reliance on synthetic pesticides (Ochilo et al., 2019). Farmers in Kangai clearly demonstrate the severe farm level impact of T. absoluta in accordance with the literature. For example, in recently invaded areas, losses of 80–100% have been found and without control losses of 100% can be expected (Desneux et al., 2010; Retta & Berhe, 2015; Urbanija et al., 2012; Zekeya et al., 2017). In addition, farmers are already refraining from growing tomato due to this pest in Kangai. This has also been found elsewhere, for example, Brévaut et al. (2014) report that “four out of nine fields in Senegal were abandoned by growers as a result of T. absoluta crop damage”. Growing high value crops is promoted as a way of improving livelihoods, however this potential opportunity is being undermined by pests in Kangai. This is supported by the findings of Ochilo et al. (2019) who found tomato growing in Kenya is highly constrained by a range of biotic constraints, of which migratory pests, such as T. absoluta are having a serious impact. In addition, in the survey area, farmers are experiencing significant marketing problems. Thus, growing tomato is proving to be highly risky with farmers confronted not only by severe pest problems but also receiving a lower than anticipated price for any remaining produce, which after initial investment doesn’t contribute significantly to improved livelihood outcomes.

In addition to pests and pathogens, weeds were also abundant in the study area resulting in the need for repetitive weeding, with invasive weeds exacerbating this problem. Overall, weeds result in a heavy burden on farmers who recognised that without weeding they would experience high or even total yield losses. This increasing weeding need places a burden on family members highlighted in this study by the fact that more females identified hand weeding within the top three constraints. It is reported that for smallholders in Kenya on average, family provides twenty times more labour than hired workers (Rapsomanikis, 2015), but particularly women and children, who are more likely to be involved in this activity (Beyene et al., 2013). The results from the analysis of constraints indicated that women view weeding as a greater problem than men, which is likely due to the fact that in general they are involved more in this task. There are also education ramifications for school age children who may be taken out of school to help with increasing weeding requirements. A national estimate of the current value of time invested by smallholders in weeding parthenium in maize in Kenya at a basic labour rate is given as US $1.5 million per annum (and likely to increase with further spread) (Pratt et al., 2017). Additional impacts include health implications linked to weeds such as parthenium (which if touched can cause severe allergic reactions in humans and livestock) and, in extreme cases, has resulted in yield losses of more than 75% and farmer land abandonment in Ethiopia (Boy & Witt, 2013). Importantly, many weeds also harbour pests and pathogens. All farmers keeping livestock adhered to zero grazing, whereby fodder is collected, in most instances by women, and brought to the farm. This is a likely route of spread for weeds in the region, since much fodder collection took place on the roadsides where weeds were abundant. Movement of IAS in fodder can lead to new outbreaks, as for parthenium in eastern and southern Africa (McConnachie et al., 2011). Importantly, farmers in Kangai identified a number of invasive weed species present that are recognised to have serious biodiversity and livelihood impacts including P. hysterophorus, A. conyzoides, D. stramonium, X. strumarium, L.camara, T.diversifolia and M.pigra (Witt et al., 2018). Thus, farmers in Kangai demonstrate high vulnerability to weeds, of which invasive weeds form asignificant, and likely increasing, component.
Not all farmers had resources available to invest in controls; furthermore, control options for pathogens are often limited. For example, achieving adequate vector control may not be feasible and a lack in availability or affordability of resistant varieties may be limiting. In addition, the costs of chemical pesticides for resource-poor farmers are sometimes prohibitively high, particularly if repeated application is necessary, with the same true for herbicides. These challenges come alongside the detrimental effects of chemical pesticides on natural enemies and also the potential effects on the health of those applying them if protective equipment is lacking (Damalas & Elefterohorinos, 2011), with any yield savings achieved likely to be offset to a degree by the broader costs and associated issues (Pratt et al., 2017; Wise et al., 2007). In general, the reported yield losses to various pests varied broadly by farm and by pest species, but a clear message was that the suite of pests attacking or competing with various crops negatively affected total farm income, and importantly net income, no matter how many cash crops were grown. When farmers grew just one crop, yield loss was likely the primary factor reducing net income below a break-even point as control costs were low/negligible. Most noticeable was that farms only became profitable in cases where maize plus two or more cash crops were grown.

