Determinants of adoption of the Banana Xanthomonas Wilt (BXW) control package in Uganda

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Introduction

Bananas represent an important staple food and cash crop in East and Central Africa (ECA) (Blomme et al., 2019; Ouma et al., 2010). Particularly, Uganda is a secondary centre of genetic diversity for bananas with one of the highest per capita consumptions of the crop in the world (Daniells and Karamura, 2013; Gold et al., 2002; Karamura and Mgenzi, 2004; Karamura et al., 2010). Unfortunately, since 2001 banana production in the region was severely affected by Banana Xanthomonas Wilt (BXW) disease.

Whereas no banana variety is resistant to the disease, a fruitful mix of global, national and local efforts has been implemented in order to find the most effective agricultural practices able to limit the disease spread and the resulting yield loss (Blomme et al., 2017a). The identified combination of practices that complement each other rather than work as a stand-alone management strategy included: (1) de-budding; (2) sick plants removal; (3) disinfection of tools; and (4) use of clean planting material (Kubiriba and Tushemereirwe, 2014; Kubiriba et al., 2014; Tripathi et al., 2009; Tushemereirwe et al., 2006). Such integrated system of cultural practices was widely promoted through awareness campaigns, community action, farmer field schools and other participatory methods that involve actively smallholder participation (Kubiriba et al., 2012) in order to effectively sensitize and mobilize households towards the disease and for adopting correctly the practices (Kubiriba and Tushemereirwe, 2014).

Nevertheless, the emergence of BXW in Uganda has been characterized by outbreaks followed by periods of low occurrence. Studies showed that during the first peak, between 2001 and 2004, the incidence in affected fields raised up to 70% in a period of one year (Kalyebara et al., 2006). Losses due to Xanthomonas wilt were estimated at US$ 34.3 million in 2005 and US$ 75.6 million in 2006 (Mwangi and Nakato, 2008). The second peak occurred in 2013, with more than 50% incidence rate (National Banana Research Program Website, 2015).

Only in 2015, the situation in Uganda was declared under control, with just 1.9% of households showing BXW symptoms in their fields (National Banana Research Program Website, 2015). Since then, there has been a significant reduction in public and private investments for the management of BXW that could lead to a resurgence of the disease. Indeed, the study by Tinzaara et al. (2016) reported that the disease continued to expand not only in previously disease-free areas, but also in areas where BXW had been declared under control. This possibly because of the long incubation period of the disease in banana mats, the high latent infection levels in fields (Ocimati et al., 2013a; 2015), the fact that the disease can rapidly increases to endemic level (Nakakawa et al., 2017) or the low levels of adoption of the integrated system of cultural practices (Jogo et al., 2013) due to the poor understanding by the banana-based households of the factors that influence the spread of the disease (Tinzaara et al., 2016).

It is therefore important to prevent resurgence of the disease and its spread to new areas. This will be possible only through the sustained adoption of the integrated package of cultural practices that maintain the incidence of the disease at manageable levels. Consequently, understanding the factors influencing farmers' adoption behaviour is critical for effective control of the BXW.

To our knowledge, previous studies on the determinants of adoption of BXW control package are still very limited. Gender of the household head and the household labour availability (Jogo et al., 2013; Kikulwe et al., 2018) have been identified as some of the main determinants of adoption of practices to control the BXW in Uganda. Women are less likely to adopt BXW control practices compared to men, whilst lack of labour is the key limiting factor for adoption of recommended practices (Bagamba et al., 2006; Jogo et al., 2011; Muhangi et al., 2006). Furthermore, sources of information and households' perception of BXW control effectiveness significantly influences the adoption of practices and, in turn, reduced the disease incidences (Kikulwe et al., 2019).

However, the above-mentioned studies defined adopter as a farmer who apply at least any one of the three recommended practices (de-budding; sick plants removal or disinfection of farm tools). None of them consider another important practice: the use of clean planting material. Only the study by Kikulwe et al., 2018 considered the use of tissue culture material. However, it ignored other techniques that can be incorporated in this category (for example seeds cleaned by known maternal gardens or macro-propagation techniques). In response to this, the current study aims at analyse the determinants of farmers' decisions to adopt the integrated BXW control package by farm households in Uganda. To achieve this, the sample was divided into non-adopters, partial adopters and full adopters. Among the partial adopters, it was analysed who adopted only one, only two or only three of the recommended practices. Furthermore, most of the previous studies have used either logit or multilogit models to estimate adoption (e.g. Jogo et al., 2013; Kikulwe et al., 2019). Instead, the present study used the Double-Hurdle Model developed by Cragg (1971). This model allows to separately analyse the factors that influence the choice to adopt or not the recommended practices, from those that influence the intensity of adoption.

This study is organized as follows: Chapter 1 presents the case study; Chapter 2 presents the main determinants of adoption of agricultural technologies; while Chapter 3 presents the methodological approach employed and result achieved. The final section of this study presents the discussion and some concluding remarks.

Chapter 1

Case Study - Banana *Xanthomonas* Wilt (BXW) Uganda

1. Banana production in Uganda

Uganda is the world's leading producer of cooking bananas (FAOSTAT, 2014) and it is a secondary centre of genetic diversity for this crop (Daniells and Karamura, 2013; Gold et al., 2002; Karamura and Mgenzi, 2004; Karamura et al., 2010).

Based on use, it is possible to distinguish bananas in four types: cooking, roasting, dessert and beer types (Mgenzi et al., 2005). Most bananas produced in Uganda are cooking type (East African highland banana (EAHB)) locally referred to as 'matooke'. This type of banana is steamed and wrapped in banana leaves and is the preferred staple food in most regions of Uganda. In regard to roasting type, the most common is the 'G*onja'.* As far as concern the dessert banana, 'Kisubi' and some EAHB AAA cultivars (e.g. 'Mbidde') are the most used, particularly for juice extraction and brewing. Finally, the variety most cultivated of beer banana is the 'Pisang awak' (local name 'Kayinja'). The 'Kayinja' system is prevalent because it traditionally requires little management, which allows for labour allocation elsewhere. Furthermore, beer bananas are characterized by high suitability for the erratic rainfall, low soil fertility and high pest and disease pressure associated with the lower altitudes of Central Uganda in comparison with cooking types (Rietveld et al., 2013).

In general, there are three beer banana products: juice, beer and the distillate waragi (ibid). Juice and beer have a short shelf life and are products with zero and low concentrations of alcohol. While waragi has an alcohol content of above 40%. It has been produced since the Ugandan people first encountered distillates at the end of the 19th century and discovered how to distil fermented beverages (Davies, 1995). A fourth product, wine, is a new product that has been introduced in various development projects especially in the south-western part of Uganda, but this is mainly made from cooking bananas (Rietveld et al., 2013).

However, bananas have multiple uses behind juice, beer, distillates and wine. In order to consume bananas as food, they can be prepared by boiling, steaming, crushing, cooking and drying (FAO, 1990). Banana leaves are used for wrapping, packaging and serving of food (Kamira et al., 2015).

The dried leaves, leaf sheaths and petioles are used as tether, cover for fermenting cassava, nesting materials for egg-laying poultry, building materials for temporary shelters, sponges and roofing material (Akinyemi et al., 2010; Kamira et al., 2015). Fruit peels are generally used as feed for livestock, while dried peels are used in soap production (Akinyemi et al., 2010; Kamira et al., 2015). Some cultivars are valued for their medicinal properties; Gonja is used to hasten the healing of new-born babies' navels and Mbidde to prevent vomiting (Kilwinger, 2019). Bananas are also associated with many cultural ceremonies. It is tradition to bring a banana bunch (or several if you are wealthy) to social gatherings, such as weddings. When a baby girl is born, the placenta is buried under a mat of Matooke and a baby boy's placenta under a mat of Mbidde or Kayinja. The placenta is viewed as a twin of the new-born baby and requires a respectful burial. The practices of cultivation are also subject to traditional rules and beliefs: the plantation is almost considered a living organism, which requires respect (Kilwinger, 2019). For this reason, cultivars are generally also organized in specific patterns within the plantation. There should be at least one mat of Mbidde in the middle of the plantation as this cultivar represents "the man of the plantation". Some cultivars, considered to be "bad neighbors" to other cultivars, are planted at the edges of the plantation, such as Bogoya, Ndiizi, and Gonja. Gonja is also placed at the boundaries of the plantation as a protection against thieves (Kilwinger, 2019).

Bananas are of major economic importance in Uganda, forming an important part of peoples' daily diet and providing income and food security to millions of smallholder households (McCampbell et al., 2018). It is estimated that 75% of Ugandan households grow the crop, on a total of 1.5 million hectares, which accounts for over 38% of utilized arable land (Karamura, 1993).

The bananas produced are mainly consumed locally, with an estimated per capita consumption of over 200 kg which is the highest rate in the World (ibid). Indeed, bananas are the most important staple food crop in Uganda (Biruma et al., 2007). Cooking bananas account for one third of the calorie intake from starchy staples in the region (FAOSTAT, 2014) and it is estimated that about 35% of household food budget expenditures are allocated to banana consumption (Kiiza et al., 2006).

The crop is also one of the most important cash crops in Uganda, contributing to up to 22% of national agricultural rural revenue (Embrechts et al., 1996). Furthermore, bananas are an important income source for about 30% of the Ugandan farmers, being marketed at a rate between 25 and 50% of production (Okech et al., 2004).

