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Analysing the potential of plant clinics to boost crop protection in Rwanda through adoption of IPM: the case of maize and maize stem borers

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Abstract

Maize plays an important role in the livelihoods of rural communities in Rwanda. However, maize yields are threatened by the presence of pests and diseases and a general lack of knowledge and information for their management. In this study we sought to assess if plant clinics are making farmers more aware and knowledgeable of pests and diseases and are indirectly contributing to higher yields. We interviewed 644 farmers across Rwanda, both users and non-users of plant clinics. Propensity score matching was used to match the users and non-users of plant clinics and logistic regression was used to assess a number of factors, including interactions with plant clinics, that affect farmers' adoption of pest management practices. Our analysis shows that users of plant clinics are more aware and knowledgeable in recognizing and handling maize stem borers. Furthermore, users of plant clinics have on average higher yields than non-users and this difference is highly significant ($P < 0.001$). The analysis therefore demonstrates that plant clinics are beneficial to farmers in Rwanda. However, efforts are required to diversify the spectrum of practices that are promoted by plant clinics and by extension and advisory services in Rwanda.

Keywords Plant clinics · Maize · Pests · Awareness · Adoption · Productivity · Gender

1 Introduction

Crop pests and diseases are common and important threats to the livelihoods of farmers in sub-Saharan Africa (Geddes 1990; Rweyemamu et al. 2006), where farmers live mainly on subsistence agriculture (Thornton et al. 2008, 2010). In Rwanda over 90% of the population live in rural areas and survive on subsistence agriculture: therefore, any crop loss, including those caused by pests and diseases, can have devastating effects on their livelihoods.

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Farmers need to be provided with options to address pest and disease outbreaks that are context-specific to their agricultural conditions and socioeconomic circumstances (Danielsen et al. 2013). Extension and advisory services can play important roles in supporting farmers to address the threats of pests and diseases and therefore enhancing productivity and food security. Conventional extension approaches often fail to reach and address the diverse needs of resource-poor farmers (Danielsen and Matsiko 2016). This is mainly because these approaches tend to be biased towards specific crops and areas and are not flexible enough to support farmers who have to cope with the unpredictable changes and emerging challenges faced by the wide range of crops they grow (Danielsen and Matsiko 2016).

The idea of plant clinics was developed in the early 2000s by the Global Plant Clinic Alliance. The approach promoted by plant clinics was first started in Bolivia in 2003 (Bentley et al. 2007, 2009; Boa 2010; Danielsen and Kelly 2010) and later expanded to other countries, at different rates and in different ways. Plant clinics in Rwanda were first piloted in 2011 (Majuga et al. 2018).

Plant clinics, a relatively new extension method, try to respond to farmers' demands for technical advice to solve plant health problems (Danielsen et al. 2013; Boa et al. 2016).

They are managed by extension agents, called plant doctors, and are usually organized in proximity to farmer-friendly public spaces, such as markets. Plant doctors give advice and recommendations to farmers based on field diagnosis and available information. They face the challenge of having to address multiple crops and plant health problems that farmers present. Plant doctors often make several recommendations for a single problem, which is consistent with integrated pest management (IPM) (Ehler 2006; Bentley et al. 2018).

Because plant clinics vary in how they operate and the services they offer (Boa et al. 2016), a brief description of them in Rwanda is provided below.

Plant clinics are run by plant doctors from Local Government and the Rwandan Agricultural Board (RAB) (Majuga et al. 2018). Every plant clinic operates at a market place twice a month. The responsibilities of plant clinics in Rwanda include: i) identification of the causes of plant health problems and prescription of management options; ii) field visits and inspection of pest and disease problems, advice and guidance to farmers for the management of plant health problems.

In Rwanda (between November 2015 and November 2016) there were 61 plant clinics that received in total 870 queries from farmers related to beans, Irish potatoes and maize. About 470 queries were related to maize.

The expectation of the plant clinic approach is that farmers and their households will benefit in terms of changes in knowledge and management of pests and diseases, and improved livelihoods. Assessing farm level impact of plant clinics requires a variety of methods, approaches and designs to assess changes, direct and indirect, expected and unexpected, that contribute to farm-level and other improvements. Studies have been conducted to establish outcomes for plant clinics in Bolivia (Bentley et al. 2009), Bangladesh (Rajendran and Islam 2017), Uganda (Brubaker et al. 2013), Kenya (AIR 2015) and Rwanda (Nsabimana et al. 2015). The majority of these studies showcase increased harvest for plant clinic users and behavioural change among farmers.

Yet, in countries such as India and the USA where plant clinics were established long ago, limited information is available on the evaluation of plant clinics on increasing food productivity. Therefore, a more formal and comprehensive quantifying of plant clinics would be beneficial to establishing the extent to which this extension service leads to changes in knowledge and practices for pest and disease management and ultimately to food security and livelihood improvement (Srivastava 2013).

This study sought to assess the impact of plant clinics in improving farmers' knowledge and adoption of integrated pest management practices (IPM) in Rwanda, in particular for maize stalk borer (MSB), *Busseola fusca* (Fuller). In doing so, the study examines the extent to which plant clinics are making farmers more knowledgeable of pests and diseases,

and are promoting adoption of integrated pest management (IPM) practices, that favour higher maize yield.

It is hoped that the results from this study will provide an incentive for promotion and out-scaling of plant clinics as a model of extension for other countries.

2 Analytical methods

2.1 Sampling strategy and survey implementation

A quasi-experimental approach was used for this study. This approach allowed controlling for selection bias as farmers were not randomly assigned to treatment (where by 'treatment' we mean farmers visiting and therefore using plant clinics) and control (where by 'control' we mean farmers not visiting and therefore not using plant clinics). Furthermore, because of costs constraint, it was not feasible to implement randomized control trials (RCT), as previously done in other studies (AIR 2015).

Plant clinic data were obtained from the Plantwise Knowledge Bank, which is a repository for plant health information. The data were analysed for the prevalence of crops and problems presented and the types of recommendations given. This indicated that maize was the most frequent crop brought to plant clinics. The distribution of the farmers that attended the plant clinics and brought maize damaged by stalk borer guided site selection. At the time when the survey was implemented there were no queries recorded on fall armyworm, *Spodoptera frugiperda* (Smith) at the plant clinics or, more broadly, at the national level in Rwanda. Maize and maize stalk borer (MSB) were chosen because of the occurrences in the study, and because maize is a priority staple crop in Rwanda (Wanda et al. 2002; Macauley and Ramadjita 2015).

Data for this study were collected from 13 districts and 14 sectors spanning 4 agro-ecological zones (AEZ): Cone and High Volcanic Plains, Buberuka Highlands, Congo Nile Watershed Divide and Central Plateau. Study sites were selected across four different AEZs of Rwanda. A summary of the characteristics of the AEZs and the number of farmers interviewed after propensity score matching (PSM) (Rosenbaum and Rubin 1983) is presented in Table 1.