This study emphasises the substantial impact pests are having on smallholders in Kangai. Pests are threatening essential subsistence crops as well as the viability of cash crop growing initiatives that some farmers undertake in an attempt to improve their livelihoods and food security. Considering the already high proportion of IAS in existing pest complexes farmers are highly vulnerable to the likelihood of increased spread and establishment of new IAS, with climate change exacerbating the problem (Kroschel et al., 2014). Poignantly, since this study fall armyworm (Spodoptera frugiperda) (FAW) has arrived in East Africa (in early 2017) with serious implications for maize production and food security (Day et al., 2017; Kumela et al., 2019). In Kenya, Kumela et al. report 97% of farmers surveyed encountered FAW damage on their farms with estimated maize infestation ranging from 38% to 53.9% (average 47.3%) and estimated maize yield reductions of 1381 kg/ha. Although farmers reported applying various control methods including chemical pesticides and traditional control methods, the farmer were perceived by 60% of farmers as ineffective (Kumela et al., 2019).

6. Conclusions
This case study provides an example, for a typical farming community, of the range of pest issues present. Understanding farm level pest risk is essential to support the setting of national agricultural priorities for investment in pest management that would assist smallholder farmers in improving their agricultural productivity. Unfortunately, countries with low GDP generally lack the resources and institutional support to instigate measures needed to help farmers with existing pest problems, or to prevent incursion or contain new IAS; measures for the latter including early warning systems and border controls (Early et al., 2016). Thus, there is an urgent need for additional support to assist smallholders in pest management to improve their livelihoods. Furthermore, support must engage stakeholders at all levels in order to tackle the growing impact of IAS on food security.

Acknowledgements
We gratefully acknowledge the Action on Invasives (AoI) programme for supporting this study. We also gratefully acknowledge the farmers of Kangai, Mwea West for their time and willingness to participate in the study and the Mtoaini Co-operative Board for their time and assistance during the surveys. The authors are grateful to CABI Africa colleagues for support prior, during and post surveys and for the time of the Mwea West Plantwise plant doctor Jacob Ndingu. Sincere thanks to Julius Olumeh for assistance conducting the surveys, and to Professor Jayalaxshmi Misty (Royal Holloway University of London) for review of the manuscript.

Funding
Preparation of this paper was partially funded by the CABI Action on Invasives Programme see https://www.invasive-species.org/actions/action-on-invasives/ and CABI Development Fund, which is supported by contributions from the Australian Centre for International Agricultural Research, the Netherlands’ Directorate-General for International Cooperation, the UK’s Foreign, Commonwealth & Development Office, and others all of which we gratefully acknowledge. CABI is an international intergovernmental organization, and gratefully acknowledges the core financial support from our member countries (and lead organisations) including the United Kingdom (Foreign, Commonwealth & Development Office), China (Chinese Ministry of Agriculture and Rural Affairs), Australia (Australian Centre for International Agricultural Research), Canada (Agriculture and Agri-Food Canada), Netherlands (Directorate-General for International Cooperation), and Switzerland (Swiss Agency for Development and Cooperation). See http://www.cabi.org/about-cabi/who-we-work-with/key-donors/for full details.
Author details
Kate L. Constantine¹
E-mail: k.constantine@cabi.org
ORCID ID: http://orcid.org/0000-0001-9053-3537
Seán T. Murphy¹
E-mail: s.murphy@cabi.org
ORCID ID: http://orcid.org/0000-0001-5977-7840
Corin F. Pratt¹
E-mail: c.pratt@cabi.org
ORCID ID: http://orcid.org/0000-0001-8070-7302
¹ CABI, Bokehame Lane, Surrey, TW20 9YX, UK.

Correction
This article has been republished with minor changes. These changes do not impact the academic content of the article.

Citation information
Cite this article as: The interaction between pests, mixed-maize crop production and food security: a case study of smallholder farmers in Mwea West, Kenya, Kate L. Constantine, Seán T. Murphy & Corin F. Pratt, Cogent Food & Agriculture (2021), 6: 1857099.