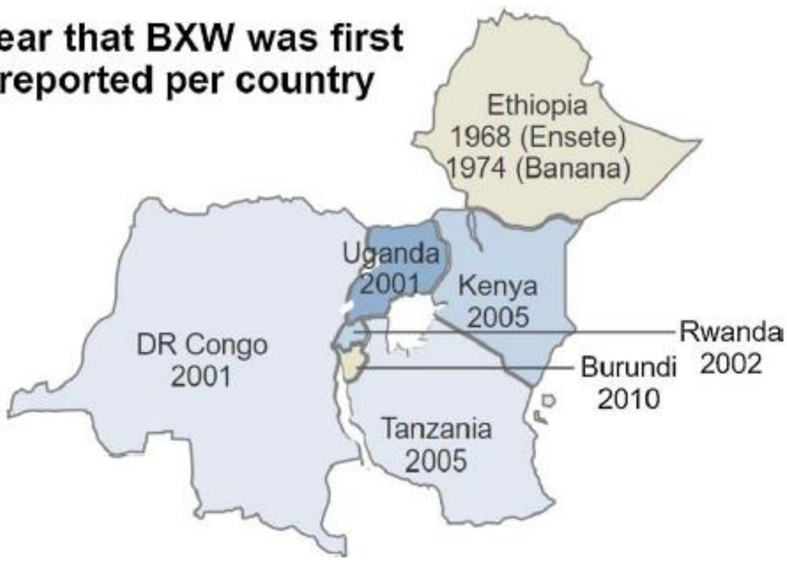
In recent years the production and processing of beer bananas are becoming an important economic activity for many households in the rural areas of central Uganda (Rietveld et al., 2013). This because it is one of the few options available to them to obtain relatively large amounts of cash throughout the year from their crop production. Indeed, alcohol consumption in the region is among the highest in the world (WHO, 2004). Although sales of hand-crafted beer banana brews account for significant parts of household total income, beer is often not professional, and sales are usually very local because of the short shelf life, implying that profits are not optimized. However, taking the rapidly growing population into account, and the resulting continuous growth in the demand for alcohol, an increase in demand for artisanal brews is expected (Rietveld et al., 2013).

2. Banana *Xanthomonas* wilt (BXW)

Banana *Xanthomonas* Wilt (BXW), caused by *Xanthomonas vasicola* pv. *musacearum* (*Xvm*) (formerly *Xanthomonas campestris* pv *musacearum*) (Valentine et al., 2006), is a vascular disease that results in permanent wilting and eventual death of the plant (Biruma et al., 2007).

Xanthomonas wilt poses one of the greatest threats to banana production in East and Central Africa (ECA) where banana represent an important staple food and cash crop and it has the potential of destabilizing food security in the region (Biruma et al., 2007; Ouma et al., 2010).

Figure 1. *Historical spread of BXW in the Great Lakes Region (McCampbell et al., 2018)*



The disease was first reported in Ethiopia on enset (Ensete ventricosum), a relative of banana, in 1968 (Yirgou and Bradbury, 1968) and afterwards on banana in 1974 (Yirgou and Bradbury, 1974) (Fig. 1). BXW remained confined to Ethiopia until first outbreaks were observed in Uganda in 2001 (Tushemereirwe et al., 2003) on both dessert and beer bananas (Tushemereirwe et al., 2003, 2004). Since then, BXW has propagated through to DR Congo (2001), Rwanda (2002), Tanzania, Kenya (2005) and Burundi (2010) (Niko et al., 2011; Tushemereirwe et al., 2003).

BXW is a vascular disease that results in yellowing and wilting of leaves (Figure 2) and yellowing of immature and mature fruits. Symptoms are cultivar-specific and determined by the course and stage of infection (Brandt et al., 1997). Broadly, the symptoms of the disease are not always the same. In some cases, the bunch may appear green and normal outwardly, whereas leaves may show yellowing and wilt symptoms and internally fruits exhibit a reddish-brown discoloration and are inedible. In other cases, the first symptoms may be blackening and shrivelling of the male bud (Figure 3); followed by premature ripening of some of the fruits and internal fruit discoloration (Figure 4). While internally, yellowing and/or brown discoloration of vascular bundles can be seen throughout the plant and a cream or yellow-coloured ooze comes out within a few minutes of cutting tissue and copious quantities may be produced over a period of several hours (Figure 5) (Karamura et al., 2008). Some symptoms, such as foliar symptoms, yellowing and wilting, resemble those of Fusarium wilt but the excretion of a yellowish bacterial ooze from cut tissues is characteristic of banana *Xanthomonas* wilt (Thwaites et al., 2000; Tushemereirwe et al., 2003, 2004).

Figure 2. *Xanthomonas* wilt leaf symptoms (Karamura *et al*., 2008)

Figure 3. *Male bud symptoms (Karamura et al., 2008)*

Figure 4. *Fruit symptoms - Premature ripening and Internal discoloration (Karamura et al., 2008)*

Figure 5. *Pseudostem symptoms (Karamura et al., 2008)*

Concerning the methods of transmission of the disease, insects and birds are considered to be responsible for spreading, together with the use of contaminated garden tools and infected planting material.

Insects are vectors for the short-distance transmission of the disease through floral parts (Tinzaara et al., 2006). The rate of spread of the disease by insects is affected by the traits of the banana cultivar's inflorescence (Tinzaara et al., 2013) and the suitability of the environment for the development of the insect vectors (Mwangi et al., 2006). Whilst, birds and bats may pose a serious threat when it comes to long-distance transmission, as they collect nectar from male gems and can reach longer distances than insects (Tinzaara et al., 2013). Tool-mediated infection is also very important as the informal agricultural input exchange is very widespread, and farmers pass from field to field using the same tools to harvest mature bunches (Ocimati et al., 2013b).

Even though understanding the mechanisms of Xanthomonas wilt transmission is relevant in the management of the disease, there are some farmers that are not aware of them (Jogo et al., 2011). Once BXW is established in an area, the disease spreads rapidly and all banana cultivars are susceptible to the disease (Biruma et al., 2007). Although no detailed studies on the assessment of crop losses due to this disease have been presented, field observations indicate that the disease reduces yields to varying levels, depending on the growth stage of the crop, degree of cultivar susceptibility and prevailing climatic conditions (Biruma et al., 2007). By 2004, 33% of banana farms in Uganda were infected by the disease with yield losses estimated at 30–50% (Karamura et al., 2010).

3. Management options

Broadly, the lack of an effective chemical or other curative treatment makes it difficult to control bacterial diseases of plants (Biruma et al., 2007). An important practice in preventing disease spread is the early detection and destruction of the diseased plants (Karamura et al., 2010). In the case of BXW, the situation is even more complicated because all banana cultivars are susceptible to the disease and no single control measure has been found to be effective (Welde et al., 2006). Accordingly, it is convenient that management focuses on a number of practices able to reduce the initial inoculum and subsequent spread of the pathogen (Biruma et al., 2007; Kikulwe et al., 2019).

A fruitful mix of global, national and local efforts has been implemented in order to find the most effective agricultural practices able to limit the spread of BXW (Blomme et al., 2017a). Such practices were identified through the use of information obtained from epidemiological studies carried out with the participation of several partnerships from both local and International Research Institutes and Universities (Tushemereirwe et al., 2006). Additional stakeholders from Government and Non-Government Organizations involved in rural development also contributed to the development, creation and promotion of these practices. Field experiments were established to validate such practices (Ssekiwoko et al., 2006) and in some cases, households have had the opportunity to adapt the recommended practices to make them more consistent with their conditions and knowledge (Bagamba et al., 2006).

The identified combination of practices that complement each other rather than work as a stand-alone management strategy included: (1) de-budding with forked stick, (2) disinfecting tools with fire or JIK, (3) sick plants removal (cutting down only the single stem affected or the whole mat) and (4) replanting using clean planting material.

3.1. De-Budding

Since disease transmission through the male bud is one of the main ways of spreading, timely removal of the male buds is regarded by extension practitioners as the first line of defence against the disease (Blomme et al. 2005). Indeed, early removal of the male bud, by twisting the peduncle with a forked stick, is an effective means of preventing the spread of BXW by insect vectors, within the same field and between different fields (Tinzaara et al., 2006; Tripathi et al., 2009). Such practice is recommended for both affected and unaffected fields (Kubiriba and Tushemereirwe, 2014), but it needs to be done correctly to eliminate the risk of infecting new plants. De-budding must be done as soon as the last hand of the bunch is formed (Blomme et al., 2005). The use of a forked stick is highly recommended, since, on the contrary of the cutting knives, it does not predispose the cut surface of the plant to the disease (Karamura et al., 2008). Different experiments have demonstrated that the use of a forked stick can highly reduce the infection rate (Blomme et al., 2005; Ssekiwoko et al., 2006; Turyagyenda et al., 2006).

In many countries removal of male bud is an adopted cultural practice in the management of banana stands, especially in commercial plantations. However, this is not practiced widely by smallholder farmers who predominate in Eastern Africa (Biruma et al., 2007).

Figure 6. *De-budding using a forked stick (Karamura et al., 2008)*

3.2. Sick Plant Removal

Once BXW infection has been detected in a field, farmers are advised to remove infected plants (Tushemereirwe et al., 2004). Some farmers uproot the whole stool once they find an affected plant, others remove the only infected plants from the affected stool (Kubiriba and Tushemereirwe, 2014).

Complete Mat Uprooting (CMU) practice after diagnosis of BXW, even if only one plant in the mat shows symptoms, has long been the recommended control BXW practice (McCampbell et al., 2018). However, the invasive nature of uprooting entire plantations is not perceived positively by farmers (Blomme et al., 2017b). Although very effective in removing most of the inoculum causing BXW, such practice is wearisome, labour intensive, time consuming and costly, since it requires that asymptomatic plants are also removed. Furthermore, it cannot guarantee long term eradication of BXW, as there is always a risk of reinfection (Tinzaara et al., 2013).

Afterwards, it was found that often the adjacent shoots of an infected mother plant are often disease-free. This because most BXW infection starts from the upper parts of the plant and takes time to spread to the rest of the plant (Ssekiwoko et al., 2006). If the infected plant is removed from the stool in time, it is possible to save other plants on the stool from BXW infection (Turyagyenda et al., 2006). This practice, based on the Single Diseased Stem Removal (SDSR), is low cost, and simple and easy to apply. Additionally, a BXW infected field can be restored in a relatively short time. This makes SDSR a suitable management strategy for subsistence banana systems (Blomme et al., 2017b). However, SDSR does not completely remove the BXW from the field and requires rigorous application for as long as the disease is present on or near the farm (McCampbell et al., 2018).

3.3. Disinfection of tools

Since the BXW is systemic, when the working tools come in contact with the bacterial ooze, they increase the likelihood of plant-to-plant disease transmission (Karamura et al., 2008). Furthermore, a study showed that the disease was still present on cutting tools even after 22 days that they were kept at room temperature (Buregyeya, 2010). During that period, BXW is spread from the tools to banana plants. For this reason, disinfection of cutting tools limits mechanical spread of BXW.

