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Tools for pest and disease management by stakeholders: a case study on Plantwise

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1 Introduction

Plantwise is a global programme led by CAB International that has been introduced in more than 30 countries since 2011. It is presented in this chapter as a case study illustrating the use of innovative approaches and tools in pest management. Plantwise puts emphasis in accurate pest diagnosis as an essential requisite for effectiveness of recommendations given to farmers in managing pests at farm level, with a strong focus on production practices by smallholder farmers in developing countries. Training of intermediaries between technology developers and smallholder farmers in diagnosing problems that farmers detect in their crops is recognized as the key starting point in pest management. The intermediaries, herein referred to as plant doctors, are specially trained government agro-advisory service providers, empowered through training on how to diagnose problems with plant

http://dx.doi.org/10.19103/AS.2020.0080.06

health, operate plant clinics and give good advice to farmers based on integrated pest management (IPM) principles. Plant clinics are an extension tool that is based on a similar approach to human health clinics. Not only do the plant clinics serve as points from which to advise farmers, but they are also frontline facilities for diagnosing and documenting the presence of pests in farmers' fields. The documented cases at plant clinics are used to build databases that serve as information resources for stakeholders in plant health. Supporting the work of plant doctors in both diagnosing and recommending solutions to pest problems is the Plantwise Knowledge Bank, an interactive online and offline open-access information resource. The knowledge bank is innovatively designed to enable diagnosis of unknown pest problems as well as ease the search for diverse pest information, with content from various expert sources in the form of high-quality images and factsheets. The Plantwise Factsheet Library app, a tool that has been developed under the programme, is widely used through digital devices to access the information in the knowledge bank. These information resources support plant doctors in providing diagnoses and recommendations to farmers who use plant clinic services. In the cases where the paucity of information is known to constrain recommendations that can be given to farmers, additional 'Plantwise Factsheets for Farmers' and 'Pest Management Decision Guides' are co-developed with country experts and placed in the knowledge bank.

Embedded within the Plantwise Knowledge Bank is the Plantwise Online Management System, a restricted access site, where data from plant clinics is continuously fed as it gets collected. The restriction of access to the site is necessitated by the sensitive nature of countries to personal data or to pest data, the latter possibly having phytosanitary implications in international trade. The usefulness of this system in enabling prompt response to threats from pests detected through plant clinic networks is enhanced by near real-time data collection and uploaded using the Plantwise Data Collection app. Plantwise therefore presents a unique innovation in which a two-way flow of information strengthens country systems for detection and management of plant pests. Information collected by plant doctors at plant clinics helps to build databases that are also used to identify the kind of information that farmers need to manage pests on their farms.

This chapter presents Plantwise as an innovative process for pest management in smallholder crop production systems. The tools and applications developed under Plantwise constitute innovations that have the potential to contribute to broad aspects of pest management. They can be easily repurposed to address specific needs and adapted to fit various country contexts and agricultural production practices.

Published by Burleigh Dodds Science Publishing Limited, 2021

1.1 Challenges faced by smallholder farmers in developing countries

Many smallholder farmers in developing countries face numerous challenges and constraints to sustainable crop production. These constraints include limited resources (land, water, funds, labour) and access to knowledge, information, inputs and technologies (Uziak and Lorencowicz, 2017). One aspect of production most seriously impacted by these constraints is crop damage by pests. In many of these countries, farmer incentives to invest in agriculture are driven by a number of factors. These include land tenure (tenancy and ownership), size of holdings and field fragmentation (effects on operational efficiency), labour and capital (access to credit), mechanization and affordability of farm equipment (affordable transportation) and guarantee of markets. Farmers' immediate concerns typically consist of improving crop yield, increasing crop diversity and income rather than the environment (Uziak and Lorencowicz, 2017). Therefore, the adoption of pest management practices by smallholder farmers is largely based on addressing these needs, particularly input costs and the value of the crop.

