Rwanda Journal of Agricultural Sciences, Vol 3, No. 2

Effects of plant doctors training in strengthening plant health services in Rwanda

P. Murekeyimana[1], B. Uzayisenga[1], J.D. Nsabimana[1], M. Mutimura[1]*

Corresponding author: mundekerep@gmail.com

Abstract

Pests and diseases cause devastating losses to global crops each year, severely impacting food security. Effective management of plant health issues is crucial to ensure an abundant supply of safe food. Agricultural extensionists were trained as "Plant Doctors" to advice farmers on managing plant pests and diseases. A study aimed to assess the effectiveness of this training offered to plant doctors and identify areas for improvement. A sample of 30 agronomists trained as Plant Doctors and 30 untrained agronomists were purposively selected from 30 districts in 2022. Data, both qualitative and quantitative were collected using a structured questionnaire and the Plantwise Online Management System. Data analysis was conducted using Statistical Packages for Social Sciences (SPSS). Findings showed that all Plant Doctors were confident in providing plant health recommendations, with 80% of respondents confirming that they could detect and address pests and diseases in a timely manner. Furthermore, 88.3% of respondents indicated that Plant Doctors promoted the proper use of pesticides, while 93.3% agreed that the training contributed to increase agricultural production, both in terms of quantity and quality. Respondents suggested that Plant Doctors should be equipped with plant clinic tools for better service. Additionally, 85% of untrained agronomists expressed a strong desire for training in the diagnosis and management of pests and diseases. We recommend the capacity-building initiatives for all agricultural agents, as this could contribute to the reduction of biotic and abiotic crop challenges.

Keywords: *Diagnosis, disease, pest, plant clinic, plant doctors*

[1]Rwanda Agriculture and Animal Resources Development Board, P.O. Box 5016, Kigali, Rwanda.

Introduction

Agriculture plays a crucial role in Rwanda's economy, contributing 25% to the country's gross domestic product (GDP) and meeting 91% of the nation's food needs (NISR, 2021; MINAGRI, 2023). Occupying 90% of arable land, agriculture is essential for sustainable economic growth and the livelihoods of the majority of the population (Gasheja and Gatemberezi, 2017; Africa Union, 2022). However, Rwandan agriculture faces numerous challenges, including small and fragmented farms, soil erosion, declining fertility, climate change, and pests and diseases (Mbago *et al.,* 2019; World Bank, 2023). These issues are further complicated by the growing global demand for food, which is projected to require a 70% increase in agricultural production by 2050 (FAO, 2010), while the spread of invasive species continues to threaten crop production (McGoven and To-anun, 2016).

Pests and diseases are a global challenge that can lead to food insecurity (Chimpokosera, 2023). Pests alone cause around 40% of crop losses annually, amounting to an estimated cost of $400 billion (Marsh, 2022 and FAO, 2023), In Sub-Saharan Africa, where many farmers lack timely advice and sufficient knowledge to manage crop pests and diseases, losses can reach as high as 60% (Ausher *et al.,* 1996; Oerke, 2006). Effective pest and disease management is therefore crucial for ensuring the availability of agricultural products in markets, increasing farmers' incomes, and improving livelihoods (Danielsen *et al.,* 2011). Reducing crop losses by just 1% could provide enough food for the 815 million people suffering from hunger globally (Otieno, 2018). Train Plant Doctors (PDs) can play a crucial role in reducing the biotic and abiotic crop problems (McGoven and To-anun, 2016). PDs are agronomists who receive specialized training in pest and disease management and offer free assistance to farmers.

Plantwise is a global programme led by Centre for Agriculture and Bioscience International (CABI), aimed at increasing food security by helping farmers reduce crop losses due to plant health problems. Plantwise works closely with national agricultural advisory services to establish plant clinics (PCs), an extension approach that begin in 2003 in Bolivia (Danielsen and Kelly, 2010). This approach was introduced in Rwanda in 2011 by Rwanda Agriculture and Animal Resources Development Board (RAB) in partnership with CABI through Plantwise programme (CABI, 2020). Plantwise activities are currently implemented in 36 countries across the world, with over 4500 PCs established and operated by trained PDs (Toepfer *et*

al., 2023). In Rwanda, 66 PCs are currently running nationwide (CABI, 2020). Through PCs, farmers receive advice on plant health that meets five key criteria: practicality, local availability, cost-effectiveness, efficiency, and safety (Tambo et al., 2020). This advice has helped improve farmers' knowledge of agricultural best practices, leading to increased productivity and income (Ghosh *et al.*, 2019). For instance, a study conducted by Ghosh *et al.* (2019) in Bangladesh revealed that 61% of PC users reported an increased ability to solve plant health problems, compared to 43% of non-users. Furthermore, users' average income was 33% higher, and tomato yields improved by 20%, with gross margins increasing by 21% (Bett *et al.*, 2018). Additionally, 50% of the Rwandan farmers who followed PDs recommendations got 47–127% yield increase in different crops (Nsabimana *et al*., 2015). Clinics users in Rwanda gained a higher net income compare to non-users (Silvestri *et al*., 2019).

All Rwandan PDs were trained on Module 1, which focuses on field diagnostics and plant clinic operation, including identifying and describing symptoms, understanding the diversity of causes, microbial causes of plant problems, insects, nematodes, mineral nutrition and operating PCs. While Module 2 covers developing effective recommendations based on eight principles of Integrated Pest Management (IPM) (Barzman *et al*., 2015; Mur *et al*., 2015). This includes, five things to consider when giving a recommendation, management options for pests and diseases, explaining chemical products, selection and use of correct pesticides, pests and diseases management using the green and yellow concept and safe use of pesticides. PDs also have access to additional training materials through the Plantwise Knowledge Bank and can receive further training on pest and disease management (Mur *et al.*, 2015).