The tools can be disinfected by washing them in Sodium hypochlorite solution, locally named "Jik." Otherwise, the metal tools may be flamed in fire. But many farmers find the use of fire to disinfect the tool too laborious to apply. While, the use of Jik is limited due to the relatively high cost and limited accessibility in the rural areas.

Figure 7. *Disinfecting tools with "JIK" (Karamura et al., 2008)*

Figure 8. *Disinfecting tools with fire (Karamura et al., 2008)*

3.4. Clean planting material

In many cases, the disease could spread due to the use of infected planting material. For this reason, the use of clean planting material represents another important practice to avoid the dissemination of infected suckers and plantlets. Where possible, tissue culture material, seeds cleaned from known mother gardens of clean seeds or macro-propagation techniques should be used (Karamura et al., 2008).

However, very few farmers use this technique. All farmers preferred to source suckers from existing mats on their own farm because they were familiar with these plants and could thus predict performance, properties and pest and disease status of the sucker. If, for whatever reason, farmers cannot use suckers from their field, then they prefer to source planting materials from within their own social networks (Kilwinger, 2019). In fact, the informal source of inputs (such as farmer-to-farmer exchange) is preferred by farmers as the cost is lower than when buying from formal sources (Bagamba et al., 2006; Staver et al. 2010). However, this socio-cultural practice based on the exchange of inputs rather than on their purchase aggravates the problem because it increases the risk of BXW spreading (McCampbell et al., 2018; Tinzaara et al., 2013).

Successful control of BXW is possible by deploying these practices together with participatory approaches that sensitize and mobilize households towards the disease and for adopting correctly the suggested practices (Kubiriba and Tushemereirwe, 2014). For this reason, the integrated system of cultural practices has been widely promoted through awareness campaigns, community action, farmer field schools and other participatory methods that involve actively smallholder participation (Kubiriba et al., 2012).

4. Communication Approaches

The majority of farmers in Uganda have considerable difficulty in managing plant diseases (Sherwood, 1997). This may be due to the fact that they cannot see the organisms that cause the plant diseases (Nelson et al., 2001). Successful control of BXW is possible by deploying the integrated package of practices indicated above, with communication approaches that sensitize and mobilize households towards the disease and adopting correctly the suggested practices (Kubiriba and

Tushemereirwe, 2014). This is because the acquisition of information on a new technology allows farmers to learn about the existence and effective use of the technology and this facilitates their adoption.

However, there are some elements (such as the different socio-cultural backgrounds, linguistic barriers and geographical remoteness) that make the task of disclosing information challenging. Because of such heterogeneity, communities have a complex understanding of diseases, their spread and management (Tinzaara et al., 2013). It is therefore important to communicate the message in a clear and concise manner stating the epidemiological underpinnings, negative impact of failure to implement the intervention as well as the benefits of such interventions (Kubiriba and Tushemereirwe, 2014). Furthermore, the choice and design of the communication strategies should take into account the dynamics of the target area such as literacy levels, numbers of radio receivers and availability of extension support (Kubiriba and Tushemereirwe, 2014).

In Uganda, BXW control technologies were promoted using a mix of top-down extension and participatory approaches (Kubiriba et al., 2012).

4.1. Conventional communication approaches

Conventional communication approaches adopted in Uganda are commonly top-down approaches that consider affected communities as passive recipients of information (Tinzaara et al., 2013). Generally, pest and disease epidemic control programmes start with the bearing of practices and usually stop at dissemination of information to the farming communities, hoping that the recipients will use the information to control the spread of the disease (Hawkins et al., 2009). These approaches are discussed separately below.

- *Print and mass media*

  The most common mass media channel used in ECA are the radio and leaflets/pamphlets/posters/manuals (Tinzaara et al., 2009). A study of Kiiza et al. of 2006 shows that television and newspaper messages were considered to be very expensive but not effective in reaching the intended communities. Probably this is due to the fact that most farmers in Uganda do not own televisions and newspapers are only accessible to the elite who reside in towns and cities. While for traders, the major sources of information on BXW are fellow traders, radio and farmers (Kiiza et al., 2006).

- *Seminars and workshops*

Several seminars and workshops at regional, national and community level have been conducted in ECA by trained trainers (Tinzaara et al. 2013). These events are major tools for informing different stakeholders about BXW (Kiiza et al., 2006). However, the effectiveness of these approaches depends on the subsequent application by the participants of the information received.

- *Training of trainers*

The trainings generally focused on disease identification, spread and control (Karamura et al., 2008). This strategy can help raise farmers' awareness of the disease (Kiiza et al., 2006).

- *The mobile phone system*

This system requires that local communities provide information on the occurrence and spread of the disease to the government and researchers through text messaging. In this way the communication is bidirectional and immediate. This provides opportunities for obtaining and accumulating surveillance data in a cost-effective manner (Kiiza et al., 2006).

- *Publications*

The research center Bioversity International, via the Banana Research Network for East and Southern Africa, has facilitated communication among regional partners through the development and dissemination of a regional Xanthomonas wilt management strategy. Most of the documents that are accessible provide information on disease diagnosis, spread and management.

4.2. Participatory communication approaches

The use of participatory approaches can improve the percentage of farmers adopting control measures at community level (Kubiriba and Tushemereirwe, 2014).

- *Participatory Development Communication (PDC)*

  This approach uses communication as an instrument to promote community participation in a development strategy (Bessette, 2004). Indeed, community members are involved in problem identification and analysis. In this way the community is encouraged to analyse and identify alternative solutions to the problem, and to establish the best solutions that they are prepared to implement (Nankinga and Okasaai, 2006). The approach warrants that the needs, preferences, knowledge and constraints of the community are understood and taken into account in developing disease management strategies. As a result, the chosen strategy at the end of this process is effective, practical and locally adapted, and can be easily adopted and sustained by communities.

  In Uganda, this approach was adopted to better reach out to the public with clear messages about BXW management, and to solicit their support in control campaigns (Nankinga and Okasaai, 2006; Tushemereirwe et al., 2006). When the PDC approaches were rigorously implemented, the incidence of BXW was drastically reduced (Kubiriba and Tushemereirwe, 2014).

- *Farmer Field School (FFS)*

  Farmer field schools are a community-based approach used to disseminate new science-based knowledge and information to farmers in the field (Kubiriba and Tushemereirwe, 2014). The approach enables farmers to make logical crop management decisions, exposes them to new ways of thinking and problem solving, and encourages them to implement and discuss their own ideas (Hakiza et al., 2004; Nankinga and Okasaai, 2006). The method also provides a framework through which farmers can learn together through testing and demonstrating technologies on their fields (Okoth, 2006). FFS are particularly important when recommended practices must first be tested, validated and adapted locally (Kubiriba and Tushemereirwe, 2014).

The FFS approach was developed by NARO (National Agricultural Research Organisation) and FAO (Food and Agriculture Organization of the United Nations) in Uganda in 2006–2009. By April 2008, BXW had been significantly reduced in all the groups of participating farmers (Kubiriba and Tushemereirwe, 2014).

Broadly, the approach has potential benefits because it is flexible, incorporates farmers' aspirations and empowers them (Kubiriba and Tushemereirwe, 2014). In addition, FFS approach has an in-built monitoring and evaluation mechanism and it can be integrated with other research/development approaches. The approach is, however, a very intensive format, which makes it difficult to work with thousands of farmers (Tinzaara et al., 2013).

- *Farmer exchange visits*

Farmer exchange visits, or farmer-to-farmer visits, are the key in promoting awareness among stakeholders along the value chain. These activities facilitate cross-border exchanges of information and technologies (Karamura et al., 2008). The countries visited depended on the needs of the visiting teams and the experiences of the hosting teams (Tinzaara et al., 2013).

- *Community structures (task forces)*

Task forces were formed from the national level down to the village and community level and these were charged with different roles in the management of BXW. Through these community-based structures, the disease and its control strategy became a responsibility of the community which, as a result, became highly motivated in the implementation of control measures. However, the success of this approach depends partly on social cohesion in the community which, in turn, is influenced by the socio-economic and cultural heterogeneity of the community.

Chapter 2

Determinants of adoption

The adoption of an innovation is the end-result of farmers' decisions based on maximization of their expected utility (Bonabana-Wabbi et al., 2006; Mauceri et al., 2005). If the expected utility of the new technology exceeds that of current technology, farmers will adopt the new one. Farmers' expectations can be economic, social or environmental and can be influenced by various factors.

Previous studies on adoption of banana technologies have shown that farmers' adoption decisions depend on farm and farmer socio-economic characteristics and specific characteristics of the technology (Kabunga et al., 2011; Aitchedji et al., 2010; Katungi and Akankwasa, 2010).

1. Farmer characteristics

1.1. Demographic characteristics

- *Gender of the Household Head*

  Gender can influence technology adoption since the head of the household is the primary decision maker. Gender-linked disparities in access to inputs, resources and services, due to socio-cultural values and norms, can be the channel through which these decisions are influenced (Mignouna et al., 2011; Omonona et al., 2006; Mesfin, 2005; Doss and Morris, 2001; Tiruneh et al., 2001). Gender issues in agricultural technology adoption have been investigated for a long time and the reported effects are pretty mixed (Bonabana-Wabbi, 2002). Kabunga et al. (2011) and Katungi and Akankwasa (2010) found gender to be significant in adoption of corm paring and tissue culture bananas, respectively, with female-headed households being more likely to adopt these two technologies. Furthermore, a study by Obisesan (2014) on adoption of technology found that, gender had a significant and positive influence on adoption of improved cassava production in Nigeria. His result conquered Lavison's (2013) which indicated male farmers were more likely to adopt organic fertilizer unlike their female counterparts (Mwangi and Kariuki, 2015). On the other hand, Aitchedji et al. (2010) found gender to be insignificant in the adoption of disease-resistant plantain and banana hybrids in Nigeria and Morris and Doss (1999) had found no significant association between gender and probability to adopt improved maize in Ghana. In their opinion, technology adoption decisions depend primarily on access to resources, rather than on gender. Then, only in cases where the adoption of improved maize depends on access to specific resources for which men tend to have better access than women, the technologies will not benefit men and women equally.

