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Public and private investments for banana Xanthomonas Wilt control in Uganda: The economic feasibility for smallholder farmers

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Banana Xanthomonas Wilt (BXW) poses a serious threat to livelihoods and food security for millions of households in Africa. Despite considerable investments in Uganda by the Government and other national and international stakeholders, the disease persists in the country after periods of significant resurgence. Building on the Agricultural Innovation Systems framework, this paper reviews the role of the major stakeholders involved in controlling the disease in Uganda. Next, using household survey data, it analyzes economic costs and benefits of adopting an integrated BXW control package for the Ugandan smallholder farmers.

After 2015, there has been a significant reduction in both public and private investments in BXW management, which may contribute to future disease resurgence. Our analysis reveals a high level of partial adoption of BXW recommended practices, and just a third of farmers adopting a full control package. This means significant economic losses for non-adopters, as indicated by our findings that households adopting the full package registered a net balance of US$65 per acre higher than non-adopters. We find that disproportionally large costs need to be borne at the beginning of the process, while the benefits are distributed over time, which may present a barrier to adoption by resource-poor smallholders.

Keywords: technology adoption, Xanthomonas Wilt, cost–benefit analysis, banana farming, Uganda

Introduction

Bananas represent an important staple food and cash crop in East and Central Africa (ECA), contributing to food security and household income of rural populations (Ouma et al. 2010; Blomme et al. 2019). Since 2001, regional banana production has been seriously affected by Banana Xanthomonas Wilt (BXW) disease, caused by the bacterium *Xanthomonas Vasicola pv. Musacearum* (*XVM*) (Valentine et al. 2006). The disease often leads to complete crop loss, seriously compromising the food security and livelihoods of many rural households (Ssekiwoko et al. 2015; Blomme et al. 2017a). While it has clearly affected food security in East and Central Africa, its impact on the welfare of the farmers is not yet fully understood (Geberewold 2019).

Uganda is a secondary centre of genetic diversity for bananas where per-capita banana consumption is amongst the highest in the world (Gold et al. 2002; Karamura and Mgenzi 2004; Karamura et al. 2010; Daniells and Karamura 2013). Therefore, BXW poses an extremely high threat to the farmers' livelihoods, food security and even the overall economy. Studies show that during the first peak, between 2001 and 2004, the incidence in affected fields increased by 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).

Over the years, a mix of global, national and local research and extension efforts have been deployed to manage the disease. The development of a genetically modified (GM) banana resistant to BXW could represent an economically viable option (Ainembabazi et al. 2015). However, in Uganda the GM technology is not available yet (Bendana 2020). In the absence of any reported BXW resistance, the most effective agricultural practices for containing disease spread and resulting yield loss were developed (Blomme et al. 2017a). Such practices were identified using information obtained from epidemiological studies implemented within several partnerships from local and international research institutes and universities (Tushemereirwe et al. 2006). Rural development stakeholders from government and non-governmental organizations also contributed to developing, creating and promoting these practices and linked field trials (Ssekiwoko et al. 2006). In some cases, households have been involved in the process in order to adapt the recommended practices and make them more consistent with the reference context (Bagamba et al. 2006). Combinable complementary practices (rather than stand-alone measures) include: (1) de-budding; (2) removing diseased plants;[1] (3) disinfection of tools; and (4) use of clean planting material (Tushemereirwe et al. 2006; Tripathi et al. 2009; Kubiriba et al. 2014; Kubiriba and Tushemereirwe 2014). Importantly, complete BXW control is only possible by deploying all these practices together, which can be achieved with participatory approaches that effectively sensitize and mobilize households regarding BXW and its control (Kubiriba and Tushemereirwe 2014). For this reason, the Ugandan Government jointly with different NGOs has widely promoted an integrated system of cultural control through awareness campaigns, community action, farmer field schools and other

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participatory methods that involve smallholders' active participation (Kubiriba et al. 2012).

Despite these efforts, the emergence of BXW in Uganda continues to pose a significant problem. After a period of lower incidence, the second peak occurred in 2013, with more than 50% incidence (National Banana Research Program Website 2015). BXW is also currently present in the whole of the African Great Lakes region (AGLR), i.e. Burundi, Democratic Republic of Congo (DR Congo), Kenya, Rwanda, Tanzania, and Uganda and it is spreading westwards putting the plantain belt of central and west Africa at risk (Ocimati et al. 2019). When studying BXW management it is necessary to understand the causes of disease persistence. Following the Agricultural Innovation Systems (AIS) perspective, we recognize that agricultural innovation involves many different actors and factors and that it can only be successful if it meets the farmers' needs. The Food and Agriculture Organization (FAO) defines AIS as 'a strategic framework that takes a demand-driven, interactive approach to technological and institutional change in agriculture. It emphasizes a continuing process of stakeholder interaction in a wider enabling environment to address constraints, thus inducing innovation' (FAO 2015). In a robust AIS, actors must operate independently while maintaining continuous connections with other system players in order to form interactive networks (Sanya et al. 2018). No single actor dominates, and farmers are recognized as equally valuable sources of innovation (Poncet, Kuper, and Chiche 2010; Dolinska 2017). In addition, socio-technical adaptation of the innovation in specific contexts is important in order to meet the needs of the end user (Cullen et al. 2014). Effective interventions depend on actions on all decision-making levels, from the government to farmers. Consequently, it is crucial to understand actors' involvements in the 'value chain' of BXW management and what are their costs and benefits.