A sample of 644 farmers was interviewed, out of which 260 were users of plant clinics (hereafter 'users') and 384 were non-users of plant clinics (hereafter 'non-users').

The variables used to select clinic users sites were also used to select non-user sites. The control group was as similar as possible to the treatment group in terms of socio-economic (pre-intervention) characteristics. Characteristics considered were: i) similarity of agro-ecological zone, a necessary condition because elements such as soil, temperature and rainfall are important drivers of production; ii) similarity of crops

Table 1 AEZs where the survey took place and number of household per AEZ

Agro-ecological zone	Number of HHs[a]	
	Users	Non-users
The Cone and High Volcanic Plain	48	56
The average altitude is 2200 m, and the average rainfall is about 1500 mm. Average temperature is 17 °C. The main crops are potatoes, wheat, peas, maize, common beans.		
Buberuka Highlands	21	21
The average altitude is 2000 m, and the average rainfall is about 1200 mm. Average temperature is 16 °C. The main crops are potatoes, maize, common beans, wheat and peas. The main cash crop is tea.		
Congo Nile Watershed Divide	27	15
The altitude varies between 1900 and 2200 m. Annual rainfall ranges between 1400 and 1500 mm. The minimum temperature is 14 °C and the maximum temperature is 30 °C. The main crops are common beans, maize, sweet potatoes, sorghum and peas. Common cash crops are tea, banana and coffee.		
Central Plateau	119	123
The altitude characterizing this zone ranges between 1500 and 2100 m, annual rainfall between 1000 and 1600 mm that increases with altitude. The average temperature is about 19 °C with minimum of 10 °C and maximum of 30 °C.		
Mixed cropping and rotation practices are well known practices in the area. The important crops are cassava, sweet potato, banana, bean, sorghum, maize. Coffee is the main cash crop.		
TOTAL	**215**	**215**

[a] This only includes households that were kept in the analysis after PSM

grown; iii) similarity of pests and diseases; iv) absence of spill-over effect into the non-clinic user area.

The proportion between users and non-users was approximately 1:1.5 with more control respondents to ensure that a matched group could be created. From a gender perspective, 351 interviews were conducted with male farmers and 293 with female farmers.

The household survey was conducted in May 2017, in line with the cropping season and included information about: household size and composition; household assets; maize yield; agricultural inputs (use and barriers to use) and labour use for cropping; interventions for pest management; sources of information for pests and diseases; market; reasons for crop failure; access to credit. Farmers were asked also about practices dismissed and introduced during the last two cropping seasons before survey implementation. Data collection was done by trained local enumerators, through face to face interviews conducted using tablets with the questionnaire inbuilt using Open Data Kit (ODK) technology (Hartung et al. 2010).

2.2 Data analysis

Propensity score matching (PSM) technique was applied to enable a valid comparison group and reduce the risk of bias. PSM is a statistical matching technique that enables selection of users and non-users of plant clinics with similar characteristics. In this study, PSM allowed comparison of users and non-users with respect to the use of IPM and yields of maize. PSM reduces the possibility that the observed differences in the outcomes between the two groups of interest may be due to an imperfect match rather than caused by the intervention

(Adelson 2013; Rudner and Peyton 2006; Stone and Tang 2013).

PSM was done in R (R Core Team 2016) using the MatchIt package (Ho et al. 2011) with nearest-neighbour 1-to-1 matching and a calliper of 0.16. In its simplest form, 1:1 nearest neighbor matching selects for each treated individual i the control individual with the smallest distance from individual i (Stuart 2010). A calliper is the maximum tolerated standard deviation between matched subjects. Several matching methods were fitted but the nearest neighbour technique was found to be the best, giving standardized mean difference of variables much below 0.1.

The following set of variables was used in the PSM and model fitting: importance of on-farming activities for the household; total household members; household members above 15 years (this is a proxy for household labour supply, considering the threshold of 15 as the minimal working age, ILO 2004); gender of the respondent; age of the respondent; level of education of the respondent; total land cultivated with maize; young dependent ratio (given by the ratio of dependents aged 14 years and below to total household size).

This yielded a final number of 430 households considered in the analysis, out of which 215 were users (of plant clinics) and 215 were non-users (of plant clinics).

Data analysis was conducted using both descriptive and inferential statistics. Data were analysed using the R statistical package. Inferential statistics were used such as t-test, non-parametric (chi-squared) test, Wilcoxon rank sum test with continuity correction, and logistic regression. This helped ascertain the level of significance of difference for selected parameters, between users and non-users and across gender categories.

2.3 Indicators of impact

The primary objective of any extension approach is to influence farmer learning in such a way that it influences positive change in farming practices and application of technologies. We evaluated the efficacy of the extension service provided by plant clinics through the application of the awareness, knowledge, adoption, productivity (AKAP) sequence (Evenson 1996).

Awareness and knowledge In this study *awareness* and *knowledge* are bundled and are measured in terms of capacity of farmers to recognize symptoms of MSB presence. Farmers were shown 12 pictures of maize plants affected by MSB and were asked whether they thought these pictures indicated the presence of a pest in the maize plant. Awareness of the presence of a problem, is a necessary, although not sufficient, prerequisite for adoption, together with the knowledge of alternatives, the motivation for change and the resources to implement change (Hatfield and Karlen 1994).

Adoption *Adoption* was measured by how many suitable practices for pest management the farmers implemented. An implicit hypothesis is that users of plant clinics have access to a greater array of information about interventions options than the non-users of plant clinics; in turn this would, on average, lead to a greater amount of pest management practices in place.

Productivity *Productivity* was measured in terms of yield of maize per hectare (ha). An implicit hypothesis is that users of plant clinics would on average have a greater knowledge of the practices to implement. This would help them to prevent/contain the impact of MSB in their maize fields and therefore preserve yields.

2.4 Analysis of determinants of adoption

A logistic regression was used to analyse the factors influencing farmers' adoption of pest management practices for MSB. This allowed analysis of what set of determinants could influence adoption, besides plant clinics. The data analysis followed four steps:

2.4.1 Definition of categories for pest management practices

The first step was the aggregation of pest management practices for MSB into eight main categories. Practices were aggregated according to their purpose. Table 2 shows the categories, the corresponding pest management practices and explains the selection of the categories.

The adoption of each of the categories of technique was measured as a binary variable, with 1 meaning that at least one practice within each category was adopted and 0 meaning that none of the practices within a specific category was adopted.