References
Abate, T., van Huis, A., & Ampono, J. K. O. (2000). Pest management strategies in traditional agriculture: An African perspective. Annual Review Entomology, 45(1), 631–659. https://doi.org/10.1146/annurev.ento.45.1.631
Adesina, A. A., Johnson, D. E., & Heinich, E. A. (1996). Rice pests in the ivory coast; West Africa: Farmers' perceptions and management strategies. International Journal of Pest Management, 40(4), 293–299. https://doi.org/10.1080/09670879.09317902
Bart, D. (2010). Using weed control knowledge from obtaining agricultural communities in invasive-species management. Human Ecology, 38(1), 77–85. https://doi.org/10.1007/s10745-009-9293-7
Beyene, H., Gebrehiwot, L., Nigatu, L., Zewdie, K., Regassa, S., Tadesse, B., Dejen, A. and Mersie, W. (2013). Impacts of Parthenium (Parthenium hysterophorus) on the life of Ethiopian Farmers. ETH Journal of Weed Management, 6, 1–14.
BioNET-EAFRINET, Keys and Fact Sheets. (2011). Bionet. Accessed 26 April 2019, from https://keys.lucidcentral.org/keys/v3/earfinet/index.htm
Boy, G., & Witt, A. (2013). Chaper One: Confronting the Problem. Alien invaders and their impacts. In Invasive alien plants and their management in Africa (pp. 17–46). UNEP/GEF Removing Barriers to Invasive Plant Management Project, International Coordination Unit, CABI Africa.
Brévart, T., Sylla, S., Diatte, M., Bermados, G., & Diarra, K. (2016). Tuta absoluta Meyrick (Lepidoptera: Gelechiidae): A New Threat to Tomato Production in Sub-Saharan Africa. African Entomology, 22(2), 441–444. https://doi.org/10.4001/003.022.0202
CABI Crop Protection Compendium. (2017). CABI. Accessed 28 April 2016, from http://www.cABI.org/cpc/
CABI Invasive Species Compendium. (2017). CABI.
Damolas, C. A., & Eleftherohorinos, I. G. (2011). Pesticide Exposure, Safety Issues, and Risk Assessment Indicators. International Journal of Environmental Research and Public Health, 8(5), 1402–1419. https://doi.org/10.3390/ijerph8051402
Dey, R., Abrahams, P., Bateman, M., Beale, T., Clotey, V., Cock, M., Colmenero, Y., Corniani, N., Early, R., Godwin, J., Gomez, J., Gonzalez Moreno, P., Murphy, S. T., Oppong-Mensah, B., Phiri, N., Pratt, P., Silvestri, S., & Witt, A. (2017). Fall armyworm: Impacts and Implications for Africa. Outlooks on Pest Management, 28(5), 196–201. https://doi.org/10.1564/v28_oct_02
De Grooto, H., Olof, F., Tonguksawottana, S., & Dos, B. (2011). Community-survey based assessment of the geographic distribution and impact of maize lethal necrosis (MLN) disease in Kenya. Crop Protection, 82, 30–35. https://doi.org/10.1016/j.cropro.2015.12.003
Desneux, N., Wojcieszek, E., Wyckhuys, K. A. G., Burgio, G., Arpalo, S., Narváez-Vasquez, C. A., González-Cabrera, J., Catalán Ruescas, D., Tabone, E., Frandon, J., Pizzol, J., Poncet, C., Caballo, T., & Urbaneja, A. (2010). Biological invasion of European tomato crops by Tuta absoluta: Ecology, geographic expansion and prospects for biological control. Journal of Pest Science, 83(3), 197–215. https://doi.org/10.1007/s10340-010-0321-6
Dixon, J., Gulliver, A., & Gibbon, D. (2001). Hunger, poverty and agriculture. In M. Hall, (Ed.), Farming Systems and Poverty, Improving Farmers' Livelihoods in a Changing World. FAO. http://www.fao.org/3/Y1860E/y1860e00.htm#TopOfPage
Dooley, K. E. (2007). Viewing agricultural research through a qualitative lens. Journal of Agricultural Education, 48(4), 32–42. https://doi.org/10.5032/jeoe.2007.04032
Early, R., Bradley, B. A., Dukes, J. S., Lawler, J. J., Olden, J. D., Blumenthal, D. M., Gonzalez, P., Grosholz, E. D., Ibáñez, J., Miller, L. P., Sorte, C. J. B., & Tatem, A. J. (2016). Global threats from invasive alien species in the twenty-first century and national response capacities. Nature Communications, 7(1), 12485. https://doi.org/10.1038/ncomms12485
East African Plants, A photo guide. (2011). Senckenberg. Accessed 28 October 2018, from http://www.eastafricanplants.senckenberg.de/root/index.php?page_id=47&id=5779
English, P., Joffe, S., & Okello, J. (2004). Exporting out of Africa: Kenya's horticulture success story. Scaling up poverty reduction: A global learning process Conference. Shanghai, May 25 – 27,2004. http://info.worldbank.org/eftools/docs/reducingpovertycase/120fullcase/KenyahorticultureFullCase.pdf
FAO. (2014). Food and Agriculture Organization, Country Programming Framework for Kenya 2014–2017. Faostat. FAO. http://faostat3.fao.org/FAO. (2015). A data portrait of smallholder farmers: An introduction to a dataset on small-scale agriculture. FAO. http://www.fao.org/fileadmin/templates/esa/smallholders/Concept_Smallholder_Dataportrait_web.pdf
Global Invasive Species Database. (2019). ISSG, SSC, IUCN. Accessed 4 February 2019, from http://www.iucngisd.org/gisd/search.php.
Infonet Biovision. (2017). Biovision Foundation. http://www.infonet-biovision.org/PlantHealth/Insects/Cutworms
Kenya Agricultural Research Institute. (2012). Food Security Report. Food Security Portal.Facilitated by IFPRI/supported by the European Commission. Accessed 6 March 2019, from http://www.foodsecurityreport.kenya/food-security-report-prepared-kenya-agricultural-research-institute
Kenya Information Guide. (2015). Kenya County - Kenya. Accessed 28 April 2016, from http://www.kenya-information-guide.com/kenya-county.html
Kipkoech, A. K., Schulthess, F., Yabonn, W. K., Maritim, H. K., & Mithofe, D. (2006). Biological control of cereal stem borers in Kenya: A cost benefit approach. Annales De La Societe Entomologique De France, 42(3–4), 519–528. https://doi.org/10.1080/00379271.2006.10697487
Kirinyaga County Government. (n.d.). About Kirinyaga County. County Government of Kirinyaga. Accessed 28 April 2016, from http://www.kirinyaga.go.ke/about-us/