From the farmer perspective, the promoted BXW control practices were viewed as effective, however their adoption and impact on livelihoods is complex and depends on a variety of factors (e.g. Okurut et al. 2006; Biruma et al. 2007; Blomme et al. 2007, 2019; Mwangi et al. 2007; Jogo et al. 2013; Kikulwe et al. 2018). For instance, household perception of BXW control effectiveness significantly influences adoption of practices which, in turn, influences household food security. Households that perceive practices to be cost effective are more likely to adopt them which, in turn, enhance household food production resulting in increased food security (Kikulwe et al. 2018). Additionally, training received is an important factor boosting the adoption of the practices, especially in the case of women (Kikulwe et al. 2019).

Both from the national and household perspective, the assessment of economic feasibility of the package is still missing. Much of the literature focuses on methods for identifying and promoting the practices (Muhangi et al. 2006; Okurut et al. 2006; Ssekiwoko et al. 2006; Kubiriba and Tushemereirwe 2014; Blomme et al. 2017b); however, evaluating the corresponding benefits of their adoption is usually omitted. The same observation can be made with reference to the long-term economic feasibility of households adopting these cultural practices. Kubiriba and Tushemereirwe (2014) argue that no single management option in isolation can effectively contain the spread of the disease, and only the adoption of the whole package of practices is effective. Kikulwe et al. (2019) report on the impact of adoption level of BXW control practices on the value of banana production, which is a step towards better understanding the economic benefits of BXW management. The authors show a positive and significant impact on banana farmers' productivity and sales resulting from adoption of BXW control practices. Despite this, we did not manage to find any studies that analyze both the economic capacity of banana-based households to support the adoption of such practices in the long term and the overall investment returns.

In response to this, in order to improve the effectiveness of the BXW management in Uganda and to provide lessons for other countries that face the same battles, it is crucial to answer the following questions:

- Who are the main actors in the AIS of the BXW management, and what are their interactions, efforts and costs related to fighting the disease? What has proven effective and what has failed?
- What are the costs and benefits of managing BXW for smallholder farmers? Are there economic reasons behind the low adoption rates of the integrated package of cultural practices?

In this study, we aim to answer these research questions. We follow the AIS framework and use qualitative and quantitative data to identify the main economic actors involved in the banana value chain, including national and international institutions, together with their investments in disease management in Uganda. Moreover, we quantify the costs and returns on investment into BXW control at farm-household level to determine if the integrated package of cultural practices promoted to limit the spread of BXW is economically feasible for the banana-based households in Uganda.

This paper is organized as follows. The next section introduces data sources, followed by a presentation of the outcomes of the analysis. The final section presents the discussion and conclusions.

Data sources and analytical framework

AIS actors can be all public and private actors involved in the development, dissemination, adaptation, and utilization of all kinds of information related to agricultural production and marketing. In sub-Saharan countries, an AIS usually includes: traditional sources of innovation (indigenous technological knowledge); modern actors (NARIs, international institutes of agricultural research, universities, and advanced research institutes); the private sector, including (local, regional, and multinational) agro-industrial firms and entrepreneurs; civil society organizations (NGOs, farmers, consumer organizations, and advocacy groups); and institutions (laws, rules, values, traditions, and norms) that influence the production and distribution of innovations (Anandajayasekeram 2011).

In this study, the innovation is represented by the full package of practices to be applied against BXW. Therefore, the actors highlighted in this study are those who have a role in the creation, implementation, dissemination, and communication of the practices to contain the spread of BXW. As can be seen from Figure 1, multilateral organizations (such as Bioversity International) together with national agencies (such as National Agricultural Research Organization (NARO)) are responsible for bringing research and education into the framework; the political system, such as local governments, National Agricultural Advisory Services (NAADS), and the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) can be considered the bridge between science and the agricultural value chain actors (Aerni et al. 2015). Finally, private companies and sub regional and continental organizations contribute to agricultural value chain in many ways.

Regarding the data sources, this analysis is based on two different types of data: (1) qualitative data collected through key informant[2] interviews in 2018, and (2) quantitative data collected through a survey conducted in 2018 among smallholder farmers in four different regions of Uganda. Data were collected and analyzed separately and then combined for validation (Gotor, Caracciolo, and Watts 2010). Qualitative information provided by key informants was also used for a better understanding of the smallholders' data obtained through the survey. We identified a relatively small group of key informants[3] upon their in-depth knowledge of the banana sector, with focus on BXW and the related investments. Table 1 shows the list of the 14 experts that were interviewed following a semi-structured format.

The informants can be mapped along the value chain of the stakeholders belonging to the AIS framework, as shown in Figure 1. Data were analyzed through narrative analysis (Kawulich 2004) to identify common narrative patterns.