2.4.2 Selection of adoption determinants

The second step was to select drivers of adoption for the eight categories of pest management practices. These determinants of adoption were later tested for heterogeneity and multicollinearity for inclusion in the model. The selected variables were classified into three main categories namely:

a) social and environmental characteristics, including: gender and age of the respondent; household size; level of education; labour surplus, deficiency and balance; shocks.
b) economic factors, including: area under maize cultivation; maize yields; net income; costs of inputs; access to credit and other sources of cash; household asset index; inputs received for free.
c) information sources, including only those sources that were used by at least 5 farmers. Information sources were chosen among the following ones: own experience; another household member; neighbours; friends and family; agricultural programmes on the TV; government extension officers; books/flyers/pamphlets; agro-dealers; demonstration plots/field days; farmers promoters; RAB agronomist; NGO; agricultural shows; newspapers/magazines /bulletins; mobile sms and voice services; farmers field school (FFS)/farmers facilitators; plant clinics/plant doctors; women's group.

Labour surplus, deficiency and balance provide an indication of labour availability at household level. This was computed as the ratio of the total land farmed by a household to the number of household members. In determining the number of household members to supply labour, those above the age of 15 were considered. It is assumed that one individual above this age is capable of cultivating 1 ha of land in a season (LNV and Euroconsult 1989). A ratio equal to 1 indicated labour balance: farm labour is enough for the cultivated land. A ratio lower than 1 indicated a labour shortage and a ratio greater than 1 indicated a labour surplus at the household level.

Shocks were defined by different phenomena that can cause crop failure: pests and diseases, excess rain or flooding, drought or insufficient water, hailstorms, crop destroyed by livestock, theft, and sickness of the farmer.

The household asset index was calculated with the simple poverty scorecard that uses low-cost indicators from Rwanda's 2010/11 Integrated Household Living Standards Survey to estimate the likelihood that a household has consumption below a given poverty line (Schreiner 2016).

Table 2 Set of eight pest management practices for Maize Stork Borer Control

Categories	Pest management practices for MSB	Explanation of the selection of the categories
Cultural prevention/avoidance	• Early planting (plant early so the plant is well established when the pest comes, and it has more chance of surviving) • Frequent weeding (*to remove alternative host plants*) • Improve soil fertility - manure or chemical fertilizer (*to stimulate strong plant growth and ability to tolerate pest attack*)	This category includes the first line of defence that might be put in place by farmers to prevent a pest population from infesting a crop or field, together with some cultural practices that can be put in place to avoid the impact of the pest
Cultural planting/cropping patterns	• Intercrop maize with non-host non legume crops such as cassava or others • Intercrop maize with non-host legumes such as cowpea or others • Trap cropping: use a trap plant e.g. Napier grass-Urubingo as a border crop (*to draw/'pull' pest out of maize crop and into this preferential host plant*) • Push-pull: use a trap plant e.g. Napier grass-Urubingo as a border crop (*to draw/'pull' pest out of maize crop and into this preferential host plant*) and intercrop with a repellent plant e.g. legume such as *Desmodium* (*to 'push' repel pest out of the crop area*) (these options work also alone but are more effective together) • Crop rotation - recommended to rotate with non-host plants e.g. legumes, cotton, sunflower, etc. (*to avoid build up of pests*)	These include cultural practices associated with implementation of specific planting and cropping patterns
Cultural resistance/Tolerant varieties	• Plant resistant varieties/tolerant varieties	These resist or tolerate MSB, reducing loss to the pest
Mechanical late stage interventions	• Uproot and burning of infected plants (*to destroy larvae and pupae*) • Plough infected stalks deep into soil (*deeper than 30 cm to kill larvae & prevent adult emergence*) – bury them. The larvae *will not survive and if they pupate (begin to change into adults) then the adult insects will not survive.* • Feeding stubble to livestock (*to destroy larvae and pupae*) • Remove crop residues that are damaged by pests or diseases (*to remove pest from the field and avoid build up in following year*)	These include suppressive type of practices that are implemented on the crops and fields at a late stage of development of the pest, when the damage by the pest has already caused economic losses
Mechanical early stage intervention	• Handpicking young larvae (*needs labour and only effective for early larval stages before larvae enter the stem*) • Early slashing of maize stubble and laying it out on the ground (*exposes the pest larvae or pupae to sun (heat & drying) and/or to predators such as ants/birds*) – cut it down and make it lie on the ground to capture sun that can kill any larvae • Applications of dusts to the leaf e.g. apply fine wood ash (dust) to leaves affected by larvae (before they enter the stem). Ash dust can be mixed with a pinch of dry chilli (*Insecticide and irritant*) • Application of Neem powder – can be mixed (1:1) with dry clay or sawdust – wood dust (natural insecticide and irritants)	These include suppressive type of practices that are implemented on the crops and fields at an early stage of development of the pest, to avoid economic losses
Biological control	• Biological control options - Encouraging natural enemies (predators & parasites) into field by planting their host plants in field boundaries – the plants are the ones that host the predators and parasites. Larvae can be eaten by birds, spiders, ants and killed by parasitic wasps; wasps lays their eggs inside the larvae and when they grow they kill the larvae.	These involve the use of other organisms to suppress MSB
Pesticide	• Application of Pesticides - several different options are available as granules, dusts or sprays	This includes a suppressive type of practice based on use of chemical pesticide
Monitoring	• Monitoring the stem borer (checking for insects) – when the larvae are very young using ash can be effective in killing the pest. Once the larvae are older it is too late for this intervention.	This includes prevention practices that allow checking for presence of the pest on the crops and field.

2.4.3 Assessing the influence of the three categories of determinants on adoption

The influence of the determinants of adoption on the uptake of pest management practices was assessed through a fitted logistic regression. The dependent variables were dummy variables taking the value of 1 if farmer i adopted a determined practice and 0 otherwise. A farmer i chooses a certain adaptation measure if the derived benefits B_i are higher than a certain threshold T (Kabubo-Mariara 2008; Staal et al. 2002):

$Y_i = 1$ if $B_i > AM \rightarrow X_i\beta + \alpha_i > AM$ farmer i decides to adopt

$Y_i = 0$ if $B_i < AM \rightarrow X_i\beta + \alpha_i < AM$ farmer i decides not to adopt

Where X_i is a vector of explanatory variables, β is a vector of coefficients to be estimated and α_i is an independent, farm specific, *ex ante* stock. The model has the form:

$$Y_i = x_i\beta + \alpha_i \tag{1}$$

Where x_i is a vector of explanatory variables derived from the survey, β is the corresponding regression coefficients and α_i are the intercept parameters.

2.4.4 Evaluating potential for adoption of agricultural practices

The last step was to evaluate the potential for adoption of the eight pest management practices for MSB. The likelihood of adoption was derived from the coefficients of the categories, estimated through the logistic model. The probability of adoption of each category of pest management practices was calculated by substituting the β in Eq. (1) by the estimated coefficients in the logistic regressions.