PC services are demand-driven, with farmers themselves determining the need for advice. When farmers discover crop health problems, they bring fresh, unhealthy plant samples to the PD, who carefully handles them to prevent the spread pathogens (Boa *et al*., 2016), identifies the problem, and provides recommendations. PDs operate PCs at specific times on regular days of the week, in easily accessible public places such as markets, allowing any farmer to seek the advice they need (Tambo *et al.*, 2021). PDs also systematically record their diagnoses and recommendations, which are then analyzed by the Plantwise national data manager through the Plantwise Online Management System (POMS). This system enables the tracking of pest and disease prevalence and monitors whether farmers are receiving

appropriate advice. The data also informs future training needs and helps improve extension materials (Otieno, 2018). Validated data are shared with various stakeholders for different purposes (Danielsen *et al*., 2012; Boa *et al*., 2016).

The objective of this study was to assess the effects of training provided to PDs and to identify areas for improvement in managing plant health problems. By enhancing plant health management practices, the PDs will contribute to increase of quality and quantity of crop production in Rwanda.

Materials and Methods

Description of the study location and methodology

The study, conducted in 2022, spanned all 30 districts of Rwanda. A structured questionnaire, featuring both open-ended and closed-ended questions, was developed and administered to 30 trained Plant Doctors (PDs) out of the 120 who operate Plant Clinics (PCs), as well as to 30 untrained sector agronomists. The PDs interviewed were those managing PCs established initially in each district from 2011 to 2021 (one PD per PC). The untrained sector agronomists, randomly selected from sectors without PCs, were also one per district. Additionally, data from the Plantwise Online Management System (POMS), which includes information from PCs and other Plantwise activities, were analyzed.

Data Collection

Data were collected using a structured questionnaire, with some questions formatted on a 5-point Likert scale (ranging from "strongly disagree" to "strongly agree"). Most of the questions were identical for both groups, although a few were tailored specifically to each group.

The structured questionnaire covered four main sections. The first section focused on general information about the respondents, the second on information related to PCs, the third on the importance of Plantwise services, and the final section addressed the effects of plant doctors' training in pest and disease management, as well as areas for improvement. In the last section, questions centered on the effects of PD training on pests and diseases management, the training needs of both PDs and untrained agronomists, and ways to improve the working conditions of PDs in Rwanda. Data collection was conducted through face-to-face interviews. Additionally, secondary data were gathered from existing literature on plant health clinics.

Data analysis

The qualitative and quantitative data were coded, cleaned, and analyzed

using Statistical Package for the Social Sciences (SPSS), with descriptive statistics applied. The data presented in tables and figures were discussed, compared with other findings, and synthesized into general conclusion. Additionally, POMS data were analyzed to assess crop queries and the management of diseases.

Results and Discussion

Effects of Plantwise and PDs in pests and diseases management

Importance of Plantwise services

To assess the importance of the Plantwise program, both Plant Doctors (PDs) and untrained extensionists were surveyed using a 5-point Likert scale in response to four statements. Table 1 presents the results on the importance of Plantwise services. The survey found that all PDs (100%) and nearly all untrained extensionists (96.7%) strongly agreed that Plantwise has significantly enhanced the capacity of extensionists in managing plant pests and diseases. Approximately 93.3% of PDs and 83.3% of untrained extensionists acknowledged that Plantwise provided essential PC equipment. Additionally, 65% of respondents strongly agreed that Plantwise conducts Plant Health Rallies (PHRs) in the country (Table 1). Furthermore, 78.2% of those surveyed agreed that Plantwise prepares and distributes valuable extension materials.

Table 1. *Importance of Plantwise services to extensionists*

Importance of Plantwise Services	Range	Plant Doctors	Untrained extensionists	All (%)
Give Capacity building on pests& diseases control	Agree	0.0	3.3	1.7
	strongly agree	100.0	96.7	98.3
Avail equipment of Plant clinics	Agree	93.3	83.3	88.3
	strongly agree	6.7	16.7	11.7
Conduct plant health rallies	Agree	26.7	43.3	35.0
	strongly agree	73.3	56.7	65.0
Prepare & distribute extension materials	Agree	83.1	73.3	78.2
	strongly agree	16.9	26.7	21.8

Respondents strongly agreed that Plantwise has been instrumental in building the capacity of extensionists for pest and disease management and in providing essential equipment for plant clinics. Plantwise also conducts plant health rallies and distributes extension materials to farmers. In Rwanda, where 11% of farmers are uneducated and 69% have only completed primary school

(NISR, 2020), most farmers lack formal agricultural education. Additionally, many extension workers have not studied crop protection. Training these individuals can significantly contribute to food security.

By 2018, Plantwise had trained over 10,000 extension workers globally, including 350 in Rwanda, to diagnose plant health problems and provide sound recommendations (Tambo *et al.*, 2020; Otieno, 2018). According to survey results, 88.3% of respondents confirmed that Plantwise provides essential tools for diagnosing pests and diseases, such as large umbrellas, banners, megaphones, tables, chairs, hand lenses, dustbins, factsheets, and logbooks. PDs also have access to the Plantwise Online Management System (POMS) for practical plant health information (Bandara *et al.*, 2014; Majuga *et al.*, 2018).

Plantwise organizes plant health rallies in areas affected by pest or disease outbreaks to disseminate crucial information quickly. People received important knowledge about current pests or diseases, along with the relevant extension materials (Nsabimana *et al.*, 2015) and in 2017, these rallies reached 68,000 farmers (CABI, 2017; Otieno, 2018). Additionally, Plantwise has developed over 13,600 factsheets and photo sheets available online, and more than 1.43 million people used the online knowledge bank to improve their pest and disease management practices in 2017 (Otieno, 2018).