Crop pests, considered here inclusively as a species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products (IPPC, 2007), constitute one of the major limiting factors to agricultural productivity in many farming systems, causing losses that generally range from 30–40% (Oerke, 2006). As such, pest damage adversely affects food security and diets across the globe. The situation is particularly dire in smallholder farming systems where uptake of technologies to modernize agriculture is slow. To promote effective pest management at farm level, it is essential that key interventions target information on production practices with technologies that are socially and economically feasible for smallholder farmers (Bottrell and Schoenly, 2018; Dara, 2019). Even where information is available and knowledge is accessible, access to inputs by smallholder farmers is often limited by poor supply and distribution systems, inadequate regulatory framework and on-farm economic factors, for example, access to credit facilities (Langyintuo, 2020). For example, where collateral is a requirement, inadequate trust on individual farmers as dependable borrowers can only be overcome when they are organized into groups (Ainembabazi et al., 2017). Farmer groups can act as business or commercial entities with economic incentives to invest in agriculture. However, coordination among farmers is often missing, particularly for those practicing purely subsistence farming. Organizing farmers into farmers' associations based on common interest groups has been shown to enhance the ability to advance their needs at research or policy levels, bargain or negotiate with suppliers for certain inputs at scale and with appropriate package sizes, as well as eases technology adoption by enhancing cooperation from all interested parties (Grasswitz, 2019). This is best initiated through government interventions, for example, in India where the National Bank for Agriculture and Rural Development (NABARD) supports initiatives to develop farmer producer organizations and links them with markets.

Even where farmers are organized into groups, the success of interventions to mitigate crop damage and loss to pests is accurate pest diagnosis and up-to-date knowledge on best management practices. However, diagnosing and managing most plant health problems effectively is often constrained by inadequate access to information on appropriate tools and processes for pest management, especially for smallholder farmers. Uptake of technologies for integrated pest management and/or correct use of inputs such as pesticides is dependent on farmer awareness and understanding of crucial factors relating to plant health problems, for instance, the perceived threat to the crop and the availability of safe and effective solutions (Uziak and Lorencowicz, 2017). Most farmers continue to rely on intermediaries, such as providers of agricultural advisory services, for information on pests. These intermediaries may be public servants working as agricultural extension officers, non-governmental organizations, or small businesses dealing with agro-input supply. However, many of these intermediaries themselves do not have access to up-to-date information and skills on diagnosis and effective pest management.

Digitizing agriculture is increasingly becoming one of the core technologies for agricultural modernization in many parts of the world. In recent years, a number of tools have been developed and are progressively being tested and deployed to support agricultural production systems, including those focussed on pest management (Deichmann et al., 2016; Bacco et al., 2019). Thus, the use of ICT-driven processes in pest management is a growing trend across the globe, particularly in supporting pest diagnosis, reporting and alerts (Barbedo, 2017; Elijah et al., 2018; Inwood and Dale, 2019). However, the usefulness of such tools must be grounded on basic principles of pest management including diagnosis and documentation of diagnosed problems in dependable data systems. Access to and use of pest data and information needed for practical pest management in crop fields forms part of what is described in this chapter, using the Plantwise concept as an exemplar. Ideally, a plant health-focused development programme should prioritize the use of innovative processes and tools to deliver impact. The fact that this has resulted in rapid evolution of systems that digitize and ease analysis of pest data, through a suite of tools, continues to present excellent opportunities for countries to apply data-driven decisions in responding to pest problems (Sharma et al., 2014; Wright et al., 2016).

In India, for example, Sharma et al. (2014) describe the use of an ICT-based system that caters for the needs of rural farmers who grow pulse crops. The system works well but mainly because of the link with internet connection and mobile phones as an essential component. In CABI's Plantwise programme, using SIM-equipped tablet computers has been demonstrated to reduce the time taken between pest detection through a farmer query at a plant clinic and response by government authorities, in some cases from 2 months to less than one day. For instance, this contributed to prompt management of a potential threat by the banana skipper (*Erionota* spp.) to the banana industry in Sri Lanka, thereby averting major adverse impact on the economy (CABI, 2019).

ICT tools have gained wider use in pest management because of the efficiency they confer on information management systems. Additionally, they enable pest data to be collected, stored, processed and interpreted more rapidly in easily retrievable forms than the conventional practices. This should, among others, empower plant protection authorities to issue appropriate, prompt and area-wide pest advisories to farmers and proactively support pest surveillance programmes through centralized server systems, a basic requirement for the functions of national plant protection organizations (IPPC, 1997).