3 Results and discussion

3.1 Sources of information

Farmers in Rwanda access information on pests and diseases from a variety of sources: through personal experience; consultation with peers; plant doctors and other extension officers from the government; and various other sources of information as illustrated in Fig. 1. The most frequent responses were reliance on personal experience and on information sources based on personal relationships, which might include other household members, neighbours, and friends and family, but also reliance on local experts such as trained farmer facilitators, extension officers, agro-dealers, farmers field schools (FFS), RAB agronomists, and plant doctors where available, to mention some.

There are a few information sources that seem to be the prerogative of male farmers and are not used at all by female farmers, such as participation in agricultural shows and use of reading material (such as books, flyers and pamphlets), though both these seem to be rare in any case. Mainly female respondents sought help from household members. There are other sources of information whose access significantly differs between male and female farmers. These include sources such as farmer promoters, NGOs and RAB agronomists who seem to be mainly targeting male rather than female farmers. These results confirm that male farmers have access to a more diversified set of information and, as found in literature, are in general the target of information from these dissemination sources (Kristjanson et al. 2017; Perez et al. 2014; Bryan et al. 2013).

Non-users of plant clinics appear to refer to the same type of information sources as the users of plant clinics, except for the use of plant clinics themselves and the fact that they seem to rely more on own experience and neighbours' advice.

3.2 Indicators of impact

3.2.1 Awareness and knowledge

A pre-requisite for the implementation of a control measure for pest and disease management is the capacity to recognize that the plants present a pest problem. When this happens, a farmer is in the position to detect the presence of a plant pest problem by recognizing one or more signs that the damaged plant displays. This process might not be that straightforward, but if farmers are guided through it, they might be able to recognize it independently and subsequently in the future. We, therefore, measured the capacity of farmers to recognize signs of the presence of a pest such as MSB in their maize plants. We found that although all signs were recognized by both users and non-users of plant clinics but the frequency of recognition by users was greater than non-users, although the difference was not statistically significant (Fig. 2).

3.2.2 Adoption

When farmers recognize that their field of maize presents a pest problem, depending on their motivation, availability of and economic access to resources, etc., they are going to act to restore their field. We measured the number and type of practices for pest management that maize farmers implemented. In Fig. 3 we present the frequencies of adoption of practices for MSB management. Although all practices were implemented by both users and non-users, for most practices higher adoption rates were found for users. Some practices, although with low adoption rate, are the prerogative of users, such as trap cropping. The highest rate of adopters was found for application of pesticide, followed by the removal of damaged crop residues, the handpicking of larvae and the monitoring of stem borers.

Fig. 1 Gender disaggregated
sources of information for pest
and disease management
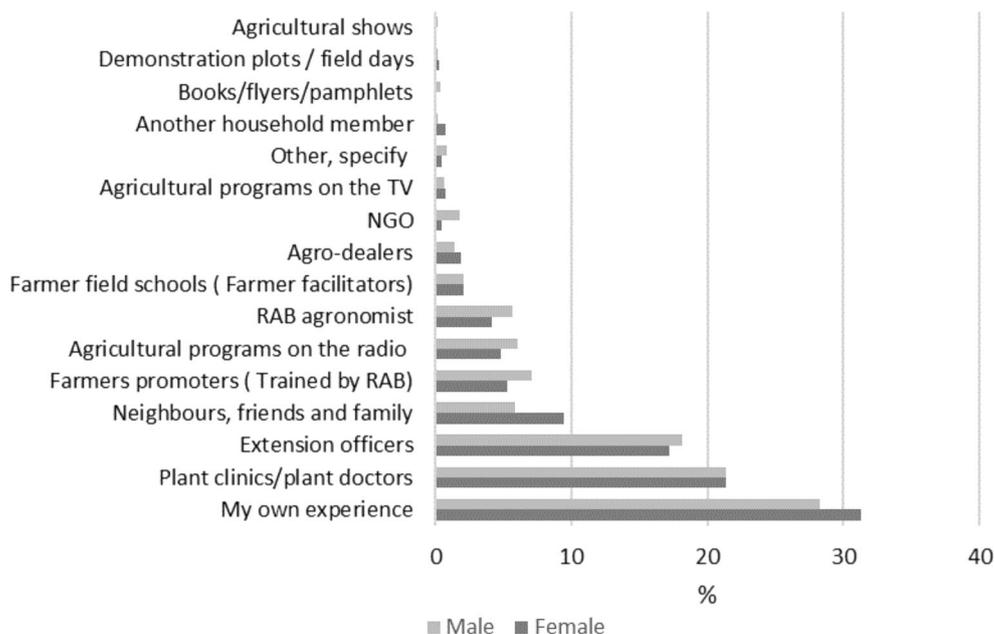
The non-parametric (chi-squared) test shows that significant differences were found for 'application of pesticide' and 're-move crop residues that are damaged', which were more frequently adopted by users. This could be explained by the fact that more users received inputs for free than non-users, in particular fertilizer and pesticide (55 users against 27 non-users). Significantly more non-users than users fed stubble to livestock.

Of the farmers interviewed, 24% non-users and 11% users declared they would like to put in place other interventions, in particular 'improving soil fertility' and 'applying pesticides'. Input availability and costs seem to be the major barriers to adoption for 'improving soil fertility' and pesticide use for non-users. The fact that there were more plant clinics users than non-users using pesticide, could suggest that they were