Advantages of Plant Doctor training in pest and disease management

The benefits of PDs in agriculture, based on the training they received, are varied. Table 2 highlights the key impacts of PDs on pest and disease control as a result of the Plantwise training. Survey findings revealed that 93.3% of respondents strongly agreed that the training provided to PDs significantly contributed to increased agricultural production, both in quantity and quality. Additionally, 80% of respondents confirmed that PDs effectively identified and reported pest and disease outbreaks in a timely manner.

Our findings also showed that 88.3% of respondents strongly agreed that PDs have reduced pesticide misuse due to their training. Furthermore, 98.3% of respondents strongly agreed that PDs offer free agricultural services related to pest and disease management to farmers. The survey also indicated that 80% of respondents agreed that farmers have gained valuable knowledge about pests and diseases management from PDs. These results underscore the importance of Plantwise training in enhancing agricultural productivity and promoting sustainable pest and disease control practices.

Table 2. *Advantages of Plant Doctors' training in Pest and Disease Management*

Advantages of PDs 'training	Range	Plant Doctors	Untrained extensionists	All (%)
Increase agricultural production quantitatively &qualitatively	Agree	3.3	10.0	6.7
	Strongly agree	96.7	90.0	93.3
Timely discover and announce pests &diseases	Agree	11.1	30.0	20.0
	Strongly agree	88.9	70.0	80.0
Reduce misuse of pesticides	Agree	13.3	10.0	11.7
	Strongly agree	86.7	90.0	88.3
Provide free agricultural services on pests control	Agree	0.0	3.3	1.7
	Strongly agree	100.0	96.7	98.3
Enhance knowledge of farmers	Agree	80.0	80.0	80.0
	Strongly agree	20.0	20.0	20.0

Majority (93.3%) of respondents strongly agreed that the training provided to PDs had significantly contributed to increasing agricultural production, both quantitatively and qualitatively. Many respondents also confirmed that PDs were effective in detecting and communicating pest and disease outbreaks in a timely manner and reducing pesticide misuse due to the training they received. Furthermore, 98.3% of the respondents strongly agreed that PDs offer free agricultural services related to pest and disease management, and 80% acknowledged that farmers gain valuable knowledge from PDs.

Plantwise plays a crucial role in ensuring food security by increasing yields through quality plant health advice provided by PDs, leading to improved incomes (Otieno, 2018). Other studies also highlighted the positive impact of PD training on yield improvements (McGoven & To-anun, 2016; Uzayisenga *et al.*, 2020). Ghosh *et al.* (2018) found that following PD advice reduces crop losses from diseases and increases production per unit of land, thereby

raising household income and alleviating food insecurity. Tambo *et al.* (2020) reported that farmer involvement in plant clinics reduced food insecurity by 10%, 14%, and 20% for non-poor, moderately-poor, and extremely-poor households, respectively. In addition, according to Uzayisenga *et al*. (2020), the yield of banana in Rwanda increased by 400%, coffee by 200%, maize by 100%, beans by 82%, irish potato by 79% and tomatoes by 56% through PD support. The work of PDs has proven to enhance food security, as increased yields lead to better household food availability (Bett *et al.,* 2018; Tambo *et al.,* 2020). Additionally, trained PDs guide farmers toward more sustainable farming practices, improving livelihoods (Ghosh *et al.,* 2019).

The success of PDs to timely detect and announce pests and diseases (80%of respondents) is attributed to their regularity in work and their ability to diagnose and manage various plant health problems, due to the trainings received. PDs are also supported by laboratories that analyze samples to confirm the presence of new diseases. An example of this is, the discovery of Maize Lethal Necrosis Disease, which was reported for the first time by PDs in Byangabo PC (Adams *et al*.,2014). They detected new pests across the world, such as the fall armyworm (FAW) in Maize and tomato leaf miner (Otieno, 2018). According to Tambo *et al*. (2020), PDs are the main source of plant health information for 97.5% of respondents, and their competence is appreciated by 79.5%. Moreover, PC records provide valuable information about status of existing and emerging pests and diseases, which enables researchers and regulatory agencies to responses quickly (Negussie *et al*., 2011). Otieno (2018) confirmed that PDs can play a crucial role in the early warning of pest outbreaks. In addition, Plantwise Rwanda has started linking PCs with Farmer Field Schools (FFS) and Twigire muhinzi groups, utilizing mobile PCs, where PDs operate at the site of FFS on the farms (RAB, 2018). With this approach, PD received around 30 farmers with 40 queries per day (Murekeyimana, 2019), whereas during the regular PCs session, the PD received around 10 farmers' queries (Tambo *et al*., 2020). This enables the timely resolution of a significant number of farmers' queries.

Somefarmers apply pesticides incorrectly: using excessive or insufficient quantities or incorrect pesticide, applying it at the wrong time or under inappropriate condition. The misuse of pesticides can lead to the different environmental problems (Bandara and Kulatunga, 2015; Majuga

et al., 2018). Generally, PDs recommend the use of pesticides as the last option. When necessary, they suggest using the least harmful pesticides at lowest effective levels and provide clear instructions on their use (Bandara and Kulatunga, 2015).

Other effects of plant doctors' training

In addition to the advantages of PDs related to their training and job performance, respondents highlighted other positive effects, as shown in Table 3. Approximately 81.4% of respondents indicated that farmers saved money previously allocated for purchasing pesticides. The findings also revealed that 78% of respondents confirmed that PDs helped farmers adopt Integrated Pest Management practices, which contributed to reducing pesticide use. Moreover, 73.4% of those interviewed stated that PDs' efforts have led to a decrease in pesticide residues in agricultural products.