- *Age*

Age of the adopter is supposed to be a determinant of adoption of new technology. However, contention on the direction of the effect of age on adoption exists with researchers finding mixed effects of age. Older farmers are assumed to accumulated knowledge and experience of farming systems obtained from years of observation and experimenting with various technologies (Kariyasa and Dewi, 2011; Mignouna et al, 2011). Age as positive influence on adoption of sorghum in Burkina Faso, IPM on peanuts in Georgia and on adoption of chemical control of rice stink bugs in Texas, is found in Adesina and Baidu-Forson (1995); McNamara et al. (1991) and Harper et al. (1990) respectively. On the contrary, age was found to be either not significant or negatively correlated with adoption of land conservation practices in Niger (Baidu-Forson, 1999), rice in Guinea (Adesina and Baisu-Forson, 1995), and fertilizer in Malawi (Green and Ng'ongo'ola, 1993). The negative effect of age is thought to stem from the fact that as farmers grow older, there is an increase in risk aversion and a decreased interest in long-term investments in the farm. While, younger farmers are typically less risk-averse and are more willing to try new technologies (Mauceri et al., 2005; Adesina and Zinnah, 1993). On the other hand though, Alexander and Van Mellor (2005) found that adoption of genetically modified maize increased with age for younger farmers as they gain experience and increase their stock of human capital but declines with age for those farmers closer to retirement (Mwangi and Kariuki, 2015).

- *Educational Level*

The level of education of a farmer is an important factor influencing technology adoption (Feder et al., 1985). This is because higher education influences farmers' attitudes and thoughts making them more able to acquire, synthesise and use information and knowledge about the problem and technologies which is critical for technology adoption (Lavison 2013; Mignouna et al., 2011; Katungi, 2007; Namara et al., 2003; Waller et al., 1998). This simplifies the introduction of an innovation which in turn affects the adoption process (Adebiyi and Okunlola, 2013).

Some studies have reported a positive relationship between education and adoption: Okunlola et al. (2011) on adoption of new technologies by fish farmers, Ajewole (2010) on adoption of organic fertilizers, Katungi and Akankwasa (2010) on adoption of corm paring technology, Mishra and Park (2005) and Mishra et al. (2009) on use of internet, Roberts et al. (2004) on precision farming, Traore et al. (1998) on on-farm adoption of conservation tillage, Goodwin and Schroeder (1994) on forward pricing methods, Huffman and Mercier (1991) and Putler and Zilberman (1988) on adoption of microcomputers in agriculture, and Rahm and Huffman (1984) on reduced tillage.

On the other hand, some authors have reported insignificant or negative effect of education on the rate of technology adoption (Samiee et al., 2009; Banerjee, et al., 2008; Khanna, 2001; Grieshop et al., 1988). Indeed, studying the effect of education on technology adoption, Uematsu and Mishra (2010) reported a negative influence of formal education towards adopting genetically modified crops.

- *Household Size*

Family labour contributes greatly in agricultural activities. Labour costs still play a major role in limiting the adoption technologies even in relatively high population density areas in developing countries (Nin-Pratt and McBride, 2014; Supaporn et al., 2013). Indeed, one of the major reasons for the low adoption of IPM practices among vegetable growers in Thailand was the amount of time required for monitoring the area (Timprasert et al., 2014).

Therefore, the number of family members is used as a proxy for availability of labour. It determines adoption process in that, a larger household have the capacity to relax the labour constraints required during introduction of new technology (Mwangi and Kariuki, 2015; Mignouna et al, 2011; Bonabana-Wabbi 2002; De Souza Filho et al., 1999). Households containing members able to participate in on-farm activities enable farmers to adopt labour-intensive technologies (Feder et al., 1985). If technologies are capital-intensive, household members may work off-farm to generate income to purchase farm inputs. Household size and the extent of family involvement in agriculture positively and significantly influenced the adoption of integrated control of rice stem borer in the Isfahan province (Pezeshki-Rad et al., 2006), the adoption of biological control in northern Iran (Noorhosseini et al., 2010) and the adoption of corm paring banana technology for pest management among banana farmers in Uganda (Katungi and Akankwasa, 2010).

- *Farming Experience*

It appears that farmers' experience level plays an important role in the adoption, probably because more experienced farmers may have better skills and access to new information about improved technologies (Idrisa et al., 2012). It could also imply that knowledge gained over time from working in uncertain production environment may help in evaluating information and technology adaptation to local conditions (Feder et al., 1985). Studies on adoption of banana technologies by Kabunga et al. (2011) and Aitchedji et al. (2010) have shown that farming experience positively influences farmers' adoption decisions. Joshi and Pandey (2006) in a study of the factors affecting the adoption of new varieties of rice among the Nepalese farmers found that experience in rice farming was positively correlated with the adoption. Similarly, highly experienced cranberry growers from the USA, in charge of large operations, showed a tendency of using more frequently practices of IPM than less experienced growers who managed small farms (Blake et al., 2007). Recent studies from Iran reported that experience in paddy rice farming promoted the adoption biological control in northern Iran (Abdollahzadeh et al., 2015; Noorhosseini et al., 2010). Farming experience is useful especially in early stages of adoption of a farming technology when usually farmers are still evaluating its potential benefits, which later will determine its retention or disadoption over time (Ainembabazi and Mugisha, 2014).

1.2. Economic Characteristics

- *Off-farm Income*

Off-farm income performances as an important strategy for overcoming credit constraints faced by many rural households in developing countries (Reardon et al., 2007). This type of access to forms of capital other than that deriving from the farming system represents a substitute for borrowed capital in rural economies where credit markets are either missing or dysfunctional (Diiro, 2013; Ellis and Freeman, 2004). The positive effect generated by the off-farm income on the adoption of new technologies has been demonstrated by some studies (Mwangi and Kariuki, 2015). For instance, Diiro (2013) reported a significantly higher adoption intensity and expenditure on purchased improved maize varieties in Uganda among households with off-farm income compared to their counterparts without off-farm income. However, this positive relationship between off-farm income and adoption is not always confirmed. Some studies focus on labour intensive technologies have shown a negative effect. According to Kikulwe et al. (2019), Bagamba et al. (2007) and Goodwin and Mishra (2004) working off-farm may undermine the adoption of modern technology by reducing the amount of productive labour from the farm.

- *Access to Credit*

Access to credit has been reported to positive influence technology adoption (Mohamed and Temu, 2008). Probably this because access to credit loosens the liquidity constraint and stimulate household's-risk bearing ability (Simtowe and Zeller, 2006). Whit a loan, a household can reduce the adoption of low-risk but inefficient income diversification strategies and concentrate on more risky but efficient investments (Simtowe and Zeller, 2006). The study of Idrisa et al. (2012) showed that access to credit had positive and significant influence on the extent of adoption of improved soybean seed in southern Borno State, Nigeria. However, access to credit has been found to be gender biased in countries where female-headed households are discriminated against by credit institutions. This does not allow them to finance innovative technologies and therefore low adoption rates are generated (Muzari et al., 2013).

2. Farm characteristics

- *Size*

Access to physical and financial assets influences the capacity of farm households to invest in innovation (Mwangi and Kariuki, 2015; Jogo et al., 2013). The total farm area serves as one of the most important economic factors for farmers, particularly in developing countries, where small-scale farmers are mostly concerned with production costs. For this reason, farm size, which is a measure of household wealth, has been widely analysed as one of the determinants of technology adoption (Langyintuo and Mulugetta, 2008; Nyangena, 2007). Availability of land gives farmers more freedom to consider risky options beyond conventional crop production, given that large landholders can wait longer for returns than small-scale farmers. Thus, the adoption of new farming technologies is normally driven by the availability of farmland (Ajayi et al., 2003). In case of technologies that are capital-intensive, these are only affordable by wealthier farmers (El Osta and Morehart, 1999) and hence adoption of such technologies is limited to larger farmers who have the wealth (Khanna, 2001). Though, the effect of farm size on adoption of agricultural technologies is ambiguous. On one hand, more land allows a farmer to take the risk of experiment with new technologies and positively influence adoption. Many studies confirm this positive relation between farm size and adoption of agricultural technology (Mignouna et al, 2011; Uaiene et al., 2009; Ahmed, 2004; Gabre-Madhin and Haggblade, 2001; Kasenge, 1998). Farmers with large farm size are likely to adopt a new technology as they can afford to devote part of their land to try new technology unlike those with less farm size (Uaiene et al., 2009). In addition, lumpy technologies such as mechanized equipment or animal traction require economies of size to ensure profitability (Feder et al., 1985). On the other hand, more land may reduce the incentive to invest in productivity enhancing technologies. Some studies have shown a negative association between the size of the farm and the adoption of new agricultural technologies. Small farm size may provide an incentive to adopt a technology especially in the case of an input-intensive innovation such as a labour-intensive or land-saving technology (Mwangi and Kariuki, 2015). Farmers with small land may adopt land-saving technologies such as greenhouse technology, zero grazing among others as an alternative to increased agricultural production (Yaron et al., 1992; Harper et al, 1990). The study of Idrisa et al. (2012) showed a significant, but negative relation among farm size and the adoption of improved soybean seed in Nigeria. They assess that this is due to the fact that small farmers live at subsistence level that attracts them to adopt improved varieties which give better yields, earn more income and thereby help in raising their standard of living. While, in India, mixed evidence was recorded concerning the relationship between farm size and adoption of Integrated Pest Management practices, depending on crop; in the case of paddy rice, a negative relationship was found, while the reverse was true for cotton (Singh et al., 2008). Other studies have shown insignificant or neutral association with adoption. For instance, the studies of Samiee et al. (2009), Bonabana-Wabbi (2002), Mugisa-Mutetikka et al. (2000), Waller et al. (1998), Ridgley and Brush (1992) and Grieshop et al. (1988) concluded that the farm size did not affect Integrated Pest Management (IPM) adoption implying that IPM dissemination may take place regardless of farmers' scale of operation. Kariyasa and Dewi (2011) also found that extensive of land holdings had no significant effect on the degree of Integrated Crop Management adoption probability.

The studies mentioned above consider total farm size and not crop acreage on which the new technology is practiced. The rate and extent of adoption of technology may best be explained by considering the crop acreage suitable to the new technology (Bonabana-Wabbi, 2002; Lowenberg-DeBoer, 2000). For instance, to analyse farmers' decisions to invest in controlling pests and diseases affecting bananas, the study of Jogo et al. (2013) used the proportion of land area allocated to banana production as a proxy for the importance of banana as a food and income crop.