Fig. 2 Frequencies of farmers
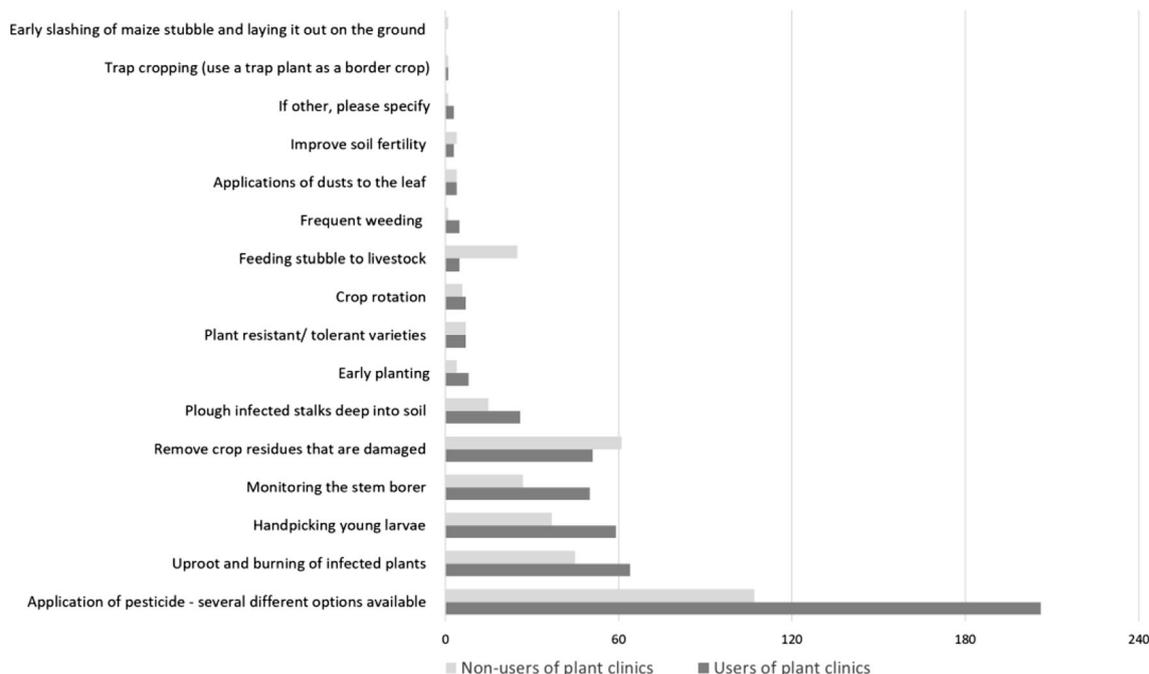who recognized specific signs of
the presence of MSB
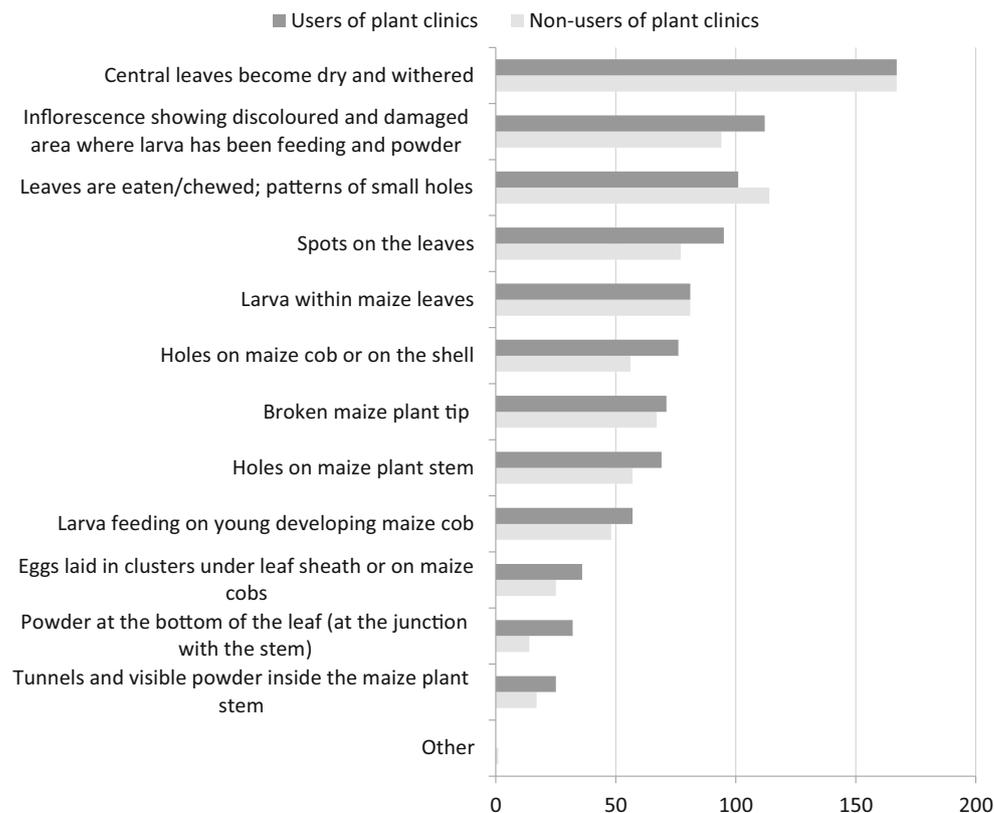
Fig. 3 Frequencies of adopters of practices for management of MSB

better informed about where to obtain inputs and were direct-ed towards purchasing the correct pesticide as well as how to use it. This aspect was also seen in the study of Majuga (2016), who showed that non-users of plant clinics often pur-chased pesticides without consultation, resulting in purchas-ing the wrong product. This has cost implications, and can have a series of other implications such as causing pesticide resistance, permanent yield loss and possible repercussion on human health.

Other studies that looked into barriers to input use (Jama and Pizarro 2008; Kelsey 2013; Nicol et al. 2015) showed that barriers to adoption are on both the supply-side (the price, availability, or lack of information about the inputs), and on the demand-side (farmers that do not buy inputs because of lack of credit, labour, sufficient land, or knowledge of tech-nologies, among other possibilities).

In attributing adoption of interventions to a specific source, one has to ensure that farmer adoption took place after the rec-ommendations became available, and verify that the information utilized by farmers originated in the research and extension pro-gram (CIMMYT 1993). In this study we asked farmers how they learnt about each intervention they put in place. Table 3 shows sources of information and frequencies of adopters.

Removal of crop residues is a practice, which is mainly based on experience that the farmers have gained over time. Information about uprooting and burning were provided in the majority of cases to adopters through extension officers from the government and plant clinics. Farmers learnt through per-sonal experience and plant clinics the importance of handpicking of larvae and monitoring of stem borer attacks.

In order to compare if the advice coming from plant clinics had changed what the farmers decide to do to address plant pest problems, we asked farmers about practices recently in-troduced and dropped. We found that only about 12% of the non-users had introduced new practices, especially applica-tion of pesticides and uprooting and burning. However, about 38% of users had introduced new practices, especially appli-cation of pesticides, handpicking of larvae and uprooting and burning. Users attributed the lack of use of these practices in the past mainly due to lack of knowledge and understanding of how to apply the recommendations and the importance of how to apply pesticides. Non-users mainly attributed the lack of use of these practices to the perception that they had a minor plant pest problem.

In terms of practices dropped, only 1% of the farmers had dropped implementing some practices since 2015.

The government of Rwanda has established an elaborate extension model, called the Twigire Muhinzi. This model runs from the national to the village level where extension staff are deployed. In this extension model, the Rwanda Government has adopted several approaches in order for farmers to access extension services (Kiptot et al. 2013). Considerable attention and priority was also given to the Farmer Field School (FFS) methodology that sees trained farmers become farmer facili-tators or farmer promoters (USAID 2011; MINAGRI 2016). RAB agronomists and extension officers from the government were also very active and conducted training and meetings with farmers, especially at the beginning of the cropping sea-son. Media were also used to disseminate extension technol-ogies through local programmes on television and radio.