Table 3. ***Other effects of plant doctors' training***

Other effects of plant doctors 'training	Plant Doctors	Untrained extensionists	All (%)
Money to be used on pesticides are saved by farmers	89.7	73.2	81.4
Farmers learn to use IPM	84.9	71.2	78.0
Reduce pesticides residues in agricultural products	79.0	69.9	73.4

Respondents highlighted additional benefits, including saving money, adopting IPM practices, and reducing pesticide residues in agricultural production.

PDs focus primarily on cultural methods, such as promoting resistant crop varieties and other cost-effective agricultural practices. As shown in above table, 81.4% of respondents reported that farmers saved money initially reserved for pesticides. When cultural controls prove insufficient, PDs recommend targeted pesticides that address specific threats, rather than encouraging excessive or varied pesticide use, which is common among non-PC users. The British Society for Plant Pathology (2019) emphasized the importance of using resistant varieties to save money otherwise spent on pesticides.

Similarly, Tjamos (2013) noted that PDs reduce production costs through accurate diagnoses, timely recommendations, and appropriate control measures. Bentley *et al.* (2011) found that in Bolivia, PDs helped farmers increase their harvests while reducing spending on plant health management. Gurmessa *et al.* (2021) further confirmed that farmers who consulted PDs spent an average of USD 54 on pesticides annually, compared to USD 67 before visiting PCs.

Farmers also learn from PDs how to implement IPM, which helps reduce pesticide residues in crops. Various IPM methods, such as preventive cultural and physical controls, are practical, affordable, and effective in managing pest populations before it hits the economically damaging level. When chemical controls are necessary, farmers trained in IPM understand how to apply low-toxicity pesticides and respect pre-harvest intervals. IPM is a holistic approach that not only boosts crop productivity (Culliney, 2014) but also protects the environment and public health by minimizing pesticide hazards (Srivastava, 2013; Bastakoti, 2020).

Confident and type of recommendation provided for managing pests and diseases

Table 4 compares the competence of Plant Doctors with untrained sector agronomists (extensionists), highlighting the impact of PD training. The survey revealed that 100% of PDs feel confident in providing recommendations on pests and diseases management, whereas only 26.7% of untrained agronomists expressed the same confidence. All PDs were able to recommend both cultural and chemical control methods, compared to 63.9% of untrained agronomists. Among the untrained, 16.7% recommended only chemical methods, and 9.9% provided no recommendations at all. Moreover, the study indicated that all PDs received positive feedback from farmers, who testified to the effectiveness of their recommendations. In contrast, none of the untrained agronomist received similar feedback, underscoring the value of specialized training in pests and diseases management.

Table 4. ***Confident and type of recommendation provided for managing pests and diseases***

Confident and type of recommendation given	Plant Doctors	Untrained extensionists	All (%)
Confident to give recommendations	100.0	26.7	63.3
Recommend only chemicals	0.0	16.7	8.3
Recommend only cultural	0.0	9.5	4.7
Recommend both (cultural & chemicals)	100.0	63.9	81.9
None recommendation given	0.0	9.9	4.9
Farmers come back to PDs to thank them for the services given	100.0	0.0	100.0

All Plant Doctors (PDs) were confident in giving recommendations on pests and diseases management, offering both cultural and chemical solutions. In contrast, only a few untrained extensionists feel confident in providing recommendations, with 9.9% giving no advice at all. All PDs reported receiving feedback from farmers expressing gratitude for their effective assistance.

The full confidence of PDs stems from their training, which includes comprehensive modules on pests and diseases management, backstopping, and refresher courses offered by Plantwise. Their high competence is supported by Uzayisenga *et al.* (2020), while Ghosh *et al.* (2019) emphasized that PDs efficiently diagnose plant health problems and provide recommendations that increase crop productivity and build farmers' confidence. Danielsen and Mutebi (2010) noted that untrained extensionists often hesitate to advise farmers and rely on external resources for guidance.

Trained PDs incorporate IPM in their recommendations, prioritizing cultural methods such as using improved or resistant varieties, crop rotation, and proper fertilization. Chemical methods, typically low-harm pesticides, are recommended as a last resort. According to Danielsen *et al.* (2012), 97% of PD recommendations combine best agricultural practices. Gurmessa *et al.* (2021) reported that 69% of farmers

were advised by PDs to use monitoring, cultural practices, and pesticides. Additionally, the training offered by Plantwise to extensionists helped them to improve their knowledge for diagnose plant health problems and give appropriate advice (Toepfer *et al.*, 2023). Farmers who received assistance from PDs often returned to express gratitude, as confirmed by all interviewed PDs, and similar observation was found by Danielsen and Mutebi (2010).

Improving plant doctors' working conditions

The following suggestions were identified to improve the work of PDs. The most common recommendation, cited by 42.6% of respondents, was to ensure the availability of all necessary PC equipment. Additionally, 33.4% suggested distributing tablets to all PDs to enhance their efficiency. Furthermore, 11.6% of respondents emphasized the need for refresher courses to keep PDs updated on the latest practices.

Table 5. ***Suggestions of improving plant doctors' working conditions***

Suggestions to improve working Conditions of PDs	Plant Doctors	Untrained extensionists	All (%)
Avail all Plant clinics equipment	39.7	45.5	42.6
Distribute tablets to all PDs	30.6	36.3	33.4
Provide regular refresher courses	13.9	9.2	11.6
Give to PDs outside study tours	9.5	3.0	6.2
Increase laboratories in the country	6.3	6.0	6.2

Suggestions to improve the working conditions for Plant Diagnosticians included providing PC equipment and distributing tablets to all PDs. Key tools are essential for effective and timely diagnosis of plant issues, crucial for managing pests and diseases. The availability of these tools helps in reducing pest and disease outbreaks. PDs specifically recommended PC equipment and tablets (Table 5), as they frequently work in the field outside of plant clinics. The advancement of technology necessitates the use of tablets, which must be maintained in good condition and replaced when damaged. A lack of sufficient equipment remains a limitation for PDs' work (Ausher *et al.*, 1996).