The quantitative analysis is based on information collected from Ugandan banana-based farm-households through a survey carried out between April and May 2018. The sampling method follows a previous BXW incidence and management survey done in 2015, and more detailed data on management costs were collected from four purposively selected major banana-growing and -consuming regions (i.e. Eastern, Central, Mid-western and South-western). From each region, three districts were randomly selected, totalling 12 districts (Kamuli, Kumi and greater Mbale district from Eastern; Kayunga, Kiboga, and Luwero from Central; Bushenyi, Rukungiri and Ntungamo from South-western; and Kabarole, Masindi and Mubende districts from Mid-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 at least 15 households randomly selected per village from village household lists provided by the local council authorities. A minimum of 90 households were interviewed per district, except Bushenyi district whose sample size was doubled due to high incidence of BXW. The total sample size included 1,170 respondents. However, due to missing data, some responses were dropped. The sample frame is summarized in Table 2.

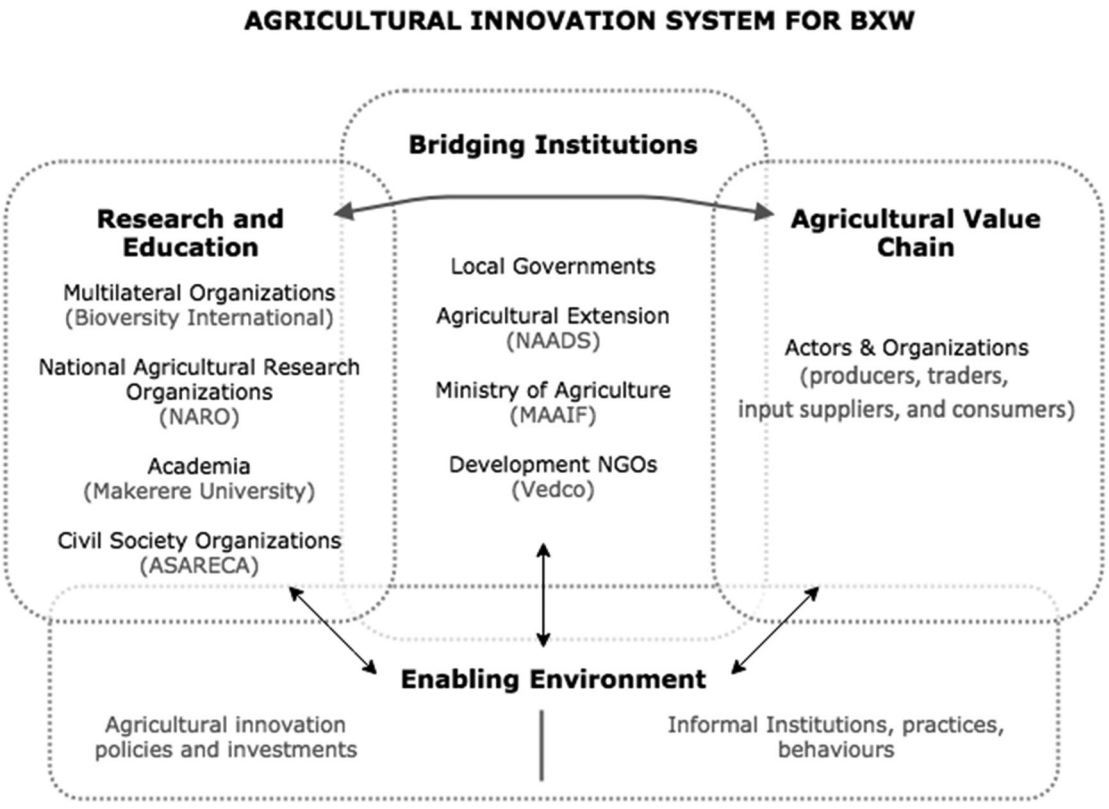

Figure 1: The Agricultural Innovation System Framework for BXW.
Source: Adapted from Aerni et al. 2015

Table 1: Key informant interview sample.

Stakeholders	Organization	Role
Local agencies	Local Government – District of Wakiso	• Head of Production and Marketing Department • Extension Officer
	Local Government – District of Mukono	• District Agricultural Officer • Head of Production and Marketing Department
	Local Government – District of Luwero	• Principal Agricultural Officer
National agencies	National Agricultural Advisory Services (NAADS)	• Head of Account Unit
	National Agricultural Research Organization (NARO)	• Responsible for Banana Program
	Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)	• Commissioner Crop Protection • Director of Agricultural Extension Service
Multilateral organizations	Bioversity International	• Regional representative in East and Southern Africa • Associate scientist
	Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)	• Interim Executive Secretary
Private companies	Private company	• Chief Executive Officer • Account Assistant

Table 2: Study quantitative sampling frame.

Region		District		Sub-counties	Parish	Village	Household
Eastern	1	Kamuli	1	2	2	6	90
		Kumi	1	2	2	6	90
		Greater Mbale	1	2	2	6	90
Central	1	Kayunga	1	2	2	6	90
		Kiboga	1	2	2	6	90
		Luwero	1	2	2	6	90
South-western	1	Bushenyi	1	2	2	6	180
		Rukungiri	1	2	2	6	90
		Ntungamo	1	2	2	6	90
Mid-western	1	Kabarole	1	2	2	6	90
		Masindi	1	2	2	6	90
		Mubende	1	2	2	6	90
Total	4		12	24	24	72	1170

The survey is composed of several sections including household information, activities for BXW management, and banana production costs and yield. We focus on the data coming from the latter section in order to verify if the integrated package of cultural practices promoted to limit the spread of BXW is cost effective at farm level.