Table 3 Sources of information and frequencies of adopters for MSB management practices. The table shows practices adopted by more than 40 farmers and sources that provided information to more than 5 farmers for at least one practice

| | Practices for management of MSB | | | | | | | | | |
| | Application of pesticide | | Remove crop residues | | Uprooting and burning | | Handpicking of larvae | | Monitoring the stem borer | |
Sources of information	Users	Non users	Users	Non users	Users	Non users	Users	Non users	Users	Non users
My own experience	31	40	39	57	4	15	9	10	10	13
Neighbours, friends and family	7	15	2	5	2	10	3	8	1	2
Agricultural programs on the radio	9	7	–	–	4	7	–	–	3	2
Extension officers	64	59	8	6	16	11	25	14	19	6
Agro-dealers /Demo plots/field days	10	9	–	–	1	–	2	2	2	0
Farmers promoters	25	16	–	2	10	7	1	0	9	4
RAB agronomist	16	6	1	–	3	3	4	1	2	2
Farmers field schools – farmers facilitators	11	9	–	1	9	6	–	–	6	6
Plant clinics/plant doctors	193	–	9	0	50	–	37	0	34	0

These contributed to increased information dissemination and chances of adoption among farmers. For those farmers who could access plant clinics, there was an additional chance offered to gather information on pest and disease management, which seems to have boosted the adoption rate in particular for: hand picking of larvae, uprooting and burning, monitoring the stem borer and application of pesticides.

3.2.3 Factors influencing farmers' adoption

Table 4 reports the variables that showed significant impact in influencing the uptake of management options. The following variables were not significant and were not included in Table 4: age, household size, household assets, level of education, and net income. In addition, we did not include in the model the following variables: i) maize yields and cost of inputs (because of simultaneous causality); ii) labour surplus, deficiency and balance (because of multicollinearity).

The management option 'biological control' was not included in the model since it was not adopted by any of the survey participants.

We included these information sources in the model: agricultural programmes on TV and radio; own experience (past experience of pest management practices); extension officers; and plant clinics.

The coefficients of the logistic regressions (Table 4) show that information sources seem to have stronger influence on adoption than the other variables. In particular, 'plant clinics' and 'extension officers' are variables associated with the adoption of all or most practices. Social barriers in terms of information sources have been widely described in the literature to be an important cause of failure in the adoption of practices that do not require a substantial financial investment (Adger et al. 2009; De Jalón et al. 2015). Yet, the role that information and knowledge play in the uptake of recommended practices has been highlighted in various studies (Jabbar et al. 2003; Abebe et al. 2013). The positive high association with 'own experience', as per Table 4, suggest that practices are often implemented as the result of self-acquired knowledge, or may indicate increasing confidence generated through personal experience. The study of Jabbar et al. (2003) would support this, showing that farmers move from learning to adoption, and to continuous and discontinuous use over time. The information gathered, the learning and the experience play pivotal roles in the process of adoption.

The high association between adoption and information sources does not necessarily mean that information sources are the most powerful drivers of adoption. Receiving information might not be a sufficient condition for adoption if farmers are unable to access inputs or do not have the funds to purchase them. Consistent with the literature on technology adoption, we also find that farmers with access to credit are more likely to adopt practices that involve liquidity, such as use of inorganic fertilizer and improved seeds (Bryan et al. 2009; FAO 2016). As shown in previous studies (Keya et al. 2017), we also observed a positive impact of free inputs on adoption, in particular of fertilizer and pesticide, which are provided free of charge to farmers by the government and RAB. Furthermore, our data show that the recipients of free inputs are mainly men (two thirds against one third women), which would also explain the positive relationship between gender and prevention/avoidance practices that foresee the use of fertilizer.

Farmers mentioned that the main reasons behind crop failure were drought and insufficient water (mentioned by 55% of farmers) and pests/diseases (mentioned by 37% of farmers). Other reasons of crop failure were sickness (2%) and crops destroyed by livestock/theft (2%).

Table 4 Estimated coefficients of the logistic regressions assessing adoption of MSB management practices, p-values and odds ratio (OR)

	Cultural prevention/ Avoidance			Cultural planting/ Cropping patterns			Cultural resistance/ Tolerant varieties			Mechanical late stage – intervention			Mechanical early stage – intervention			Pesticide			Monitoring		
		p value	OR		p value	OR		p value	OR		p value	OR		p value	OR		p value	OR		p value	OR
Social and environmental characteristics																					
Gender	1.686	0.091.	1.64	−1.306	0.191	0.63	0.299	0.765	1.10	−0.749	0.454	0.83	0.442	0.659	1.12	0.427	0.640	1.16	−0.614	0.540	0.84
Shocks	−3.392	0.001***	0.55	−0.849	0.396	0.84	−3.738	0.000***	0.49	1.731	0.083.	1.31	−0.353	0.724	0.94	−0.366	0.714	0.93	−0.486	0.627	0.92
Economic factors																					
Maize land	1.024	0.306	2.39	−0.204	0.839	0.76	−0.829	0.407	0.47	1.928	0.054.	5.21	−1.877	0.060.	4.20	2.820	0.005***	0.43	0.978	0.328	0.22
Credit and cash sources	2.143	0.007***	1.72	0.730	0.465	1.30	3.047	0.002***	2.28	−0.557	0.578	0.86	0.124	0.901	1.04	0.929	0.353	1.28	2.137	0.301	1.70
Inputs received	0.327	0.744	1.09	−0.588	0.557	0.85	−0.131	0.896	0.97	−0.083	0.934	0.97	−0.826	0.409	0.80	2.806	0.005***	2.96	0.311	0.756	1.10
Information sources																					
My own experience	4.484	0.000***	1.73	5.405	0.000***	2.13	4.225	0.000***	1.70	3.350	0.001***	1.42	−0.977	0.329	0.91	0.114	0.909	0.99	0.110	0.913	1.01
Plant clinics	1.942	0.052.	1.24	3.557	0.000***	1.47	2.049	0.040*	1.25	2.488	0.013*	1.31	3.034	0.002***	1.32	4.905	0.000***	3.85	4.186	0.000***	1.59
Radio + TV	1.241	0.214	1.22	2.000	0.045*	1.39	1.307	0.191	1.24	−1.721	0.085.	0.78	1.933	0.053.	1.31	0.168	0.867	1.01	1.838	0.066.	1.31
Extension officers	1.942	0.052.	1.64	3.440	0.000***	1.46	4.795	0.040*	1.64	−2.656	0.008***	0.79	3.050	0.002***	1.31	1.912	0.056.	1.28	2.023	0.043*	1.21

***$p < 0.00$; **$p < 0.01$; *$p < 0.05$;. $p < 0.1$

Usually, the most common ex-ante coping strategy for farmers in Africa includes the choice of the crop varieties (e.g. drought tolerant and short term maturing varieties), together with adjustment of cropping patterns and planting dates (Shiferaw et al. 2014). However, our study shows that shocks present a significantly negative effect on adoption of practices such as prevention/avoidance (see Table 4), in particular early planting, or use of resistant/tolerant varieties. These results could be explained by the fact that Rwandan agriculture is mostly rain-fed, and therefore more exposed to weather-related risks, especially to severe, frequent, and prolonged dry spells occurring during the cropping seasons; yet, promotion of drought-resistant crop varieties, together with early warning and agro-meteorological information systems with rapid response mechanisms are part of the relatively recent National Adaptation Program of Action (NAPA 2016) that has been tested in a few areas across Rwanda and should be further extended to target larger areas.