Additionally, respondents suggested various types of training to stay updated, as illustrated in Figure 1. Both PDs and untrained agronomists supported training on the manipulation of crop samples in the laboratory, with 32% of PDs and 4% of untrained agronomists endorsing this. Training on

the use of biological control was recommended by 27% of PDs and 4% of untrained agronomists. Soil testing and management of soil threats were suggested by 22% of PDs and 4% of untrained extensionists. Furthermore, only PDs identified a need for training in managing new pests and diseases (19%) to address invasive diseases, while a significant majority of untrained agronomists (85%) emphasized the need for training in the diagnosis and management of pests and diseases.

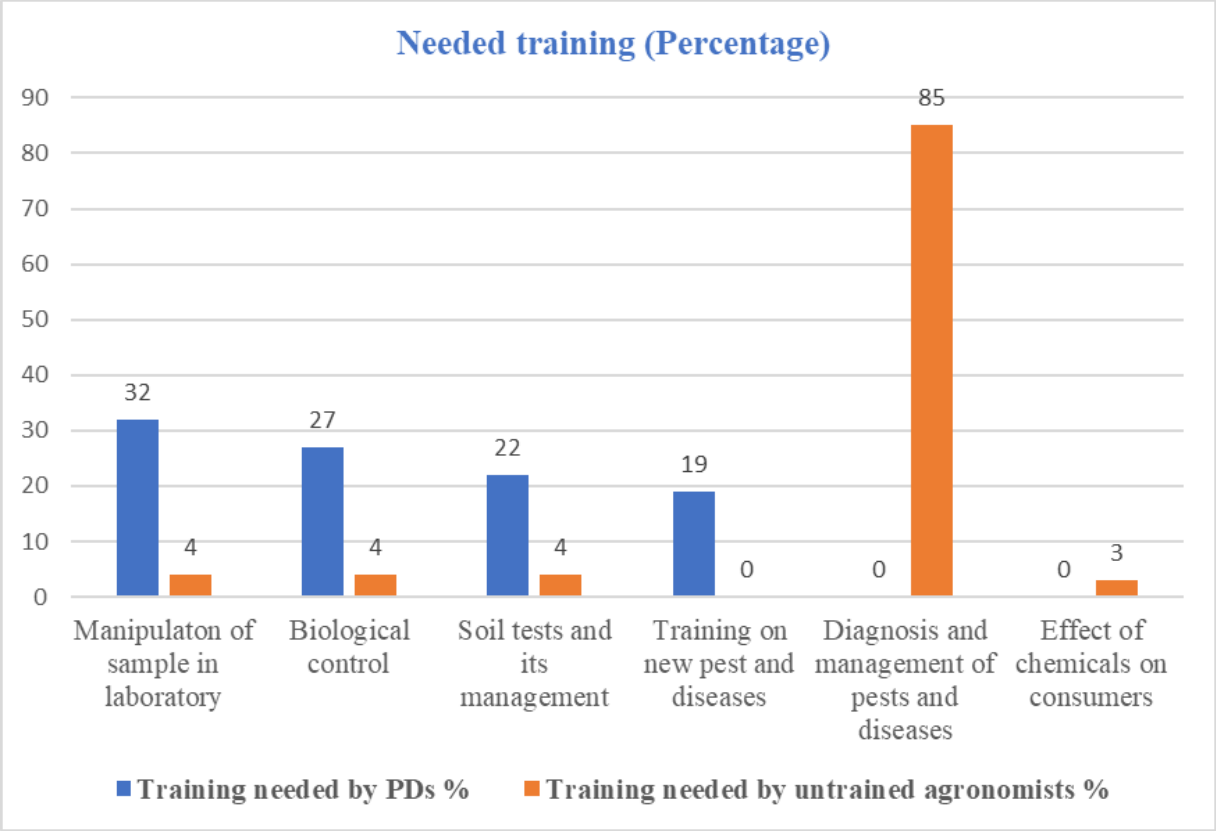

Figure 1. Needed training (%) by PDs and untrained Agronomists

In line with increasing knowledge, PDs recommended training on the manipulation of crop samples in the laboratory. In contrast, most untrained agronomists emphasized the need for training in the diagnosis and management of pests and diseases. This specialized training is prioritized because it supports the adoption of effective technology, boosts household income, and enhances human and environmental protection. Once trained, extensionists could significantly improve food security and safety. Aloki

et al. (2014) highlight the necessity of training in pests and diseases diagnosis control including IPM and the safe handling of agrochemicals.

Regarding the importance of Plantwise training, Ngororero District has already trained its extensionists and included Plant Clinics (PCs) in the performance contracts of extension staff. Additionally, seven districts in Rwanda have allocated funds to support the training of their extension officers (CABI, 2017). These districts are Rwamagana, Nyanza, Ngororero, Nyabihu, Musanze, Bugesera, and Nyamasheke. Furthermore, some universities and colleges are recognizing the value of the Plantwise approach and are considering its integration into their curricula (CABI, 2017; Otieno, 2018).