In recognition that both information gaps and inefficiency of conventional methods for plant health management, including response to pest threats, continue to constrain efforts to reduce crop losses in smallholder production systems, CABI developed the Plantwise concept into a global programme. Plantwise is a plant-health capacity development initiative that works to reduce crop losses to pests through interconnected activities in the following areas:

i training agricultural advisors on visual pest diagnosis and how to give good advice based on the IPM principles to farmers by serving as plant doctors,
ii establishing networks of plant clinics where farmers can consult the plant doctors on issues affecting the health of their crops and get timely and good actionable advice,
iii developing open-access information resources for easy reference to support the work of plant doctors and other intermediaries,
iv building the capacity of in-country experts in the development of extension material such as factsheets and Pest Management Decision Guides, and
v developing an access-controlled databank and associated tools that ease data capture, storage and retrieval by plant doctors and other plant health stakeholders to help inform decisions and actions on plant health issues frequently raised by farmers in any country.

The Plantwise programme recognizes that an effective plant health system is dependent on strong interactions among various stakeholders, both governmental and non-governmental organizations including agricultural extension services, research institutions, diagnostic service providers, universities and colleges, farmers' associations and community-based organizations. It therefore works to strengthen linkages among these diverse actors, enabling them to respond to farmers' needs with appropriate techniques. In its implementation, Plantwise has partnered with over 175 different organizations from public, private and civil society in over 30 countries to ensure efficient delivery of actionable advice to farmers.

2 Plantwise trainings

The main driver of the Plantwise concept is its provision of information needed by farmers to manage pests on their crops. Capacity to provide such information to the millions of smallholder farmers in developing countries is best built through tailored trainings of agricultural service providers on pest diagnosis and management. To be able to serve as plant doctors, agricultural advisory service providers undergo short training courses organized in two modules. Module 1 focuses on symptom-based field diagnosis of pests and comprises the study of distinguishing features of major pest groups and pest identification by a process of elimination, as well as methodologies to gather background information, for example, crop and pest history. It also trains the plant doctors on how to set-up and run a plant clinic. Module 2 mainly deals with giving good IPM-based advice through prescribing to farmers locally appropriate preventive and/or curative recommendations for pest management.

With increased use of digital devices, training on both modules has integrated elements on the use of tablet computers and smartphones to access information and capture data. The training on use of digital devices involves a generalized introduction to handle the devices, how the devices can be deployed in specific activities of Plantwise work and their practical use to collect pest data through the Plantwise Data Collection App or to access pest management information through the Plantwise Factsheet Library App.

3 Plant clinics

One major intervention of Plantwise is the plant clinic concept. Modelled on the system for providing services in human health at community level, plant clinics serve as focal points where farmers bring samples of affected crops and consult plant doctors, who make diagnoses and provide recommendations for managing the problem. Plant clinics operate as a demand-driven extension tool and are typically run in designated locations weekly or fortnightly between 0900 h and 1500 h. Each clinic is manned by one or more 'plant doctors' (agricultural extension workers or other agricultural service providers trained by the programme). Typically, plant clinics are situated in areas easily accessed by farmers, including village centres, fresh produce markets or other gathering places.

A farmer who comes to a plant clinic with a query receives advice on the diagnosed problem and the recommended solutions in a prescription form. For those plant doctors using a digital version of the prescription form, it is even possible for them to send the prescription as an SMS directly to the farmer's phone. The plant doctor also retains a copy of this form and the information therein (i.e. the name of the farmer, the type of crop presented, approximated size of area planted, approximated size of the planted area affected by the problem, the problem identified and recommendation given by the plant doctor) is used to develop a database known as Plantwise Online Management System for each country. One of the uses of this database is to identify areas where additional information is needed, in terms of factsheets, to address the most common problems presented by farmers to plant doctors. Thus, plant clinics not only serve as frontline diagnostic facilities but are also the starting point of the two-way flow of pest information between the farmers and plant health decision-makers who are also the custodians of plant clinic data.