However, conflicting reports regarding the influence of farm area are not surprising, given that this variable has been reported as the most controversial variable in adoption studies in the past (Zerihun et al., 2014). This probably because farm size can affect and in turn be affected by many other factors influencing adoption (Lavison, 2013).

- *Farming Objective*

Farming objective is another element that can play and important role in the decision process of adoption of a new technology. For instance, the study of Kikulwe et al. (2019) showed that subsistence farmers are more likely to adopt all the control practices compared to semi-commercial farmers. They stated that this result could be related to the centrality of the crop to farmers' livelihoods or the relative ease of adopting the practices on their smaller acreage.

- *Production System*

The study of Jogo et al. (2013) highlighted the role play by the production system in the adoption process. In Uganda, the main banana systems are the East African Highland Banana (EAHB) and the Beer banana systems. These two systems present some differences: the former plays a much bigger role in enhancing farmers' incomes and food security than the latter (Bagamba et al., 2006); the EAHB system is managed intensively while the beer system is poorly managed (Kagezi et al., 2006; Bagamba et al., 2006) and, even if both systems are affected by BXW disease, the beer banana clones are more vulnerable to the disease than EAHB cultivars (Kagezi et al., 2006). These different features of the production systems are likely to influence the potential for adoption of the new technology.

- *Location*

Regional differences can influence farmers' adoption decisions (Kikulwe et al., 2019; Otieno et al., 2011; Adeoti, 2008). For instance, the study of Kikulwe et al. (2019) showed that regional differences significantly influenced adoption of the control practices against bananas' pest spread. The authors stated that the significant influence of regional differences in adoption decisions can be attributed to the variation in the importance of banana and banana farming objectives across Uganda. In addition, after the disease outbreak, there were more task forces, by-laws, and ordinances developed to oversee regular surveillance and enforcement control of the disease in southwestern Uganda with active involvement of all banana stakeholders. This implied BXW control was taken as a communal activity rather than individual farmer responsibility, and hence contributed to higher levels of adoption of BXW control practices in southwestern region.

- *Agro-ecological Factors*

But also, the agro-ecological characteristics of the area in which the farm is located can influence the adoption of innovations. For instance, altitude influences rainfall, temperature and pests and diseases pressure (Jogo et al., 2013). Furthermore, Mazvimavi and Twomlow (2009) argued that farmers located in high potential regions with better chances for increased crop production tend to be less risk averse and are likely to adopt new practices (Jogo et al., 2013).

3. Technology Characteristics

The characteristic of the technology represents a critical role in adoption decision process (Mignouna et al., 2011; Dzomeku et al., 2010; Katungi, 2007; Kivlin and Fliegel, 1967). Farmers who perceive the technology being consistent with their needs and compatible to their environment are likely to adopt since they find it as a positive investment (Mwangi and Kariuki, 2015). Indeed, farmers' perception about the performance of the technologies significantly influences their decision to adopt them (Mwangi and Kariuki, 2015). A study by Adesina and Zinnah (1993) showed that farmers' perception of characteristic of modern rice variety facilitated its uptake. A similar result was shown by Wandji et al. (2012) for the adoption of aquaculture technology in Cameroon. While, Kagezi et al. (2006) observed that adoption of de-budding in the beer banana system is limited partly due to the perception by farmers that it has a negative impact on juice quality.

3.1. Information and Knowledge

Several studies have shown that information and knowledge are important determinants of adoption (Kabunga et al., 2011; Aitchedji et al., 2010; Katungi and Akankwasa, 2010). Acquisition of information about a new technology enables farmers to learn the existence as well as the effective use of technology and this facilitates its adoption. Farmers will only adopt the technology they they know or have heard of. Access to information reduces the uncertainty about a technology's performance hence may change individual's assessment from purely subjective to objective over time (Bonabana-Wabbi, 2002; Caswell et al., 2001). Having sufficient knowledge about the technology enables farmers to optimize these decision-making processes (Feder et al., 2003). However, access to information about a technology does not automatically mean it will be adopted by all agriculturalists. This simply suggests that farmers may perceive the technology and subjectively evaluate it in a different way than researchers (Uaiene et al., 2009). Access to information may also generate dis-adoption of the technology. For example, where experience within the population about a specific technology is partial, more information generates negative attitudes towards its adoption, probably because more information exposes an even bigger information blankness hence increasing the risk related with it (Bonabana-Wabbi, 2002). It is therefore important to ensure the information is reliable, consistent and accurate. Farmers need to know the existence of technology, its advantageous, and its us in order to decide to adopt it. For these reasons, even information sources about the technologies need to be considered. For instance, the study of Kikulwe et al. (2019) about the adoption of the BXW control package in Uganda showed that the intensity of adoption of the practices was influenced by the type of information source about the disease. Farmers who accessed information from fellow farmers were more likely to use one control practices; those who accessed information from radio were more likely to adopt two control practices, whereas farmers who accessed information through exchange visits were more likely to adopt all the control practices (Kikulwe et al., 2019).

Broadly, the knowledge of rural households about new agricultural technologies can be increased in different ways: through participation in agricultural organizations, access to extension services, trainings or farmers field schools.

- *Farmers' Association*

  Belonging to a social group enhances social capital allowing trust, idea and information exchange (Mignouna et al., 2011). Agriculturalists within a social group learn from each other the advantages and use of a new technology. Uaiene et al. (2009) indicates that effects generated by social networks are significant for individual decisions and especially in the context of agricultural innovations as farmers share information and learn from each other. Broadly, farmers' membership and active participation in farm organizations is indicative of farmers' interest in good husbandry practices and enables them to improve their farm decision-making processes (Bonabana-Wabbi et al., 2006). Studying the effect of community-based organization in adoption of corm-paired banana technology in Uganda, Katungi and Akankwasa (2010) found that farmers who participated more in community-based organizations were likely to engage in social learning about the technology. This increases their likelihood of adopting technologies. Furthermore, social organizations were found to facilitate adoption of banana technologies (Katungi and Akankwasa, 2010; Aitchedji et al., 2010; Katungi, 2007).

  Even though many researchers have reported a positive influence of social group on technology adoption, social networks may also have a negative effect on technology adoption, particularly in the presence of free-riding behaviours. Most community organizations generate externalities through diffusion of information and knowledge to non-members of the organizations through interactions of the social organisations and the broader community within which they are found (Dzomeku et al., 2010). Foster and Rosenzweig (1995), when studying adoption of Green Revolution technologies in India, have discovered that learning externalities within social networks increased the profitability of adoption, but also farmers seemed to be free-riding on their neighbours' expensive experimentation with the new technology. Bandiera and Rasul (2002) suggest that, learning externalities generate opposite effects, such that the more other people engage in experimentation with a new technology, the more beneficial it is to join in, but also the more beneficial it is to free-ride on the experimentation of others. As a result of these contradictory effects, Bandiera and Rasul (2002) suggest an inverted U-shaped individual adoption curve. This imply that network effects are positive at low rates of adoption, but negative at high rates of adoption.

- *Extension Services*

Access to extension services is another important factor that influence the technology adoption process. Agriculturalists are usually informed about the presence as well as the effective use and advantage of new technology through extension agents. Extension agent acts as a link between the innovators of the technology and users of that technology (Mwangi and Kariuki, 2015). This helps to reduce transaction cost incurred when passing the information on the new technology to a large heterogeneous population of farmers (Genius et al., 2010). Several authors have reported a positive association between extension services and technology adoption. Some examples are the findings in the case of Imazapyr-Resistant Maize Technologies in Western Kenya (Mignouna et al., 2011); factors determining technology adoption among Nepalese (Karki and Siegfried, 2004); adoption of improved maize and land management in Uganda (Sserunkuuma, 2005); adoption of modern agricultural technologies in Ghana (Akudugu et al., 2012), improved cassava in southwestern Nigeria (Polson and Spencer, 1991); adoption of research results and agricultural technologies among cocoa farming households in Oyo State, Nigeria (Lawal and Oluyole, 2008) and improved maize in northern Tanzania (Nkonya et al., 1997). Similarly, the frequency of contact between farmers and extension personnel positively and significantly influenced the extent of adoption of improved soybean seed in southern Borno State, Nigeria (Idrisa et al., 2012). This could be because increased farmers' interaction with extension personnel in the form of multiple visits by extension agents, and technical support to farmers greatly increases farmers' knowledge of available technologies and their potential benefits, hence acting as a trigger mechanism for intensive adoption (Peshin, 2013). In fact, the influence of extension agents can counter balance the negative effect of lack of years of formal education in the overall decision to adopt some technologies (Bonabana-Wabbi, 2002; Yaron et al., 1992). Thus, improving agricultural extension services to facilitate participatory and discovery learning process and to provide the required proper inputs, rendering information and inputs more available and accessible is essential.

- *Trainings*

Attendance of farmers to training programs has been important in promoting the adoption of new technologies (Kikulwe et al., 2019; Aïtchédji et al., 2010). During these meetings, farmers are instructed on the application of new technologies and there is the possibility of exchanging experiences with their peers. Because of their participation, farmers were aware of the innovation and got sufficient knowledge to make the decision to adopt. The attendance to project training programs on plantain and banana significantly contributed to the adoption of hybrids by small farmers (Aïtchédji et al., 2010). Similarly, the more trainings on BXW control received, the more likely a farmer adopts any of the recommended control practices (Kikulwe et al., 2019).

- *Farmer Field Schools*

Farmer field school is essentially an informal educational approach that is experiential and participatory in nature. It is often call ‘‘school without walls’’. The sessions and learning activities are based on farmer experimentation and take place in the agricultural fields (Department of Agricultural, 1991). With this in mind, participation in FFS is a direct measure of farmers' access to information. Indeed, Erbaugh et al. (2010) found that participation of farmers in farmer field schools programs influenced increasing IPM knowledge of farmers. While, Luther et al. (2005) found significant difference between farmers who participated in farmer's field schools (FFS) for IPM adoption compared to those who did not participated in these activities. These results are accordant to the results of Tripp et al. (2005), Khisa and Heinemann (2005), Bunyatta et al. (2006), Khalid (2006), Erbaugh et al. (2010), Kimani and Mafa (1999), Ooi and Kenmore (2005), and Reddy and Suryamani (2005).