National and international effort against BXW

The first objective of the study aims to identify the main actors in the BXW management AIS and their contribution. Table 3 lists the actors involved in efforts to control BXW and their specific activities. The information contained in this table is based on the discussion with experts. The qualitative data on costs were collected from at least one representative per sector, with the purpose of identifying as many investments as possible. Thus, this is not intended to be an exhaustive representation of all the costs sustained by each sector, but rather a map of records.

Activities were listed and disaggregated by stakeholder as follows: local and national agencies, multilateral organizations, and private companies and foundations. Each stakeholder presented in the table, along with their related activities, is part of a network that covers all the fields of action of the AIS against BXW.

National agencies have played a prominent role regarding research and education within the AIS. Indeed, the national agencies have carried out communication campaigns through radio, TV, newspapers, posters, etc. They were also in charge of developing the participatory approaches implemented at local level, together with monitoring and surveillance of activities. Specifically, the National Agricultural Research Organization (NARO) carried out a study and development of control practices, as well as monitoring and evaluation activities.

More specifically, during the three-year period of 2013–2016 (at the climax of the disease), the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) created a budget dedicated exclusively to managing BXW. A total amount of 7,389 million Ugandan shillings (around US$2.9 million at the exchange rate in 2013) was allocated for this purpose. The distribution of costs among each activity carried out by MAAIF is shown in Figure 2. More than half the budget was spent on demonstrations and community actions,[4] which are considered highly effective techniques, especially at local level. In fact, a key informant stated:

Table 3: List of activities carried out at national and international level.

	Stakeholders			
Activity	*Local agencies*	*National agencies*	*Multilateral organizations*	*Private companies & foundations*
Awareness and education campaigns	✓			
By-laws	✓			
Monitoring & surveillance	✓	✓		
Distribution of clean planting material	✓	✓		✓
Communication campaigns		✓		
Quarantine		✓		
Development of resistant varieties		✓	✓	
Development of control practices		✓	✓	
Monitoring and evaluation		✓	✓	
Demonstrations			✓	
Support, coordination & management			✓	
Allocation of funds			✓	✓

Source: Key informants, personal communication

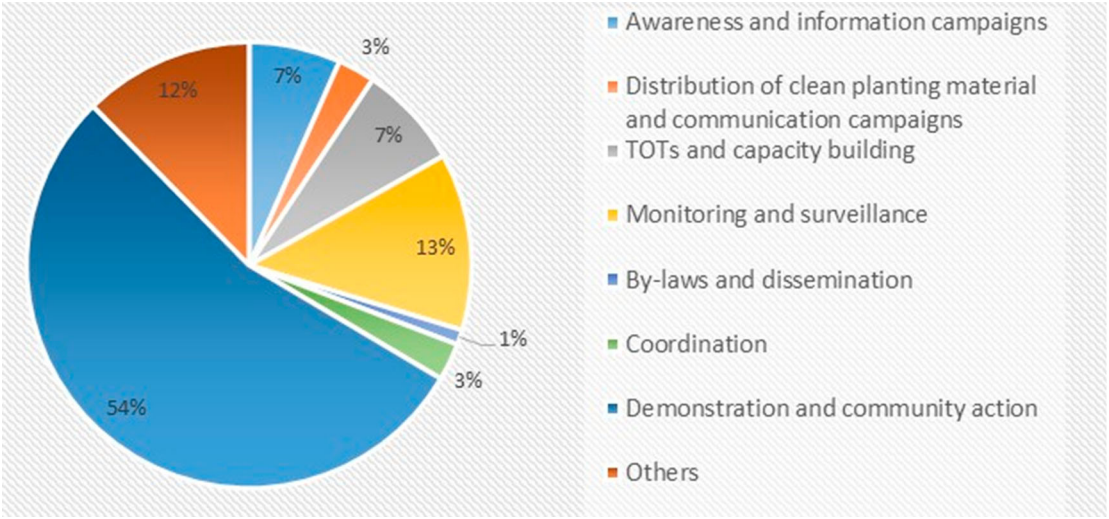

Figure 2: Distribution of costs sustained by MAAIF for BXW management.
Source: Key informants, personal communication.

> *In my opinion, the most effective activities at district level are demonstrations of* [using] *clean planting material and monitoring. Thanks to demonstrations, households know how to recognize a clean plant and now they are more careful when they buy new suckers*.

Participatory community-centred communication is important not only to enhance households' capacity and awareness, but also to adapt their interventions and increase effectiveness of communication channels (Tinzaara et al. 2013a). Indeed, the structure of knowledge development is gradually becoming more and more horizontal over time. Meetings for the exchange of knowledge between farmers and between them and government officials encourage the dissemination of knowledge and the adoption of innovations within the AIS (Leitgeb and Vogl 2010).

One of the key informant interviews revealed that the massive campaign carried out by the National Government in 2013 prevented households from heavy yield loss, managing to recover 64% of monthly sales from BXW affected areas compared to the peak period (National Banana Research Program Website 2015). Furthermore, from 2013, the Government of Uganda launched the 'Operation Wealth Creation' (OWC) project that, among the other things, provides agricultural inputs for households including clean planting material critical to fight BXW.