Plantwise Online Management System (POMS)

According to POMS, since the introduction of PCs in Rwanda in 2011 until June 2021, the PCs received 16,523 queries related to over 98 different plants across the country. For example, from 2012 to July 2019, POMS data indicated that tomato had 1,197 queries concerning 28 different plant threats. The most common pests and diseases included bacterial wilt (17.2%), tomato mosaic virus (16.9%), aphids (9.4%), late blight (8.2%), early blight (6.4%), powdery mildew (5.2%), and nutrient deficiency (5%) (Murekeyimana, 2019). This data shows that PDs manage a wide range of threats, including bacteria, viruses, insects/mites, water molds, fungi, and physiological issues. Additionally, with the crop intensification program implemented in Rwanda since 2007, farmers have made significant efforts in land consolidation and the cultivation of priority crops. Consequently, PDs have received numerous queries regarding these crops. Figure 2 illustrates the top five unhealthy crops brought to PCs from 2011 to June 2021, highlighting various health problems. Maize presented the most queries, totaling 4,267 (25.8% of all queries), followed by cassava, banana, beans, and Irish potato. These five top crops are prioritized in the country (NISR, 2015).

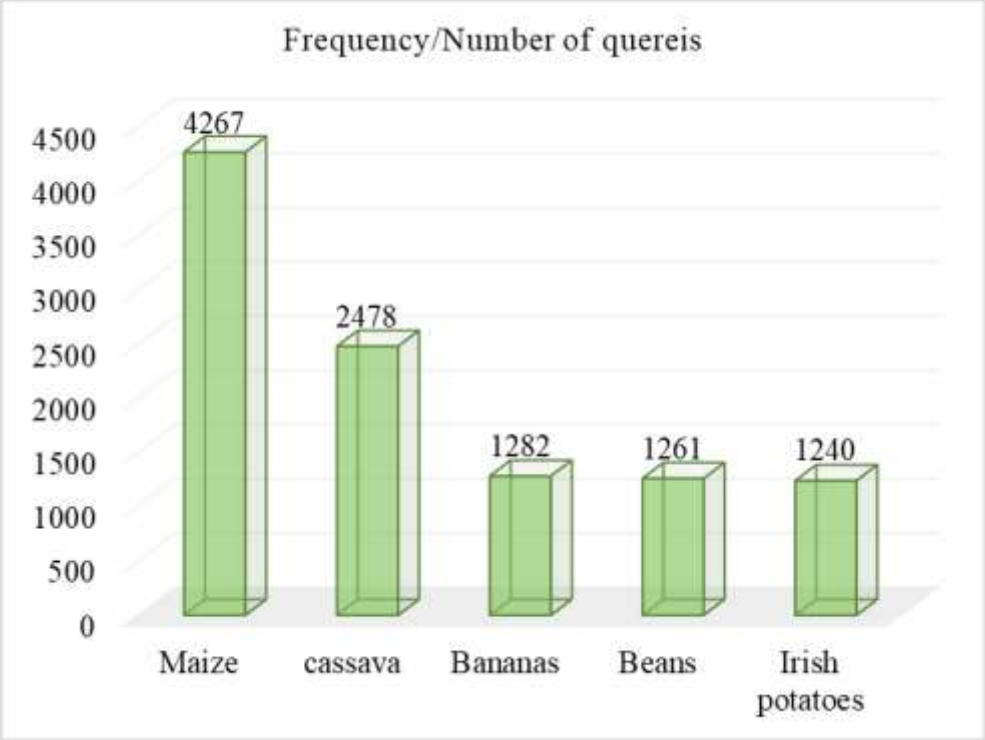

Figure 2. Five top Crops brought in Plant clinics that had different health problems

Maize received the highest number of queries at PCs. This is primarily due to the outbreak of Fall Armyworm (FAW) affecting maize since 2017. According to POMS (2021), 1,762 queries (41.2%) specifically related to FAW. Additionally, maize is the primary crop for many farmers, grown across the country during both major agricultural seasons. As a staple food, it provides high yields and substantial income for Rwandan households. Furthermore, maize is subsidized for both seeds and fertilizers. When maize is threatened, farmers frequently consult PDs, often achieving significant results; for example, Uzayisenga *et al.* (2020) reported that maize yields could increase by 128% if farmers followed PD recommendations. In comparison, while maize was the most queried crop in Kenya, in Uganda, banana was the most common query due to its significance in those countries (Negussie *et al.*, 2011).

Regarding attendance at PCs by gender from 2011 to 2021, POMS (2021) indicates that males visited PCs more frequently than females. There were 10,293 queries (63.7%) from males and 5,866 queries (36.3%) from females. Males are generally more involved in monitoring farms, whereas females are often engaged in domestic activities. Consequently, men are more likely to seek assistance from clinics when crop issues arise. This gender disparity in attendance aligns with findings from

Kenya, where 67% of PC attendees were men, often due to their control over resources and farm activities as heads of households (Negussie *et al.*, 2011).

Conclusion

The Plantwise programme has proven to be a pivotal force in enhancing pest and disease management in Rwanda. The survey results highlight the program's significant impact, demonstrating that Plantwise has effectively built the capacity of extensionists through comprehensive training and the provision of essential tools to PCs. The training provided has notably improved agricultural productivity and sustainability. Findings showed that all plant doctors, are more confident to give recommendation than untrained extensionists. Additionally, the results reveal that trained PDs have successfully increased agricultural yield, improved the timeliness of pests and diseases detection and information, and reduced pesticide misuse. The adoption of Integrated Pest Management practices has further contributed to reduced pesticide residues and cost savings for farmers.

Despite these successes, challenges remain in terms of ensuring the availability of necessary equipment and tablets to PDs for better serving a larger number of farmers. PDs also suggested additional training in laboratory analysis of samples. Most of the untrained agronomists emphasized the need for training in pests and diseases diagnosis and management. It would be beneficial if all extensionists involved in farming received this training to effective control plant of health threats in timely manner. Furthermore, gender disparities in attendance at plant clinics suggest the need for targeted strategies to engage more female farmers.

In general, the Plantwise programme's achievements underscore its crucial role in strengthening food security and supporting sustainable agricultural practices in Rwanda. The continued investment in training and resources, coupled with ongoing support for PDs, will be essential for sustaining and expanding the programme's benefits in the future.