3.2. Cost of Adoption

In studying determinants of adopting an innovative technology, all the costs related to the use of the new technology play a fundamental role (Foster and Rosenzweig, 2010). The cost of adopting agricultural technology has been found to be a hindrance to technology adoption (Mwangi and Kariuki, 2015). For instance, the study of Makokha et al. (2001) showed that high cost of inputs and limited availability of demanded packages as the key restraints to fertilizer adoption. Besides, cost of hired labour was also reported by different studies as a factor constraining adoption. Some examples are the adoption of fertilizer and hybrid seed in Embu county Kenya (Ouma et al., 2002), the adoption of improved maize variety in coastal lowlands of Kenya (Wekesa et al., 2003) and adoption of improved soybean seeds in southern Borno State, Nigeria (Idrisa et al., 2012).

Chapter 3

Methodology and Results

1. Analytical Model

A feature of many models of technology adoption is that the process, which leads to the decision to adopt or not, is assumed to be the same which determines the intensity of adoption. However, this is not always the case. Decisions about whether to adopt and how much to adopt can be done together or separately (Gebremedhin and Swinton 2003). The double-hurdle model, originally due to Cragg (1971), is based on the idea that an individual's decision is the result of two processes: the first hurdle, determining whether the individual is a zero type, and the second hurdle, determining the intensity of adoption given that the individual is not a zero type. Both hurdles have equations associated with them, incorporating the effects of individual's characteristics and circumstances. Such explanatory variables may appear in both equations or in either of one. Besides, a variable appearing in both equations may have opposite effects in the two equations. This cannot be properly handled by the Tobit model. Indeed, the implicit assumption of the Tobit model is that the two decisions (adoption and intensity of adoption) are affected by the same set of factors (Greene, 1993).

Furthermore, the double-hurdle model considers that there are two types of zero observations: an individual can be a zero type, and the outcome will always be zero, regardless of the circumstances in which the individual is at the time of the decision; alternatively, the individual might not be a zero type, but the circumstances in which the individual is at the time of the decision might dictate that the outcome is zero. This means that zero values may be reported in both decision stages. The zero-value reported in the first stage arises from non-adoption (subjects who would never adopt under any circumstances), and in the second stage it comes from non-adoption due to respondents' deliberate decisions or random circumstances (potential adopters). This characteristic of the double-hurdle model is in contrast to Heckman's (1979) procedure. In fact, the Heckman procedure does not consider the non-values in the second stage.

For these reasons, both Wooldridge (2002) and Cameron and Trivedi (2005) conclude that the double-hurdle model can be considered as an improvement both on the Tobit and Heckman models.

Finally, for the estimation of the double-hurdle model on STATA software were introduced two different commands: the dblhurdle command by Garcia (2013) and dhreg command by Engel and Moffatt (2014). The advantage of the second command compared to the first is that the dhreg command allows the capture of possible correlation of the error terms between the hurdle equation and the equation for choices that cross the hurdle by the inverse Mills's ratio. This procedure that treats correlation as an omitted variable problem was developed by Heckman (1979). If the error terms are indeed correlated, the inverse Mills ratio from the first stage must have explanatory power for the second stage. Specifically, the coefficient of this additional regressor is precisely the covariance of the two error terms. For the current study the dhreg command was applied in the STATA software.

As mentioned above, the double-hurdle model contains two equations and can be considered as a combined Probit and Tobit estimator (Engel and Moffatt, 2014). From the Probit and Tobit models derive the initial values for the estimation of the maximum likelihood.

The adoption equation (D) is:

$$d_i^* = z_i'\alpha + \varepsilon_{1,i}$$

While the intensity of adoption (Y) has an equation of the following:

$$y_i^{**} = x_i'\beta + \varepsilon_{2,i}$$

The errors terms, ε_1 and ε_2, are distributed as follows:

$$\begin{pmatrix} \varepsilon_{1,i} \\ \varepsilon_{2,i} \end{pmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & \sigma^2 \end{pmatrix} \right]$$

The first hurdle is represented by:

$$d_i = 1 \; if \; d_i^* > 0$$

$$d_i = 0 \; if \; d_i^* \leq 0$$

The first hurdle is thus assumed to be defined by the latent variable d_i^*. The second hurdle closely resembles the Tobit model:

$$y_i^* = \max(y_i^{**}, 0)$$

Finally, the observed variable, y_i, is determined as

$$y_i = d_i y_i^*$$

The log-likelihood function for the double-hurdle model is

$$LogL = \sum_{0} ln\left\{1 - \Phi(z_i'\alpha)\Phi\left(\frac{x_i'\beta}{\sigma}\right)\right\} + \sum_{+} ln\left\{\Phi(z_i'\alpha)\frac{1}{\sigma}\emptyset\left(\frac{y_i - x_i'\beta}{\sigma}\right)\right\}$$

The double-hurdle model has been extensively applied in a variety of contexts, such as Jones (1989) to analyse the cigarette consumption and Hitayezu et al. (2017) to analyse farmers' perceptions about climate change. However, this model is still not widespread in the area of adoption of agricultural technologies.

2. Data Description

The data used in this study come from a survey conducted between April and May 2018 in Uganda, a country where the disease was reported in 2001, continued to spread to all major banana growing regions, and even currently continues to spread into new areas and resurge in areas where it had been managed (Tinzaara et al., 2016; Tripathi et al., 2009; Tushemereirwe et al., 2004). With a strong possibility of disease resurgence, a better understanding of the factors that influence the level of adoption of BXW control practices is desirable for enhanced technology adoption and reducing future resurgence of disease within the region. This will be achieved through farming system analysis approach. Such approach has proved to be a powerful option to shape agricultural support to be more targeted, effective and sustainable (Michalscheck et al., 2014). This is because, biophysical, institutional, social and economic factors differ between farmers and farm, with farms in different development stages, and farmers with different skills and ambitions. As a result, there are differences in responses of farmers and communities to interventions. Establishing different farm typologies helps the intervention can be more targeted, effective and sustainable. Consequently, the general objective of the survey is to establish farm typologies for effective targeting, promotion and sustainable adoption of BXW control practices among banana farming households in Uganda.

The sampling method follows a previous BXW incidence and management survey done in the 2015. The survey was administered through face to face interviews using a pre-tested questionnaire. The enumerators were well trained and had previous experience in banana surveys. The respondents were located in four selected major banana-growing and consuming regions (i.e. Central, Eastern, Mid-Western and South-Western) in Uganda. From each region, three districts were randomly selected. Only for the Eastern region were randomly selected 5 districts. Totalling 14 districts were randomly selected: Kayunga, Kiboga, and Luwero from Central; Bukedea, Kumi, Mbale, Kamuli and Manafwa districts from Eastern; Kabarole, Masindi and Mubende districts from Mid-Western and Bushenyi, Rukungiri and Ntungamo from South-Western region. Two major banana-producing sub-counties were purposively selected per district and from each sub-county one parish was randomly selected. At the parish level, three villages were randomly selected, and 15 households randomly selected per village from village household lists provided by the local council authorities. In total 1,058 rural households were interviewed from all the study sites.

The survey collected data on the following themes: household socio-economic and farm characteristics; BXW incidence on farm; farmers' knowledge of BXW symptoms, mechanisms of spread and control measures; cultural practices in use; banana production, consumption and marketing; livelihoods strategies and coping mechanisms.

3. Empirical Model Variables

For the purposes of this analysis, the sample was divided into non-adopters, partial adopters and full adopters. Full adopters are defined as those smallholders who applied all four main practices altogether: (1) de-budding with forked stick, (2) disinfecting tools with fire or JIK, (3) sick plants removal (cutting down only the single stem affected or the whole mat) and (4) replanting using clean planting material. Full adopters represent about 17% of the sample (180 smallholders over the total surveyed 1,058). On the other side, partial adopters are defined as those banana-based households who applied only one or two or three out of the four main practices (approximately 70% of the sample). This is because not all farmers have the capacity to apply all the BXW control practices as suggested due to limitations such as cost, labour, time, and tradition (Bagamba et al., 2006; Jogo et al., 2011). Finally, non-adopters are the smallholders who did not practice BXW management at all (recognized to be almost 13% of the sample).

The explanatory variables selected for the empirical model presented in this study are based on theoretical and empirical literature on adoption and data availability.

1. Socio-Economics characteristics of the Household
   - Household head gender (1 Male, 0 Female),
   - Household head education (Years),
   - Household head age (Years),
   - Household size,
   - Households' subjective poverty assessment of two years ago (1 Poorest People; 10 Richest People),
   - Availability of Credit Facilities (1 Yes, 0 No),
   - Off-farm income (1 Yes, 0 No).

2. Characteristics of the Farm
   - Region (Central, Eastern, Mid-Western and South- Western),
   - Land Owned
   - Proportion of land under banana,
   - Banana production objective (1 Commercial, 0 Subsistence).

3. Communication Approaches
   - Availability of Trainings (1 Yes, 0 No),
   - Availability of Farmer Field Schools (1 Yes, 0 No),
   - Availability of Community Actions (1 Yes, 0 No).

In Uganda, different communication approaches have been used in order to develop the knowledge and skills of the farmers on the characteristics of the integrated package of practices against the BXW and in return to mobilize them for its adoption. Therefore, variables on the availability of specific communication approaches on the BXW have been incorporated into the analysis to assess whether they have actually been able to influence the decision of adoption of smallholder farmers.

4. Summary Statistics

Table 1 shows the mean value and the standard deviation of each explanatory variable used in this study. The descriptive statistics refer both to the entire sample and to each individual adoption category.

With regard to social-economic characteristics the table shows that the differences across the groups were significant only for the gender of the household head, the availability of credit facilities and the ownership of off-farm income.

Furthermore, it can be seen that the 74% of the households of the considered sample have a male as household head. This value is smaller for farmers that adopts only 2 practices, i.e. 70%, while the higher percentage is related to the group of full-adopters, namely 82%. As for the availability of credit facilities, the group of full-adopters shows around 94% of availability of this service, which represents the highest percentage out of all the groups considered. Conversely, when considering the ownership of off-farm income, the group of non-adopters presents the highest percentage out of all the groups considered (approximately 95%).