Currently, national agencies do not receive funds specifically for fighting BXW; and the local situation reflects that at the national level. During the last BXW peak, 40 districts in Uganda received a total of US $540,000 from MAAIF, specifically for BXW management. At present, districts receive money every year from the 'Production and Marketing Grant' founded by the national government, of which pest and disease monitoring takes 10% of the budget. As an example, Luwero District uses 1 million Ugandan shillings (around US $270 at current exchange rate) per quarter to do BXW monitoring, 500,000 Ugandan shillings (US$135) per quarter to do demonstrations and 500,000 Ugandan shillings (US$135) per quarter to pay transport and allowance for the extension staff. Out of the budget, each district is free to allocate as much as is required for BXW management. However, the opinion that has been reported at a

local level is that lately the government has not provided enough funds to carry out all the practices and activities needed to fight BXW. As an example, in Wakiso district they currently do only distribution of new planting materials and a few training sessions are implemented by extensionists.

With this in mind, the Ugandan National Agricultural Research Organization (NARO) actively co-operated with different multilateral organizations including Bioversity International for improving productivity through generating, promoting and scaling practices such as Single Diseased Stem Removal (SDSR) and de-budding, and linking households to markets through agricultural information in cooperation with other regional agencies (e.g. extension offices and local Government). Moreover, between 2012 and 2015, NARO invested US$2 million received from the World Bank and the Food and Agricultural Organization (FAO) for carrying out activities such as field trials, data collection, biosafety regulation and promotion campaigns (Figure 3). Furthermore, NARO is currently focusing on developing resistant varieties, both obtained from genetic modification and conventional breeding. Indeed, the development of disease-resistant banana cultivars remains a high priority since households are often reluctant to employ labour-intensive disease-control measures (Namukwaya et al. 2012), severely compromising its eradication. This is in line with AIS, which highlights the importance of local adaptation of agriculture innovations in order to meet the needs of the final users (Adejuwon 2019).

Many multilateral organizations and humanitarian agencies have been active in the country to fight the spread of BXW, supporting both the government and research centres through donations and providing qualified personnel to educate households about BXW control.

The main non-profit organizations that have been active during the last peak of the disease in 2011–2013 were the World Bank, FAO, USAID, the McKnight Foundation, the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and Catholic Relief Services (CRS). Unfortunately, investments at the international level were discontinued in some cases even before 2015.

Following the narrative analysis of qualitative data (Kawulich 2004), it is possible to identify a common path focused on the dissemination of information. Even if in different forms, it is possible to gauge the levels of commitment by the various stakeholders to increasing farmers' knowledge and skills on BXW control. Some examples are communication and education campaigns, demonstrations, training sessions and meetings. All these initiatives are very important in the AIS as they allow farmers to make more informed choices and promote the adoption of the package of practices promoted to limit BXW spread (Leitgeb and Vogl 2010).

Furthermore, it is possible to identify another common path that shows the difference between investments at macro-level during the last peak of BXW in the country and the current situation. Indeed, all the costs sustained by MAAIF regarding BXW during the past three years have not been specifically targeted against the disease but have been a part of the general budget for pest and disease control. As for the MAAIF, the amount of funds paid out for BXW control from multilateral organizations and private agencies has also been drastically reduced.

It is possible to observe this trend from Table 4 which summarizes the information obtained from the key informant interviews, regarding the investments made to limit the spread of BXW classified by stakeholder and time period.

This reduction in both public and private investments in management of BXW is consistent with the 2015 declaration that BXW in Uganda was declared under control, with less than 2% of banana plantations affected by the disease.

Nevertheless, some stakeholders have argued that the current level of investment is not sufficient to meet the demand of all banana-based households, especially regarding certain inputs, such as JIK (commercial sodium hypochlorite) and clean planting material, perceived by farmers as expensive and with low availability (McCampbell et al. 2018). 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). This shows that smallholder farmers depend heavily on their network relationships to seek resources to overcome the challenges they face (Magala, Najjingo Mangheni, and Miiro 2019). 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 (Tinzaara et al. 2013b; McCampbell et al. 2018).

Overall, stakeholder interviews revealed the trend of investments that occurred in the past 10 years, wherein multilateral organizations and private companies and foundations played a great role, especially during the first peak. However, the effort carried out by the

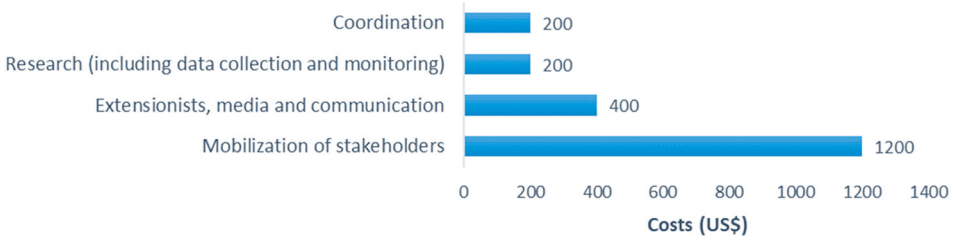

Figure 3: Distribution of costs sustained by NARO against BXW, 2012 - 2015 (US$'000).
Source: Key informants, personal communication.