Acknowledgements

This research was supported by the Centre for Agriculture and Bioscience International (CABI) through its Plantwise project. The authors gratefully acknowledge the support from Dr. Willis Ndeda Ochilo, the project scientist &PlantwisePlus CABI Country Coordinator for Rwanda; the district agriculture officers for their assistance with data collection; as well as the Plant Doctors and sector agronomists for their valuable contributions.

Conflict of interest

All authors do not have any conflict of interest to declare.

References

Adams, I.P., Harju, V.A., Hodges, T., Hany, U., Skelton, A., Rai, S., Deka, M.K., Smith, J., Fox, A., Uzayisenga, B., Ngaboyisonga, C., Uwumukiza, B., Rutikanga, A., Rutherford, M., Ricthis, B., Phiri, N., Boonham, N. (2014). First report of maize lethal necrosis disease in Rwanda. New Disease Reports 29, 22. http://dx.doi.org/10.5197/j.2044-0588.2014.029.022

Africa Union. (2022). Rwanda country food and agriculture delivery compact. February,2023

Aloki, C., Tukahirwa, B., Oruka, D., Okotel, M., Bukenya, C., Mulema, J. (2014). Reaching out to farmers with plant health clinics in Uganda. *Uganda Journal of Agricultural Sciences, 2014, 15 (1): 15 – 26*

Ausher, R., Ben-Ze'ev, S.I., Black, R. (1996). The role of plant clinics in plant disease diagnosis and education in developing countries.

Bandara, P.T., Kulatunga, W.M.D.H. (2015). Using the crop clinic concept to minimize the indiscriminate use of pesticides and promoting effective, judicious pesticide use. Pp.39-44

Barzman, M.S., Barberi, P., Birich, A.N.E., Boonekamp, P., Dachbrodt-Saaydeh, S., Greaf, B., Hmmel, B., Jensen, J.E., Kiss J., Kudsk, P., Lamichhane, J.R., Messéan, A., Moonen, A.C., Ricci, P., Sarah, J.L., Sattin, M. (2015) Eight principles of integrated pest management. Agronomy for Sustainable Development, Springer-Verlag/EDP Sciences /INRA 2015,10.1007/s 13593-0150327-9

Bastakoti, R., Pandit, V. (2020). The importance of Plant clinics to Nepalese smallholder farmers.

Bentley, J.W., Boa, E., Almdendras, F., Franco, P., Antenzan, A., Díaz, O., Franco, J. Villarroel, J (2011). How farmers benefit from plant clinics: An impact study in Bolivia. *International Journal of Agricultural Sustainability*. Vol 9. pp.393-408. https://doi.org/10.1080/14735903.2011.583482

Bett, E., Mugwe, J., Nyalugwe, N., Haraman, E., Williams, F., Tambo, J., Wood, A., Bundi, M. (2018).

Impact of Plant Clinics on Disease and Pest Management, Tomato Productivity and Profitability in Malawi. *CABI working Paper11*, 30pp. https://dx.doi.org/10.1079/CABICOMM-25-8089

Boa, E., Franco, J., Chaudhury, M., Simbalaya, P., Van Der Linde, E. (2016). Plant Health Clinics. Note 23. GFRAS Good Practice Notes for Extension and Advisory Services. GFRAS: Lausanne, Switzerland.

British Society for Plant Pathology (2019). Plant doctor book.

CABI (2017). Plantwise a country-based approach to improve farmer livelihoods through reduced crop losses and increased productivity.

CABI (2020). Plantwise Annual Report 2019; Wallingford, UK: CABI, 2020.

Culliney, W, T. (2014). Crop Losses to Arthropods. Integrated Pest Management (pp.211-218). http://dx.doi.org/10.1007/978-94-007-7796-5_8

Chimpokosera, M. M. (2023). Back to basic: Smallholder farmers embrace integrated pest and disease management in Malawi, saving ecosystems. November,2023.

Danielsen, S., Kelly, P. (2010). A novel approach to quality assessment of plant health clinics. *International Journal of Agricultural Sustainability*. http://dx.doi.org/10.3763/ijas.2010.0494

Danielsen, S., Mutebi, E. (2010). The introduction of mobile plant clinics to Uganda. *First results and lessons learned*. http://dx.doi.org/10.13140/2.1.2128.1283

Danielsen, S., Centeno, J., López, J., Lezama, L., Varela, G., Castillo, P., Narváez, C., Zeledón, I., Pavón, F., Boa, E. (2011). Innovations in plant health services in Nicaragua: From grassroots experiment to a systems approach. *Journal of International Development.* http://dx.doi.org/10.1002/jid.1786

Danielsen, S. Boa, E. Mafabi, M. Mutebi, E. Reeder, R. Kabeer, K. Karyeija, R. (2012). Using Plant Clinic Registers to Assess the Quality of Diagnoses and Advice Given to Farmers: A Case Study from Uganda. *The Journal of Agricultural Education and Extension*. http://dx.doi.org/10.1080/1389224X.2012.741528.

FAO.(2010).Climate-Smart-Agriculture'.

http://www.fao.org/3/a-i1881e.pdf.