Networks of plant clinics have been established in more than 30 countries spread across Africa, Asia and the Americas where Plantwise has been introduced. Cases of plant clinics contributing to the detection of new pest introductions have been reported in all these regions, for example, in Africa for tomato leafminer (*Tuta absoluta),* fall armyworm (*Spodoptera frugiperda*) and maize lethal necrosis disease (MLND). Their importance to farmers, in pest management, judging from the trends in plant clinic data on tomato and maize (Table 1) for a sample of four African countries, for example, cannot be overemphasized. Further examples of pest detections through plant doctors across Plantwise countries include banana skipper (*Erionota* sp), papaya mealybug *(Paracoccus marginatus,* banana weevil, (*Cosmopolites sordidus*), croton scale (*Codiaeum variegatum*), bronze bug (*Thaumastocoris peregrinus*) and red gum lerp psyllid (*Glycaspis brimblecombei).* However, it is obvious that identification of unfamiliar or new pests, still requires either expert support to plant doctors by diagnosticians, and laboratory referrals is often necessary. Through Plantwise, a referral mechanism, involving a network if in-country experts from various universities and research institutions, is now actively used. Some of the networks established are based on messaging apps such as Telegram, WhatsApp, Facebook, Messenger, Line and WeChat. The Diagnostic Advisory Services, a centralized service by CABI Labs in Egham, is now linked to many of these networks. Besides identification of pests in referred samples, it also supports the networks to remotely diagnose cases.

Table 1 Number of tomato and maize queries related to Tuta absoluta and fall armyworm as a percentage of total number of queries (n) on each crop in selected countries between 2013 and 2019

Country		Fall armyworm							*Tuta absoluta*						
		2013	2014	2015	2016	2017	2018	2019	2013	2014	2015	2016	2017	2018	2019
Ghana	%	0	0	0	14	85	90	90	0	0	0	0	1	2	1
	n	97	158	344	1496	4845	5377	4801	114	207	353	722	542	332	386
Kenya	%	0	0	0	0	50	65	54	0	12	15	12	11	12	16
	n	611	1302	1779	2255	2513	1914	628	591	1113	1858	2125	1028	717	250
Malawi	%	0	0	0	1	66	88	83	0	0	0	2	4	5	14
	n	141	786	1538	1078	2949	1715	1182	133	485	993	583	481	288	296
Zambia	%	0	0	0	15	66	53	93	0	0	0	36	45	29	30
	n	10	102	224	590	2398	664	2507	9	110	205	474	185	101	258

n = data in the rows shows total queries on the crops each year. Queries on *Tuta absoluta* started to emerge with its first appearance in farmers' fields in 2014 in Kenya and increasingly in the subsequent years in the other countries. Queries on FAW started appearing with its emergence in farmer' fields in 2016 in Ghana, Malawi and Zambia and became more widespread in additional countries in subsequent years.

4 Information resources for pest diagnosis and management

Accurate pest diagnosis is a key determinant of the effectiveness of recommendations for managing a pest in any cropping system. The diagnosis is only the first step in supporting a farmer to address a problem in his/her crop; however, it is essential for determining the right choice of pest management options from which a farmer can select what to adopt on the farm. As a result, Plantwise puts as much emphasis in building capacity for correct diagnosis as it does in promoting alternative effective and safe methods that plant doctors can recommend to a farmer. One of the tools developed for this purpose is the Plantwise Knowledge Bank (https://www.plantwise.org/knowledgebank), an online and offline open-access information resource. The online Plantwise Knowledge Bank is an interactive tool that enables users to easily filter the information they are looking for as an enabler to prompt decision and action on any pest of interest. The knowledge bank supports diagnosis of pests through its extensive content of images and information materials in the form of factsheets.

Through the Plantwise Factsheet Library App and the online Plantwise Knowledge Bank, plant doctors have unrestricted access to reference materials that enable them to provide recommendations of proven efficacy against diagnosed pests to farmers. These reference materials consist of Plantwise Factsheets for Farmers, Pest Management Decision Guides, diagnostic photo-sheets and other materials from collaborators. The majority of the Plantwise information materials have been developed over time as a result of the queries that farmers raised with plant doctors that were indicators of most commonly encountered problems for which there was paucity of information on diagnosis and/or methods for control. Additionally, there are also cases where the available information is outdated in terms of pest control products, particularly chemical pesticides. In such a situation, the content is revised to update the information that is no longer relevant. As of early 2020, the online Plantwise Knowledge Bank has over 10 500 reference materials. Of these, 3470 were specifically written through the Plantwise programme and are also available through the Plantwise Factsheet Library app. The Pest Management Decision Guides (Fig. 1) are developed on a case-by-case basis and now serve a very useful purpose in providing advice on following the IPM principles in many countries.