Table 4: Investments in BXW management (2006–2018).

Stakeholders		Amount of investment (US$' 000)		
		From 2006 to 2011	From 2012 to 2016	2017–2018
National agencies	*MAAIF*	–	2,872	13.5
	NARO	–	2,000	None
Local agencies	*Wakiso district*	–	11 (in 2013)	None specific for BXW
	Mukono district	–	11 (in 2013)	None specific for BXW
	Luwero	–	–	0.540 per quarter (not specific for BXW)
Multilateral organizations	*ASARECA*	500	None	None
	CRS	220	None	None
Private companies and foundations	*McKnight Foundation*	400	240	None

Source: Key informants, personal communication

different actors appears to be complementary over time. Even though we cannot state how much funding in total was invested to fight the spread of BXW, this qualitative analysis reveals a general course of action whereby a considerable amount of money was provided during both peak periods (2006 and 2013), compared to the period of low occurrence, when investments almost stopped. Consequently, currently local governments struggle to maintain a minimum level of awareness and monitoring among households, thus being unable to ensure that the incidence rate remains low.

Costs and benefits of BXW management at household level

As discussed above, considerable investment by different actors of the AIS was necessary in order to identify and promote the most suitable practices to limit BXW spread. However, the adoption of innovative agricultural practices is determined by a series of individual decisions which are influenced by a comparison of expected benefits with expected costs of adoption (Uaiene, Arndt, and Masters 2009; Nankya et al. 2017; Despotović, Rodić, and Caracciolo 2019). These depend on several uncertain future outcomes, like market prices of bananas or the actual share of bananas that will be lost to the disease. How farmers build their expectations, and what information they use to make decisions has long been subject to debate. Usually, it is assumed that farmers (people in general) use all available information which includes learning from the past. This is why it is crucial to assess if the adoption of the integrated package of cultural practices promoted for BXW management was cost effective for the banana-based households in Uganda in the past. It will also provide necessary information for policy makers on the strategies and actions that can be implemented along the AIS to improve adoption rates by farmers. For this reason, we collected data on costs of banana production at household level, highlighting specific costs of BXW management.

Households must sustain different costs for the adoption of BXW disease management practices. They can be organized as follows: explicit costs – monetary costs that require cash outflows (i.e. hiring labour; buying inputs as tools and JIK) and implicit costs – monetary costs for the internal resources uses and loss of potential income (i.e. yield loss; productivity loss; time used by household family members to manage the disease). Among the main benefits there are: a lower risk of loss of production, an increase in agricultural income and strengthened food security.

In the first step, we grouped households according to the number of practices effectively adopted. This was done in order to identify for each group, average benefits and costs and thus the positive or negative balance of practice adoption. Potentially, by increasing the number of practices adopted, both costs and benefits will increase, varying the net balance. The variation of the net balance allows the cost–benefit analysis of BXW management.

Full adopters are defined as those smallholders who applied all three main practices altogether (de-budding, removing diseased plants and disinfecting tools).[5] Full adopters represent about 33% of the sample (328 smallholders over the total surveyed 1,008). On the other side, low adopters are defined as those banana-producers who applied only one or two out of the three main practices (62% of the sample). It was decided to group those who have adopted only one or only two practices together as one of the objectives of the current study is to verify whether the adoption of the integrated package of practices generates a higher net balance than the partial adoption of the package of practices. Finally, non-adopters are the smallholders who did not practice BXW management at all (recognized to be 5% of the sample). Table 5 shows

Table 5: Level of management adoption rate divided by HH size, education, gender and banana acres.

Level of adoption	Households		HH size	HHD education	HHD gender	Banana acres
	Freq.	Percent	Mean (SE)	Mean (SE)	Female	Mean (SE)
Non-adopters	54	5%	6.44 (0.39)	6.06 (0.55)	15%	0.46 (0.13)
Low adopters	626	62%	6.36 (0.13)	6.04 (0.15)	28%	1.24 (0.06)
Full adopters	328	33%	6.38 (0.15)	5.90 (0.22)	24%	1.73 (0.27)
Total	1008	100%	6.37 (0.10)	6.00 (0.12)	26%	1.35 (0.09)

Note: Values in parentheses are standard errors (SE).

the descriptive statistics of each category, including household size and gender and years of education of the household head. On average, it is possible to observe that among the different groups there is a similar distribution of all the variables considered. Only with regard to the gender of the household head it is possible to observe a lower percent of females for the group of non-adopters (15% female on average compared to 28% and 24% for low adopters and full adopters respectively).

It is expected that the three groups of smallholders face different costs for the BXW management, benefiting on the other side different level of revenues, that means different level of BXW control. More in detail, for each BXW management practice, the associated specific inputs were identified. For instance, for removing diseased plants, the cost of inputs is related to the purchase of pangas (machetes) and pruning knives. For de-budding, it is related to a forked stick. Finally, regarding disinfection of tools, only the cost of JIK[6] was considered. The explicit cost of each tool (except for JIK) used in BXW management was amortized over 10 years, given their usual lifespan.

The cost of labour is composed of the explicit cost that comes from hiring labour specifically for BXW management and the implicit cost that comes from the time spent on BXW management by household members. The cost of household members' labour is considered an 'imputed cost' of two thirds of the average daily wage of the hired labourers, multiplied by total time spent on BXW management in the past 12 months.