FAO. (2023). Enhancing sustainable plant through optimization and minimization. Sustainable plant pests and diseases management

Gasheja, F. Gatemberezi, P. (2017). An Assessment of Rwanda's Agricultural Production, Climate Change, Agricultural Trade and Food Security

Ghosh, S., Taron, A., Williams, F. (2019). The impact of plant clinics on the livelihoods of Bangladeshi farmers. CABI study brief 29: Impact. https://dx.doi.org/10.1079/CABICOMM-62-8107

Gurmessa, N., Bundi, M., Williams, F. (2021). A Study of Effects of Village-based Plant Clinic services in selected regions of Ethiopia. *CABI Working Paper* 23, 18 pp. DOI: https://dx.doi.org/10.1079/CABICOMM-62-8157

Majuga, J. C., Uzayisenga, B., Kalisa.J.P., Almekinders, C., Danielsen, S. (2018). Here we give advice for free": the functioning of plant clinics in Rwanda. https://doi.org/10.1080/09614524.2018.1492515

Marsh, J. (2022), Reducing Health Risks from Pests in Agriculture

Mbago-B S., Rispoli F.M., McGrenra D. (2019). Republic of Rwanda. Country strategic opportunities programme 2019-2024. Rome, May 2019.

McGoven, R. J; To-anun, c. (2016). Plant Doctor: A critical need. *Journal of Agricultural Technology.* Vol. 12(7.1):1177-1195. http://www.ijat-aatsea.com

MINAGRI. (2023). Annual report 2022/2023

Mur, R., Williams, F., Danielsen, S., Audet-Bélanger, G., Mulema, J. (2015). Listening to the silent patient: Uganda's journey towards institutionalizing inclusive plant health services. *CABI working Paper 7*, 224pp. http://dx.doi.org/10.1079/CABIPLANT-37-55

Murekeyimana, P. (2019). Integrated production technical guidelines for tomato (*Solanum lycopersicum)* production in Rwanda.

Negussie, E., Karanja, P., Romney, D., Muriithi, C., Kamau, R., Boa, E., Zombe, N., Wanjiku, R., Murage, N., Mulaa, M., Day, R., Mutisya, J. (2011). 'Role of plant health clinics in enhancing adaptive capacity to climate

induced plant health problems: Experiences from Kenya'. Paper presented at the Africa Adapt Climate Change Symposium, Addis Ababa, Ethiopia, 9–11 March.

NISR (National Institute of Statistics of Rwanda).2015a. Seasonal Agricultural Survey 2014, Kigali, Rwanda. NISR (National Institute of Statistics of Rwanda).2015b. Gross Domestic Product 2014, Kigali Rwanda. NISR (National Institute of Statistics of Rwanda).2015c. Rwandan Integrated Household Living Conditions. Survey 2013/2014, Main Indicators Report.

NISR. (2021). Statistical report. Gross Domestic Product (GDP). Nation accounts (First quarter 2021). https://www.statistics.gov.rw/publication/1695. Accessed on August 30, 2021

NISR (National Institute of Statistics of Rwanda). 2021. Agricultural household survey 2020 report.

Nsabimana, J. de D., Uzayisenga, B., Kalisa, J.P. (2015). Farmers in Rwanda reap benefits with advice from plant clinics. CABI Study Brief 14. https://dx.doi.org/10.1079/CABICOMM-62-8111

Oerke, E.-C., 2006. Crop losses to pests. *The journal of agricultural science*. Volume 144, pp. 31-43. https://doi.org/10.1017/S0021859605005708

Otieno, W. (2018). Plantwise impact report 2011-2018

POMS. (2021). https://www.plantwise.org/knowledgebank/clinics/Account/Login?returnUrl=%2F (accessed on July 02, 2021)

Rwanda Agriculture Board (2018). Plantwise in Rwanda. 2018 Annual report

Silvestri, S., Macharia, M. Uzayisenga, B. (2019). Analysing the potential of plant clinics to boost crop protection in Rwanda through adoption of IPM: The case of maize and maize stem borers, Food Security. pp. 301–315. https://doi.org/10.1007/s12571-019-00910-5

Srivastava M.P, (2013). Plant clinic towards plant health and food security, 2013. *International Journal of Phytopathology*, 2(3):193-203. http://www.escijournals.net/EJPP

Tambo, J. A., Uzayisenga, B., Mugambi, I. and Bundi, M. (2020). Do Plant Clinics Improve Household Food Security?

Evidence from Rwanda. June,2020. *Journal of Agricultural Economics,* Vol. 72, No. 1, 2021, 97–116. http://dx.doi.org 10.1111/1477-9552.12391

Tambo, J. A., Uzayisenga, B., Mugambi, I., Bundi, M. and Silvestri, S. (2020). Plant clinics, farm performance and poverty alleviation: Panel data evidence from Rwanda. World Development, Vol. 129. https://doi.org/10.1016/j.worlddev.2020.104881

Tambo J. A., Romney D., Mugambi.I., Mbugua F., Bundi. M., Uzayisenga, B., Matimelo.M., Ndhlovu.M.(2021). Can Plant Clinics Enhance Judicious Use of Pesticides? Evidence from Rwanda and Zambia. March 2021.*Food Policy*. http://dx.doi.org/10.106/j.foofpol.2021.102073

Tjamos, E. (2013). Plant Clinic, a university science Plant Doctor, a necessary profession for a benefit for a global agriculture: Arguments and actions for their establishment

Toepfer, S.; Niyongere, C.; Ndayihanzamaso, P.; Ndikumana, D.; Irakoze,W.; Cimpaye, E.; Minani, D.;Bindariye, P.; Ochilo,W. Sustainable.(2023). Sustainable improvements in diagnostic capabilities of plant health practitioners through short In-Service Training. https://doi.org/10.3390/su151712956

Uzayisenga, B., Nsabimana, J de D., Kalisa, J.P., Bigirimana, J. (2020). Evaluation of farmers' satisfaction to plant health advice offered through plant clinics in Rwanda. *Rwanda Journal of Agricultural Sciences*.Vol 2, No.1

World Bank. (2023). Rwanda—Transformation of Agriculture Sector Program Phase 2. Program-for-Results. Independent Evaluation Group, Project Performance Assessment Report 177336, Washington, DC: World Bank