A limitation of this analysis is that the potential for adoption of the seven practices was calculated assuming the same weight for all proxies. A further analysis could help to assign different weights to the proxies.

3.2.4 Assessing potential for adoption

Figure 4 shows the distribution of the predicted probabilities of adoption of the seven pest management practices.

Considering the median values, the lowest estimated probability of adoption (12%) is associated with cultural planting/cropping patterns, while the highest is 89% and associated with pesticide use. Rational pesticide use is promoted by plant clinics, agro-dealers, who have an interest in promoting pesticide use, and government, who often provides free pesticides. A high probability of adoption is also associated with mechanical interventions in the late crop stage, possibly explained by the fact that these practices do not have an associated cost. The rest of the practices analysed present probabilities of adoption that are far below 40%. Some of these practices present an elevated cost for the household, such as for example planting resistant/tolerant varieties. Seeds are also provided for free but in low quantity (16% of farmers received seeds compared with 66% of farmers who received pesticide). Other practices require a certain degree of knowledge/training before being implemented, such as for example planting/cropping patterns, prevention/avoidance and mechanical early stage interventions.

3.2.5 Production

We found the average production of maize across Rwanda (Fig. 5) was 1.7 t/ha, with a maximum value of 4.0 t/ha and a minimum value of 0.3 t/ha. Such variability in yields has also been recorded in other studies (Kiptot et al. 2013; NIRS
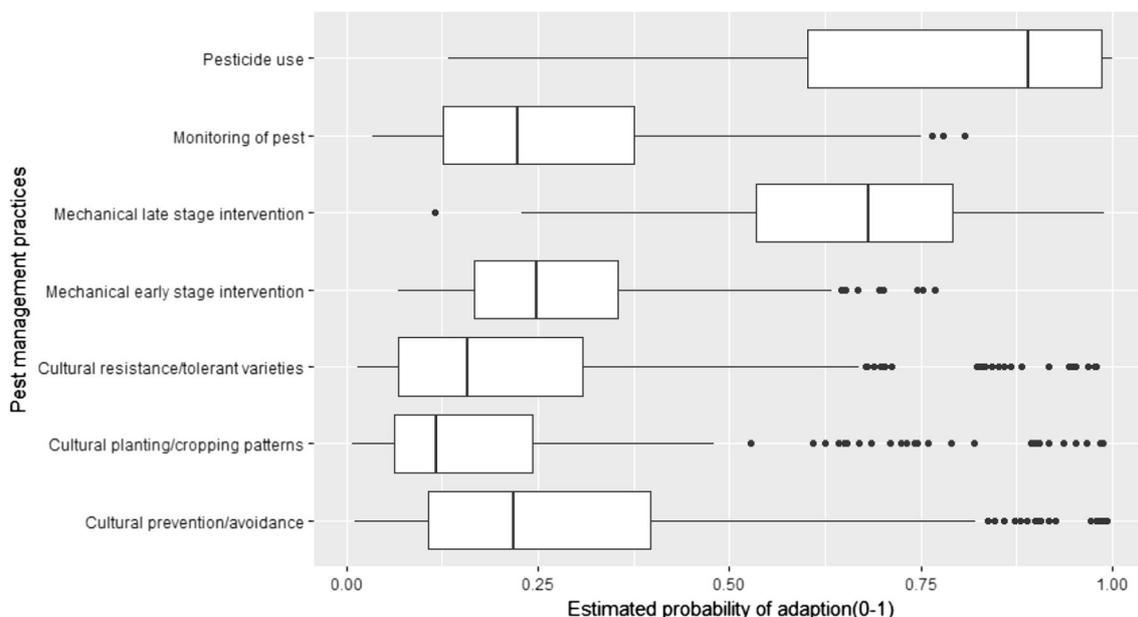
Fig. 4 Estimated probability of adoption of pest management practices for MSB. The *middle vertical lines* within each *box* indicate the median, *boxes* extend from the 25th to the 75th percentile, and *horizontal lines* (whiskers) extend from the 10th to 90th percentile of estimations. Dots are outliers

). The AEZ that showed the highest production is the Central plateau, with an average production of 1.8 t/ha, whilst the one with lowest production was the Congo Nile watershed divide, with 1.4 t/ha. The comparisons of maize yield for users and non-users of plant clinics revealed that users on average have higher yields (Fig. 5). This difference is highly significant ($P < 0.001$). In terms of differences across the AEZ, yields of users are higher than yields of non-users across all AEZs except for the Burebuka highlands. However, the difference between yields of users and non-users is highly significant only for Central plateau and Congo Nile watershed divide.

Analysis was also conducted to assess differences between yield of maize for men- and women-led households. Although men-led households on average have slightly higher production (1661 kg/ha) than women-led households (1658 kg/ha), this difference is not statistically significant. Despite maize being in general managed by women across the country, they
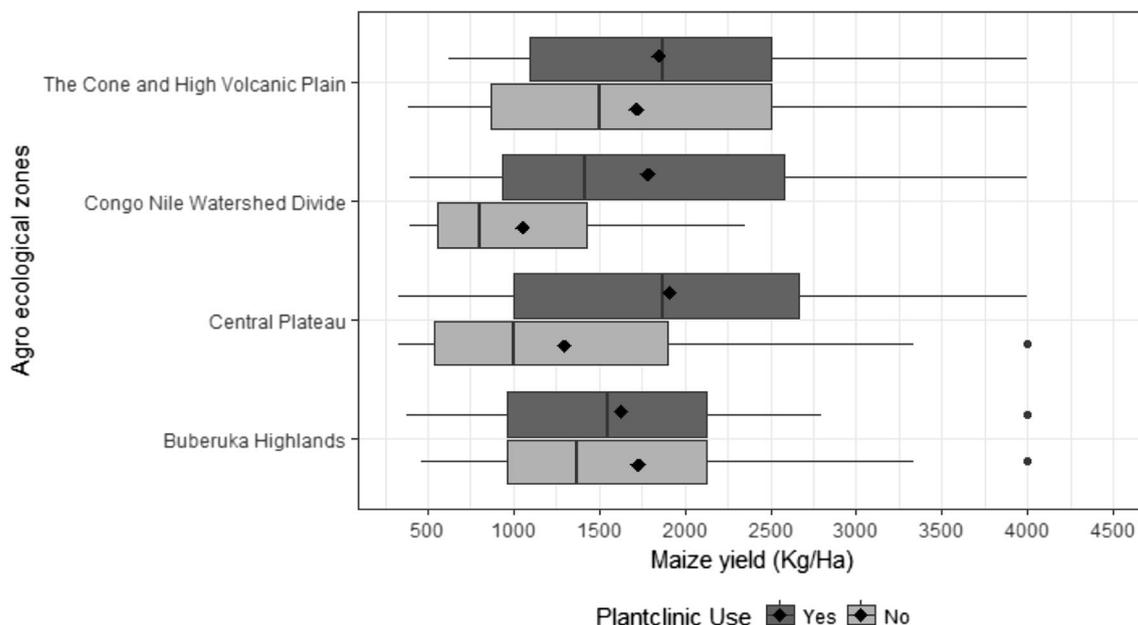