Regarding the costs of banana production that were not related to BXW, the identified input costs are the purchasing of seedlings or plantlets; fertilizer; mulches; cover crops; pesticides and herbicides. The cost of labour, the same as for BXW management, is composed of hired labour and family labour. The cost of the latter is calculated as two thirds of the average daily wage of the hired labourers, multiplied by total time spent on it by each household.

Analytically, for each n-th farmers, all the costs (C_n) are calculated per acre (eq.1), in order to have results not affected by different land size.

$$C_n = \sum_{m=1}^{M} (I_{nm} * V_{nm})/a_n + \sum_{j=1}^{J} (L_{nj} * W_j)/a_n \qquad (1)$$

where I_{nm} indicates the quantity of the m-th input purchased for banana production in the last 12 months by the n-th household; V_{nm} is the price of each input; L_{nj} represents the number of days of work undertaken in the last 12 months by both the n-th household members (implicit costs) and hired labourers for the j-th activity carried out for banana production and BXW management; W_j is the average wage[7] per day for hired workers for the j-th activity; and finally a_n are the acres under banana production at the n-th household.

Table 6 shows the median costs per acre for BXW management and banana production, sustained by the three different categories.

Results from Table 6 show that full adopters incur higher costs of BXW management than low adopters, but the overall costs of the BXW management are quite low (around 10% and 15% of the total costs for the low adopters and full adopters respectively). This could be mainly explained by different factors. First, the initial cost of inputs is low itself, and since all the inputs have a long-life cycle, the cost can be amortized in several years (10 years except for JIK). However, even if the costs can be amortized, the purchases of the inputs can be perceived quite costly by smallholders since the required initial disbursement. Indeed, the cost of inputs represents only about 1% of the total costs for BXW management for low adopters compared to 5.42% of full adopters. The relatively high initial disbursement could explain the very high percentage of low adopters, that, benefitting also from a current low incidence rate of BXW, they mainly try to minimize costs, monitoring mainly the diseased plant.

BXW control influences the banana yield, that represents the principal source of benefits between different groups. As a result, in the third step, this study analyzed the market value of banana production for each group (full adopters, low adopters and non-adopters) in order to investigate the benefits for controlling the BXW in monetary terms.

Revenues (R) of the generic n-th household (n = 1, … , N) were calculated per acre, based on the following equation (eq. 2):

$$R_n = \sum_{b=1}^{B} \sum_{s=1}^{S} [(y_{nbs} * p_{nbs})/a_{nbs}] \qquad (2)$$

where y_{nbs} and p_{nbs} indicate respectively the production in terms of bunches and the market price for bunch for each b-th specific banana variety[8] grown by the n-th households in the s-th season; while a_{nbs} represents the cultivated area in acres.

The last step of the current analysis was to calculate the net balance, in terms of difference between the revenues and the costs per acre ($P_n = R_n - C_n$) resulting from

Table 6: Median cost per acre of banana production (UGX) in the last 12 months.

	Median BXW costs per acre (UGX)		Other variable costs per acre (UGX)			
Level of adoption	Total	% Labour	Total	% Labour	Median costs per acre (UGX)	Median costs per acre (US$)*
Non-adopters	-	-	500,337	93.50	500,337	135
Low adopters	71,604	98.96	651,516	88.17	723,120	195
Full adopters	111,736	94.58	651,516	88.17	763,252	206

* Exchange rate 2018

Table 7: Net balance per acre per year deriving from the production of bananas (UGX).

Level of adoption	Median revenue per acre (UGX)	Median costs per acre (UGX)	Net balance per acre (UGX)	Net balance per acre (US $)*
Low adopters	835,402	723,120	112,282	30
Full adopters	892,546	763,252	129,294	35

* Exchange rate 2018

the production of bananas (only variable costs) and the BXW management (both fixed and variable costs). Net balances were calculated for the three categories and then compared in order to investigate whether the profit is higher for those households who adopted BXW management practices altogether, given the costs they have to sustain in order to apply them.

From Table 7 it is possible to observe that revenues obtained are markedly higher for full adopters and low adopters compared to the category of non-adopters. Also, the net balance in the last 12 months was higher within those households who applied the full package of BXW practices, compared to those who applied only one or two practices or those who did not apply any practices. It should be noted that the net balance for non-adopters is negative. This is because they sustained a cost for banana production; however, the incidence of BXW disease has reduced banana yield/ productivity and hence the revenues.

Overall, results indicate that the adoption of BXW management practices altogether led to a positive result in terms of the net balance at household level. Indeed, households who applied the full package of practices registered the highest net balance, with a difference of US$65 per acre per year compared to those who have not adopted any practice.