Kroschel, J., Mujica, N., Corhuapoma, P., Juarez, H., Okonya, J., Le Ru, B., & Hanna, R. (2014). Adaptation to pest risks under future climates in Africa. Lima (Peru), CGIAR Research Program on Roots, Tubers and Bananas (RTB). RTB Workshop Report. Available online at: www.rtb.cgiar.org

Kumela, T., Simiyu, J., Sisoy, B., Likhaya, P., Mendesil, E., Gohole, L., & Tefera, T. (2019). Farmers’ knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (Spodoptera frugiperda) in Ethiopia and Kenya. International Journal of Pest Management, 65(1), 1–9. https://doi.org/10.1080/09670874.2017.1423129

McConnochie, A. J., Strathe, L. W., Mersie, W., Gebrehiwot, L., Zewdie, K., Aburehim, A., Abrha, B., ARAYA, T., ASAREGWEW, F., ASSEFA, F., GEBRE-TSADIK, R., NIGATU, L., TADESSE, B., & TANA, T. (2011). Current and potential geographical distribution of the invasive plant Parthenium hysterophorus (Asteraceae) in eastern and southern Africa. Weed Research, 51(1), 71–84. https://doi.org/10.1111/j.1365-3180.2010.00820.x

Midega, C. A. O., Nyang’au, I. M., Pitchar, J., Birkett, M. A., Pickett, J. A., Borges, M., & Khan, Z. R. (2012). Farmers’ perceptions of cotton pests and their management in western Kenya. Crop Protection, 42, 193–201. https://doi.org/10.1016/j.cropro.2012.07.010

Mwangi, M. W., Kimenu, J. W., Narla, R. D., Kariuki, G. M., & Muiru, W. M. (2015). Tomato Management Practices and Diseases Occurrence in Mwea West Sub County. Journal of Natural Sciences Research, 5(20), 119–124. https://www.ijste.org/Journals/index.php/JNSR/article/view/26816/28097

National Irrigation Board. (2016). Mwea Irrigation Scheme. National Irrigation Authority. Accessed 28 April 2016, from https://www.nib.or.ke/projects/public-irrigation-schemes/mwea-irrigation-scheme

Ngugi, E. (2013). Exploring Kenya's Inequality, Pulling Apart or Pooling Together? Kirinyaga County. KNBS and SID. https://www.knbs.or.ke/download/kirinyaga-county-pdf/https://inequalities.sidint.net/kenya/wp-content/uploads/sites/3/2013/10/SID%20Abridged%20small%20Version%20final%20Download%20Report.pdf