Regarding the characteristics of the farm, it is possible to observe that the regional difference between each level of adoption is significant. As for the non-adopters it is possible to observe that about 59% is located in the Eastern Region and only 11% is located in the South-Western Region. On the contrary, full adopters are mostly present in the South-Western Region, i.e. 59%, while they are far less numerous in the Eastern Region, only 6%. The regional distribution of partial adopters is instead in line with the sample average.

In average, the percentage of farm land for the production of bananas is almost 42% for the sample. For non-adopters this percentage is less than 20%.

Banana production is intended for commercial purpose only for 10% of the sample. This confirms the importance of bananas in the diet of Ugandan households. Nevertheless, the difference is not significant across the groups.

Regarding the differences within the sample with regard to the variables linked to the communication approaches adopted in Uganda to mobilize smallholder farmers are all significant. However, it should be noted that the availability of these services is not very high. Trainings on BXW practices are available on average only for 8% of the sample. Such percentage is even lower among non-adopters (only 1%), while for the group of full adopters the percentage reaches the 13%. A similar trend can be observed in the case of FFSs, although the percentages are slightly higher than in trainings. On average the FFSs are available only for 10% of the sample, among the non-adopters the availability is 4% while for full adopters it is 14%. Finally, the most widespread communication approach in the sample is that at the community level (i.e. 15%). Also in this case, the availability of the service is much lower among the non-adopters compared to full adopters (3% and 28% respectively).

Therefore, in general, it is possible to observe that the availability of communication approaches increases with the increase in the level of adoption of the practices.

At the bottom of the table, information is provided on the BXW management package. Among the four BXW control practices, significantly more households practiced replanting using clean planting material, with a percentage of approximately 62%. Around 58% of the sample practiced sick plants removal, followed by timely removal of male buds with a forked stick (i.e. 50%). Use of fire and/or JIK for disinfection of tools was the least adopted practice (just 38% of the sample).

Table 1. *Descriptive statistics of the explanatory variables and BXW control practices by adoption level*

Variables	All Sample (obs. 1058)	Non-Adopters (obs. 133)	1 Practice (obs. 239)	2 Practices (obs. 272)	3 Practices (obs. 234)	Full-Adopters (obs. 180)	F-test[1]
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Explanatory Variables							
HH Head Gender (1 Male)	0.74 (0.44)	0.74 (0.44)	0.74 (0.44)	0.70 (0.46)	0.71 (0.46)	0.82 (0.39)	2.2 *
HH Head Education (years)	5.95 (3.91)	5.90 (4.00)	6.02 (3.82)	6.09 (4.13)	5.52 (3.81)	6.25 (3.71)	1.1
HH Head Age	56.62 (14.46)	57.56 (15.38)	55.44 (14.37)	56.36 (14.69)	58.12 (14.52)	55.94 (13.33)	1.29
HH Size	6.37 (3.14)	6.34 (3.83)	6.46 (3.08)	6.15 (3.15)	6.47 (3.01)	6.49 (2.81)	0.52
Subjective Poverty	4.07 (2.03)	3.95 (2.17)	4.03 (1.96)	4.13 (2.07)	4.04 (2.00)	4.12 (2.01)	0.23
Availability Credit Facilities (1 Yes)	0.81 (0.39)	0.77 (0.42)	0.74 (0.44)	0.79 (0.41)	0.84 (0.37)	0.94 (0.24)	7.8 ***
Off-farm Income (1 Yes)	0.88 (0.33)	0.95 (0.21)	0.90 (0.30)	0.85 (0.36)	0.86 (0.34)	0.84 (0.37)	3.58 ***
Region							
- Central	0.22 (0.41)	0.14 (0.35)	0.19 (0.39)	0.27 (0.44)	0.25 (0.43)	0.19 (0.39)	
- Eastern	0.20 (0.40)	0.59 (0.49)	0.29 (0.46)	0.12 (0.33)	0.10 (0.30)	0.06 (0.24)	14.63 ***
- Mid-Western	0.23 (0.42)	0.17 (0.37)	0.30 (0.46)	0.26 (0.44)	0.23 (0.42)	0.16 (0.37)	
- South-Western	0.35 (0.48)	0.11 (0.31)	0.22 (0.42)	0.35 (0.48)	0.42 (0.50)	0.59 (0.49)	
Land Owned	4.51 (7.19)	3.82 (5.16)	4.64 (8.43)	4.53 (4.69)	4.07 (4.45)	5.41 (11.43)	1.25
Land Banana Percent	41.52 (31.07)	19.84 (30.26)	40.38 (31.88)	45.03 (30.07)	46.56 (29.00)	47.22 (27.81)	21,78 ***
Farm Objective (1 Commercial)	0.10 (0.30)	0.08 (27.65)	0.11 (0.31)	0.11 (0.31)	0.09 (0.28)	0.12 (0.32)	0.49
Availability Trainings (1 Yes)	0.08 (0.27)	0.01 (0.09)	0.07 (0.26)	0.09 (0.28)	0.08 (0.27)	0.13 (0.34)	4.27 ***
Availability FFS (1 Yes)	0.10 (0.29)	0.04 (0.19)	0.08 (0.28)	0.09 (0.28)	0.11 (0.31)	0.14 (0.35)	2.86 **
Availability COMMUNITY (1 Yes)	0.15 (0.36)	0.03 (0.19)	0.12 (0.32)	0.14 (0.34)	0.17 (0.38)	0.28 (0.45)	10.61 ***
BXW Control Practices							
De-Budding (1 Yes)	0.50 (0.50)	0.00 (0.00)	0.31 (0.46)	0.57 (0.50)	0.50 (0.50)	1.00 (0.00)	131,48 ***
Disinfecting Tools (1 Yes)	0.38 (0.49)	0.00 (0.00)	0.01 (0.11)	0.18 (0.38)	0.73 (0.44)	1.00 (0.00)	477,93 ***
Sick Plants Removal (1 Yes)	0.58 (0.49)	0.00 (0.00)	0.24 (0.43)	0.58 (0.49)	0.95 (0.21)	1.00 (0.00)	296,90 ***
Clean Planting Material (1 Yes)	0.62 (0.48)	0.00 (0.00)	0.44 (0.50)	0.68 (0.47)	0.81 (0.39)	1.00 (0.00)	162,57 ***

[1] *ANOVA oneway*. Level of significance: * 10 %; ** 5 %; *** 1 %. Note: Values in parentheses are standard deviations (SD).

5. Results

Table 2. *Marginal effects of the double-hurdle model*

First Hurdle	Coef.		SE	P-value
HH Head Gender (1 Male)	-6,427		278,182	0,982
HH Head Education (Years)	-0,258	***	0,073	0,000
HH Head Age (Years)	-0,043	***	0,016	0,008
HH Size	0,464	***	0,135	0,001
Subjective Poverty	-0,017		0,090	0,849
- Central Region	4,438		136,190	0,974
- Eastern Region	-2,031	***	0,595	0,001
- Mid-Western Region	4,759		149,554	0,975
- South-Western Region			Omitted	
Land Owned	0,105	**	0,052	0,041
Land Banana Percent	0,022	*	0,012	0,062
Banana Production Objective (1 Commercial)	0,450		1,340	0,737
Availability Trainings (1 Yes)	6,514		217,056	0,976
Availability FFS (1 Yes)	-0,054		0,666	0,935
Availability COMMUNITY (1 Yes)	-1,163	*	0,691	0,093
Constant	10,592		278,188	0,970
Second Hurdle				
HH Head Gender (1 Male)	0,041		0,091	0,650
HH Head Education (Years)	0,002		0,010	0,837
HH Head Age (Years)	0,001		0,003	0,707
HH Size	0,016		0,013	0,219
Availability Credit Facilities (1 Yes)	0,411	***	0,100	0,000
Off-farm Income (1 Yes)	-0,081		0,113	0,472
- Central Region	-0,373	***	0,112	0,001
- Eastern Region	-1,014	***	0,138	0,000
- Mid-Western Region	-0,656	***	0,114	0,000
- South-Western Region			Omitted	
Land Owned	0,005		0,005	0,333
Land Banana Percent	-0,002	*	0,001	0,100
Availability Trainings (1 Yes)	0,059		0,142	0,678
Availability FFS (1 Yes)	0,087		0,129	0,499
Availability COMMUNITY (1 Yes)	0,056		0,123	0,648
Inverse Mills Ratio	-1,781	***	0,222	0,000
Constant	2,233	***	0,258	0,000
Sigma				
Constant	1,157	***	0,028	0,000

Note: Level of significance: * 10 %; ** 5 %; *** 1 %

Table 2 shows marginal effects of the double-hurdle model. As expected, there were different sets of factors behind the decision to adopt and the decision about to which extent to do so. Farm households' decision on adoption of BXW control practices was positively affected by the size of both the household and the farm, as well as the percentage of land used for banana production. The age and level of education of the head of the household have instead negatively influenced the decision to adopt. On the other hand, farmers' decision on the extent of adoption was positively influenced only by the availability of credit facilities and negatively influenced by the percentage of land used for banana production and the Region where the household is located.

Among the socio-economic characteristics, gender of a household head is not a factor that can significantly influence either the decision to adopt or the intensity of adoption. The same also applies to the subjective level of poverty and the ownership of off-farm income.

With reference to the characteristics of the farm, the intended use of the banana production was found to be not significant on the adoption decision, while farm size significantly influenced the adoption decision but not the intensity of adoption of the practices promoted to limit the spread of the BXW.

Finally, institutional approaches adopted to raise awareness and mobilize households towards the disease were not able to influence the adoption decision or the intensity of adoption of the practices. Only the availability of community level initiatives (bye-laws, action plans, BXW control committees) has significantly influenced the decision to adopt but not the intensity of adoption.