Discussion and conclusions

Banana production is an important livelihood activity for farmers in Uganda, which has been seriously threatened by BXW since 2001 (Tushemereirwe et al. 2006). The rapid spread of the disease is sometimes attributed to the lack of farmers' awareness of and knowledge about disease diagnosis, transmission, and management (McCampbell et al. 2018). Based both on the AIS framework and the narrative analysis of the qualitative data, this study provides evidence that several stakeholders have made significant investments in order to increase the knowledge and skills of farmers regarding BXW. Among activities implemented in Uganda for this purpose are communication and education campaigns, demonstrations, training and meetings. The interactions between smallholder farmers and other actors of the AIS constitute the main structure of the innovation systems as they facilitate the diffusion and the sustainability of the innovations (Nahuis, Moors, and Smits 2012; Lundvall and Lema 2014; Adejuwon 2019). Indeed, the massive awareness campaign and investments implemented during the last peak of BXW in Uganda led to the positive outcome of critically reducing the number of affected farms in just two years. During 2013 more than 50% of households were affected by BXW, whereas in 2015, after the mobilization of stakeholders, only 1.9% of households showed BXW symptoms in their fields (National Banana Research Program Website 2015). This led to a discontinuation of investments by the government and the various national and international stakeholders. In this way, control of the BXW was entirely entrusted to rural households. This may be the cause of the resurgence of BXW. Alarmingly, the current level of investments remains low and, according to many stakeholders, insufficient to effectively support farmers with BXW control. This denotes that the current linkages between stakeholders are weak, which is compromising the successful implementation of the practices. Ineffective interaction and collaboration between stakeholders are common problems in the AIS in sub-Saharan countries (Schut et al. 2016).

The analysis of quantitative data collected at a household level confirms the fact that currently Ugandan households recognize the importance of adopting the recommended practices to contain BXW. In fact, only 5% of the sample did not apply BXW management practices at all, while 95% applied at least one of them. However, only 33% of the sample adopted the full package of the practices, while 62% of the sample adopted only one or two practices. This is a significant obstacle to BXW management, as only all the management practices adopted together is an effective disease control tool (Kubiriba and Tushemereirwe 2014). According to some of the stakeholders interviewed, the direct cost of the inputs (mostly JIK and clean planting materials) is one of the reasons why the farmers do not adopt the integrated package of practices for BXW management. The current study has highlighted that there was a considerable commitment by the government of Uganda to provide inputs for households at a district level, including clean planting material critical to fight BXW. Furthermore, our comparison between non-adopters, low adopters and full adopters of the cultural practices, indicates that full adopters benefit from a median net balance of US$35 per acre per annum. Low adopters recorded a lower net balance, of about US$30 per acre per annum. Finally, non-adopters registered a net loss from the production of bananas (about US$30 per acre). This indicates economic vulnerability of households to BXW effect and stresses the importance of providing support, and information campaigns and training. This is in line with the AIS framework that highlight the importance of interaction and social learning between farmers and other actors of the innovation system (Dolinska and d'Aquino 2016). From this it follows that more emphasis must be directed at education and support of different actors of the system, especially for smallholders.

This cost–benefit analysis leads to the conclusion that the integrated package of practices against BXW is not

only cost effective, but also adopting the full range of practices generates the highest benefit. Probably, the reason why farmers did not adopt the integrated package of practices for controlling the BXW is that the initial costs of the inputs, even if depreciable in 10 years, can pose an important barrier. In addition to this, the reduction in both public and private investments in the BXW control at the country level, means that local governments cannot afford to support all the activities that should be carried out in order to guarantee a continuous presence of funds and personnel in the field.

For these reasons, it is crucial that the government increases the investments in the two major inputs that farm-households struggle to provide themselves, recognized as JIK and clean planting material. Moreover, female-led households who struggle with the adoption of the full package, need to be supported. Finally, the government and other stakeholders of the banana value chain should continue to invest in communication and awareness campaigns about the correct implementation of the practices, emphasizing that it is important to apply them all together. In particular, due to relatively high initial investment needed, it is important to inform the farmers about the distribution of the benefits in time and stress that over time the full package adoption results in the highest net benefit. National government must ensure that households receive the message about the best use of management practices and the profits that will flow from their adoption. To do so, the government should relaunch specific investments for BXW awareness campaigns and other participatory methods. It is important to prevent the next BXW outbreak as it is likely to lead to potentially heavy economic losses among banana producers.

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Notes

1. Removal of diseased plants can be done through the entire mat removal and/or single diseased stem removal (SDSR), although the latter is preferred because it is considered as effective but less labour-intensive. For this reason, the current analysis considered the SDSR as the main technique for removing diseased plants.
2. Key informants are a limited population of individuals with significant breadth and depth of knowledge to speak informatively in detail about what happened and why (Jimenez 1985).
3. An expert meeting held in Kampala, Uganda on the 1st and 2nd of February 2018 was carried out in order to identify key informants.
4. Through the community action, the community is facilitated to develop an action plan for BXW control, and all community members commit to implementing it. Stakeholders at higher levels (local and national government) are then mobilized to support the communities in implementing their plan (Kubiriba et al. 2012).
5. Use of clean planting material was excluded from the quantitative analysis because, although it represents another important practice to avoid the dissemination of infected suckers and plantlets, very few farmers use this technique as recommended by scientists due to the high cost and lack of availability.
6. The same practices can be done also utilizing different inputs, but the right way to implement them is through the inputs we listed. That is why we decided to account for the cost analysis of only those inputs recognized as adequate from the literature.
7. Wage for household's members has been calculated as 2/3 of the wage for hired workers.
8. The four varieties of bananas considered are cooking, sweet, roasting, and beer banana.

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