Ochilo, W. N., Nyamasyo, G. N., Kilalo, D., Otieno, W., Otipa, M., Chege, F., Karanja, T., & Lingeera, E. K. (2019). Characteristics and production constraints of smallholder tomato production in Kenya. Scientific African, 2, e00014. https://doi.org/10.1016/j.scafr.2018.e00014

Oerke, E.-C. (2006). Crop losses to pests. The Journal of Agricultural Science, 144(1), 31. https://doi.org/10.1017/S0021869005005708

Paini, D. R., Sheppard, A. W., Cook, D. C., Barro, P. J. D., Worner, S. P., & Thomas, M. B. (2016). Global threat to agriculture from invasive species. PNAS, 113(27), 7575–7579. https://doi.org/10.1073/pnas.1602051113

Perrings, C. (2000). The Socioeconomic links between Invasive Alien Species and Poverty. Report to the Global Invasive Species Program. GISP. http://www.gisp.org/publications/reports/index.asp

Pratt, C. F., Constantine, K. L., & Murphy, S. T. (2017). Economic impacts of invasive alien species on African smallholder livelihoods. Global Food Security, 14, 31-37. https://doi.org/10.1016/j.gfs.2017.01.011

QGIS. (2020). QGIS Geographic Information System. QGIS Association. http://www.qgis.org

R Core Team. (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing.Vienna, Austria; R Foundation. https://www.r-project.org/

Rapsomanikis, G. (2015). The economic lives of smallholder farmers: An analysis based on household data from nine countries. FAO. http://www.fao.org/3/a-i5251e.pdf

Retto, A. N., & Behe, D. H. (2015). Tomato leaf miner – Tuta absoluta (Meyrick), a devastating pest of tomatoes in the highlands of Northern Ethiopia: A call for attention and action. Research Journal of Agriculture and Environmental Management, 4(6), 264–269. Available online at http://www.apexjournal.org

Salami, A., Kamara, A. B., & Brixiova, Z. (2010). Smallholder Agriculture in East Africa: Trends, Constraints, and Opportunities. Working Paper No.105 African Development Bank Group. https://doi.org/10.1111/j.1367-937X.2007.00447.x

Sundaram, B., Krishnan, S., Hiremath, A., Ankila, J., & Joseph, G. (2012). Ecology and Impacts of the Invasive Species, Lantana camara, in a Social-Ecological System in South India: Perspectives from Local Knowledge. Human Ecology, 40(6), 931–942. https://doi.org/10.1007/s10745-012-9435-0

Tschirley, D., Ichoaumbo, M., Ayieko, M., Cairns, J., Kelly, V., & Mwiingo, M. (2012). Fresh Produce Production and Marketing Systems in East and Southern Africa: A Comparative Assessment. Gates Foundation. http://sgf.ofte.msu.edu/gis/ama/GatesHort_V0.pdf

Urbaneja, A., Gon Azel-Cabrera, J., Ar, O. J., & Gabarro, R. (2012). Prospects for the biological control of Tuta absoluta in tomatoes of the Mediterranean basin. Pest Management Science, 68(9), 1215–1222. https://doi.org/10.1002/ps.3344

Wise, R., Wilgen Van, B., Hill, M., Schulthess, F., Tweddel, D., Chabi-Olay, A., & Zimmermann, H. (2007). The economic impact and appropriate management of selected invasive alien species on the African continent. Global Invasive Species Programme. CSIR. Accessed 8 June 2015, from http://issg.org/pdf/publications/GISP/Resources/CSIRAIManagement.pdf

Witt, A., Beete, T., & van Wilgen, B. W. (2018). An assessment of the distribution and potential ecological impacts of invasive alien plant species in eastern Africa. Transactions of the Royal Society of South Africa, 73(3), 217–236. https://doi.org/10.1080/0035919X.2018.1529003

Zekeya, N., Chacho, M., Ndakidemi, P., Materu, C., Chidege, M., & Mbega, E. (2017). Tomato Leafminer (Tuta absoluta Meyrick 1917): A Threat to Tomato Production in Africa. Journal of Agriculture and Ecology Research International, 10(1), 1–10. https://doi.org/10.9734/jaeri/2017/22886