Discussion and Conclusions

1. Discussion

Results show significant effects of the age and educational level of the household head, household size, land owned, percentage of land used for banana production, as well as regional differences on farmers' adoption decision. As the negative marginal effect of age suggests, one extra year of age is likely to decrease a farmer's probability of adopt any of the BXW control practices of around 4%. This result is in line with adoption of land conservation practices in Niger (Baidu-Forson, 1999), rice in Guinea (Adesina and Baisu-Forson, 1995), and fertilizer in Malawi (Green and Ng'ongo'ola, 1993). The negative effect of age can be attributed to the fact that elderly farmers are typically more risk-averse and are less willing to try new technologies. Household size is significant at 1% and is positively related to adoption of the BXW control package. This suggests that large families are more likely to adopt the control package than smaller ones. This result is consistent with the finding by Jogo et al. (2013) that lack of labour is a key limiting factor for adoption of the recommended BXW control package. Katungi and Akankwasa (2010) similarly found a positive and significant relationship between household size and adoption of corm paring banana technology for pest management among banana farmers in Uganda. Surprisingly, the householder's educational level is significant at 1% and is negatively associated with the decision to adopt the BXW control package. However, this result is in line with what was reported by Uematsu and Mishra (2010). Indeed, their study suggests that formal education can be a barrier to technological adoption. Moreover, the extension of land owned and the percentage of land used for banana production are two variables related with the characteristics of the farm that positively influence the adoption decision. Many studies confirm this positive relation between the size of the farm and the adoption of agricultural technology (Mignouna et al, 2011; Uaiene et al., 2009; Ahmed, 2004; Gabre-Madhin and Haggblade, 2001; Kasenge, 1998). While the positive relation between the proportion of land area allocated to banana production and the adoption of the BXW control package is in contrast with the findings of Jogo et al. (2013). In that case, the variable was found not significant. Finally, the results show that farm households living in the Eastern region are less likely to adopt any of the BXW control practices than those in the South-Western region.

Focusing on the determinants of the intensity of adoption, the results of the double-hurdle model indicate that availability of credit facilities positively and significantly influence this decision. The availability of credit lines increases the likelihood that smallholder farms adopt a greater number of practices by 41%. The result is in line with the study of Idrisa et al. (2012) that showed that access to credit had positive and significant influence on the extent of adoption of improved soybean seed in Nigeria. As for the proportion of land area allocated to banana production, its coefficient is negative and significant at the 10% but it is near to zero. Going further, from the results of the model it is possible to observe that the marginal effects of the dummies regions are all negative and significant (at 1%). Farm households living in the Central, Eastern and Mid-Western region are less likely to adopt more than one BXW control practice compared to those in the South-Western region of around 37%, 101% and 66% respectively. The findings are in line with the study of Kikulwe et al. (2019) that showed that regional differences significantly influenced adoption of the control practices against BXW spread.

Before concluding, it is appropriate to highlight some of the limitations of the present study. First of all, the study does not consider the origin of the clean planting material. In fact, the informal source of inputs (such as farmer-to-farmer exchange) is preferred by farmers as the cost is lower than when buying from formal sources (Bagamba et al., 2006). However, this socio-cultural practice based on the exchange of inputs rather than on their purchase could aggravates the problem because it increases the risk of BXW spreading (McCampbell et al., 2018; Tinzaara et al., 2013). Despite this, for the purposes of this study it was not considered relevant to deepen the distinction between formal and informal source of clean planting material.

Furthermore, the database has some limitations regarding the timing of some variables. While the variables on the adoption of the BXW control practices refer to the last twelve months, the variables on participation in institutional initiatives (such as FFSs and trainings on BXW) refer to the last six months. Furthermore, from the survey, it is not possible to know if the respondents have previously participated in these initiatives. In this way it is not possible to correctly determine the influence of these variables on the adoption decision. The variables on the availability of these activities, on the other hand, had no time frame. For this reason, we have decided to include only the variables on the availability of these institutional activities in the analysis.

Finally, it is important to note that BXW was first reported in Uganda in 2001. Since 2002, there has been a series of campaigns to sensitize farmers and other stakeholders on the disease symptoms, its spread mechanisms and to promote available control options. The data used in this study come from a survey conducted between April and May 2018, where the variables on the adoption of the BXW control practices refer to the last twelve months. With this in mind, it is possible to conclude that the present study does not take into consideration the determinants of adoption of a new agricultural technology, but the factors that push later adopters to adopt a technology now widespread in Uganda.

2. Conclusions

Banana Xanthomonas Wilt is the major biotic threat to banana production in Uganda that can cause the loss of the entire production, hence threatening the income and food security of millions of smallholder farmers in the region. No banana variety is resistant to the disease, but thanks to a fruitful mix of global, national and local efforts, an integrated system of cultural practices has been identified. The cultural practices recommended to limit the spread of the BXW are the following four: (1) de-budding, (2) disinfecting tools, (3) sick plants removal, and (4) clean planting materials.

This study contributes to the growing literature on pest management by identifying factors responsible to sustain the rate and intensity of adoption of the entire BXW control package in Uganda. Indeed, this study is the first to include the use of clean planting material in the analysis of the determinants of adoption of the practices to limit the spread of the BXW. Furthermore, the base assumption of this study is that the two adoption decision processes (adoption and intensity of adoption) are separate. The double-hurdle class of model has been applied in this study with this important distinction in mind. The model was fitted to a sample of 1058 smallholder farmers located in four selected major banana-growing and consuming regions (i.e. Central, Eastern, Mid-Western and South-Western) in Uganda.

Among the four BXW control practices, the present study has shown that the practice most adopted by the sample analysed is the use of clean planting materials, while the less adopted is the disinfection of agricultural tools, with an adoption rate of 62% and 38% respectively. Moreover, the analysis shows that those who fully adopt the integrated package of practices against BXW are about 17% of the sample. The farm households who have not practiced BXW management at all are approximately 13% of the sample. Finally, those banana-based households that adopt only one, only two or only three of the four recommended practices represent the remaining 70% of the sample. Therefore, it is possible to conclude that still few farmers are deploying the full package on their farms making eradication of the disease difficult.

One aspect in which the model result is interesting is the apparent differences in explanatory variables between the two hurdles. Although different, they can be linked to the economic availability of rural households. Indeed, access to physical and financial assets influences the capacity of farm households to invest in innovation (Mwangi and Kariuki, 2015; Jogo et al., 2013).

The number of family members is used as a proxy for availability of labour. It determines adoption process in that, a larger household have the capacity to relax the labour constraints required during introduction of new technology (Mwangi and Kariuki, 2015; Mignouna et al, 2011; Bonabana-Wabbi 2002; De Souza Filho et al., 1999). Households containing members able to participate in on-farm activities enable farmers to adopt labour-intensive technologies (Feder et al., 1985). If technologies are capital-intensive, household members may work off-farm to generate income to purchase farm inputs. Household size and the extent of family involvement in agriculture positively and significantly influenced the adoption of integrated control of rice stem borer in the Isfahan province (Pezeshki-Rad et al., 2006), the adoption of biological control in northern Iran (Noorhosseini et al., 2010) and the adoption of corm paring banana technology for pest management among banana farmers in Uganda (Katungi and Akankwasa, 2010).

The total farm area serves as one of the most important economic factors for farmers, particularly in developing countries, where small-scale farmers are mostly concerned with production costs. For this reason, farm size, which is a measure of household wealth, has been widely analysed as one of the determinants of technology adoption (Langyintuo and Mulugetta, 2008; Nyangena, 2007). Availability of land gives farmers more freedom to consider risky options beyond conventional crop production, given that large landholders can wait longer for returns than small-scale farmers. Thus, the adoption of new farming technologies is normally driven by the availability of farmland (Ajayi et al., 2003). In case of technologies that are capital-intensive, these are only affordable by wealthier farmers (El Osta and Morehart, 1999) and hence adoption of such technologies is limited to larger farmers who have the wealth (Khanna, 2001). Farmers with large farm size are likely to adopt a new technology as they can afford to devote part of their land to try new technology unlike those with less farm size (Uaiene et al., 2009). Many studies confirm this positive relation between farm size and adoption of agricultural technology (Mignouna et al, 2011; Uaiene et al., 2009; Ahmed, 2004; Gabre-Madhin and Haggblade, 2001; Kasenge, 1998).

As for the availability of credit facilities, it positively influences the intensity of the adoption. This because access to credit loosens the liquidity constraint and stimulate household's-risk bearing ability

(Simtowe and Zeller, 2006). Consequently, a rural household will perceive the adoption of the integrated package of cultural practices less risky and will have more incentive to adopt it if it can receive financial aid to support the initial investment required.

From this we can conclude that farm households with a high number of family members, a large extension of land owned and with the possibility of accessing to credit are the most likely to adopt the BXW control package. Conversely, small farming households may have budgetary constraints that limit the adoption of practices. Probably, the reason why farmers did not adopt the integrated package of practices for controlling the BXW could be the initial costs of the inputs. Indeed, in studying determinants of adopting an innovative technology, all the costs related to the adoption and use of the new technology play a fundamental role (Foster and Rosenzweig, 2010). The cost of adopting agricultural technology has been found to be a hindrance to technology adoption (Mwangi and Kariuki, 2015). For instance, the study of Makokha et al. (2001) showed that high cost of inputs and limited availability of demanded packages as the key restraints to fertilizer adoption. Besides, cost of hired labour was also reported by different studies as a factor constraining adoption. Some examples are the adoption of fertilizer and hybrid seed in Embu county Kenya (Ouma et al., 2002), the adoption of improved maize variety in coastal lowlands of Kenya (Wekesa et al., 2003) and adoption of improved soybean seeds in southern Borno State, Nigeria (Idrisa et al., 2012).

For these reasons, it is crucial that the government re-launch specific investments to effectively support farmers in the adoption process of the BXW control package. Particularly regarding two major inputs that farm-households struggle to provide themselves, recognized as JIK and clean planting material.

Furthermore, the National Government and other stakeholders of the banana value chain should continue to invest in communication and awareness campaigns. It is important to inform farmers about the distribution of the benefits in time and the profits that will come from the adoption of the full package. Although the application of this practices implies a relatively high initial investment of money, time, and labour, they represent the only possible solution against this great biotic threat to banana production. With a strong possibility of the disease resurgence, it is important to prevent the next BWX outbreak as it might lead to potentially heavy economic losses among banana producers.

Aware of the difficulties and limitations of this analysis, the current study aims to provide the basis for new research in this area. This in order to make the farm households able to promptly prevent damage caused by a next outbreak of BWX or another disease in Uganda or in the East and Central Africa in general.

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