Fig. 5 Yield of maize (kg/ha) across the four different AEZ. The *middle vertical lines* within each *box* indicate the median and the *black diamonds* indicate the means. Boxes extend from the 25th to the 75th percentile, and *horizontal lines* (whiskers) extend from the 10th to 90th percentile of estimations. Dots are outliers

Table 5 Determinants of yields (correspondent regressions coefficients)

Variables	Coefficient	p value
Gender	0.776	0.438
Age	−0.289	0.773
Household size	−0.278	0.781
Maize land	−2.038	**0.042***
Cost of inputs	6.562	**0.000****
Credit source	2.203	**0.028***
Education	1.696	**0.091.**
Inputs received	−0.652	0.515
Shocks	−2.456	**0.014***
Own experience	1.751	**0.081.**
Radio and TV	−1.721	**0.086.**
Extension	−0.595	0.552
Plant clinics	1.369	0.172

*** $p < 0.00$; ** $p < 0.01$; * $p < 0.05$;. $p < 0.1$

experience limited access to government initiatives in Rwanda, such as the Crop Intensification Program (CIP), because the inputs (chemicals, fertilizers, seeds) are too expensive and many of the technologies are labour intensive, restricting women's participation (World Bank 2015).

To further assess variables that influence yields we ran a multiple linear regression (Table 5). The regression shows that variables that have a positive and significant relationship with yields are inputs costs and access to credit. The variables that have a negative relationship with yield are shocks, and land size. The latter finding conforms to the global literature

Table 6 Summary of main statistics for users and non-users of plant clinics (mean and t-test)

Variables	Users	Non-users	T-test
Age	46.6	46.5	0.904
Education highest level for respondent	1.4	1.5	0.273[+]
Household size	5.1	5.1	0.788[+]
Land per capita (ha)	0.097	0.079	0.012**
Yield (kg/ha)	1854.9	1458.7	0.000***
Labour surplus, deficiency, balance	0.09	0.08	0.009***
Asset	34.7	34.6	0.792
Pesticide cost per ha (USD)	12.3	6.0	0.000***
Seeds cost per ha (USD)	4.5	5.1	0.066*
Fertilizer cost per ha USD	35.5	27.1	0.001***
Total costs per ha (USD)	77.2	67.5	0.047**
Total costs per tonnes (USD)	46.2	52.5	0.084*
Net income per ha (USD)	348.2	268.9	0.000***

[+] these are discrete variables, therefore we used the non parametric Wilcoxon rank sum test with continuity correction to assess whether users and non-users differences are statistically significant

*$p < 1$; **$p < .05$; ***$p < .01$

(Eastwood et al. 2010; Lipton 2011), and specifically to a study about Rwanda (Ali and Deininger 2014). Labour market imperfections seem to be a key reason for the inverse farm-size productivity relationship.

Overall, users of clinics have a higher net income per ha than non-users (348.2 USD/ha vs 268.9 USD/ha) and this difference is highly significant. This reflects the higher yields, despite higher average costs per ha for users (77.2 USD/ha) than non-users (67.5 USD/ha; Table 6).

Our calculation of total costs includes: improved seeds, fertilizers, and pesticides. Whilst the survey also collected information on herbicide costs, none of the farmers declared expenditure for this input. This is in line with the Rwandan national policy, which does not support the use of herbicides (Kabigiri et al. 2015; REMA 2011). However, it is also possible that farmers combine herbicides with other pesticides. We found high man-hour variability among farmers, and, therefore, could not include this variable among the costs.

4 Conclusions

Our results suggest that plant clinics can boost the awareness and knowledge of signs of pests, and also facilitate adoption of integrated pest management practices. This in turn would lead to higher yields for plant clinic users. Higher yields are also accompanied by greater use of complementary inputs, which increase production costs. However, the net income for users is greater despite higher costs per ha.

Extension officers from the government play an important role in Rwanda among the information sources contributing to pest management practice adoption. The country benefits from a solid extension service, which, combined with the service rendered by plant clinics, enhance the probability of adoption further.

Nonetheless, we found evidence that targeting male and female farmers equally in terms of both provision of information and free inputs, could improve adoption rates for female farmers. A gender asymmetry in information is also found with respect to provision of free inputs, with initiatives that still target males. "Anti-women biases" by public and private agencies still prevail, which pose a real challenge to overcome.

The practices associated with the highest likelihood of adoption are pesticide use and mechanical interventions at late crop stage. Further efforts should be made to promote those options for pest management that currently have lower adoption probabilities, such as resistance/tolerant varieties, planting/cropping patterns, prevention/avoidance and mechanical early stage interventions. The least adopted pest management practices are in general associated with technical challenges - e.g., lack of knowledge of technology implementation – and financial constraints. The latter

especially concerns the cultivation of resistant/tolerant maize varieties. The government of Rwanda has developed an integrated pest management framework, which emphasises the use of resistant varieties. Under the Crop Intensification Program (CIP) initiated in 2007 by the Ministry of Agriculture and Animal Resources (MINAGRI), seeds of some priority crops such as maize were imported and distributed freely to farmers. Despite this, there seems to be room for improvement regarding the distribution of seeds of resistant varieties to more farmers.

Additional policy implications are that there is a need for a coordinated effort from the government to increase the economic support toward the promotion of more expensive practices, and enhancing training for those practices that require extra knowledge. Countries that significantly increase their investment in agricultural research, extension and farmers' schooling achieve faster rates of adoption of a wide range of technologies (Mundlak 2000; Cervantes-Godoy and Dewbre 2010). Policy makers would be interested in the most effective ways to improve adoption at minimal cost. Therefore, this kind of research could be integrated and further developed with an analysis of those options that would enhance cost-effective patterns of adoption.

Adoption of pest management practices can be fostered in a number of ways and this study shows that plant clinics and extension are excellent ways of doing so. However, improvements in extension services, both in terms of coverage and efficiency, would be necessary to help farmers overcome barriers to information and adoption.

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

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