Regarding outdated products for pest control, analyses of plant clinic data have shown some cases where pesticides whose use is now restricted through international conventions due to their toxicity are still being recommended by agricultural advisors in some countries. In such situations Plantwise has intervened through national institutions to create awareness about the risks,

PEST MANAGEMENT DECISION GUIDE: GREEN AND YELLOW LIST

plantwise

Fall armyworm on maize

Spodoptera frugiperda

Damage on the funnel by larvae (Photo: M. Kasina, KALRO, Kenya)

Inverted "Y" pattern on the head of Fall armyworm larva (Photo: Desiree van Heerden, Syngenta)

Egg mass of *S. frugiperda* (Photo: Desiree van Heerden, Syngenta)

Prevention	Monitoring	Direct Control	Direct Control	Restrictions
• Avoid late or off-season planting. • Plant tolerant maize varieties (e.g. with hard husk cover to prevent the pest from penetrating) • Regularly weed to remove alternate hosts • Plough after infested fields are harvested • Ensure optimum use of fertilizer for strong maize plants able to compensate for damage done • Avoid planting new crop near infested fields • Do not move infested maize materials from one area to another; instead feed to livestock	• Start monitoring for the pest one week after germination, continue weekly or every second week • Monitor 10 consecutive plants in 10 locations of the field. • Look for creamy / grey egg masses covered in a felt-like layer of grey-pink scales on the underside of leaves • Look for caterpillars having a dark head with a distinct pale, upside-down Y-shape on the front and 4 dark spots on the second-to-last body segment; do so in early morning or evening hours • Check for large amounts of moist sawdust-like frass near the whorl and upper leaves • Look for small shot or large ragged and elongated holes on the leaves and inside whorls of young plants • At early whorl stage, take action if >20% of plants are damaged or infested with larvae. At late whorl stage, if small larvae can be found then consider taking control measures if >40% of whorls are damaged. At tassel and silk stage, do not spray anymore	• Handpick and destroy caterpillars (e.g.in hot water). • Spray neem based product	• Insecticides are most effective on young larvae and before they enter the funnel and ears.	
			• Spray only according to needs identified by monitoring (including decision for a second application)	
			• Spray early morning or late afternoon when larvae are active.	
			• Minimise usage of WHO class II chemicals for own safety and protection of natural enemies which will help in pest control Always check label for details and wear appropriate PPE	
			• *Bacillus thuringiensis* var *aizawai*	• WHO Class III - (slightly hazardous). PHI 1 day, REI 1 day
			• Spinosad (e.g. Tracer at 4ml/20L). Repeat spraying after 14 days	• WHO class III (slightly hazardous). PHI 1 day, REI 12 Hours. Toxic to honey bees; avoid spraying during flowering and near water ways
			• Chlorantraniliprole (e.g. Corragen)	• WHO Class U (Unlikely to cause hazard under normal use). PHI 21 days
			• Indoxacarb (e.g. Avaunt 150 SL)	• WHO class II (Moderately hazardous)
			• Alpha-cypermethrin (e.g. Bestox 100Ec at 60 ml/20L or Tata alpha 10EC at 6ml/20L of water)	• WHO class II (moderately hazardous). REI is 24hours. PHI is 21 days.

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Figure 1 An example of Pest Management Decision Guide (PMDG) – presenting processes to follow in the case of fall armyworm on maize.

resulting in the reduction of recommendations of the high-risk pest control products for use by farmers.

Information about new pests reported anywhere in the world is also provided through the Plantwise Knowledge Bank. There are over 1900 subscribers to this pest alert service. From inception to date, well over 50 000 pest alerts have been sent to subscribers.

There have been recent improvements in the Plantwise Knowledge Bank These improvements make access simpler and more efficient for users. Tracking Plantwise Knowledge Bank and Factsheet Library App user journeys shows that these are invaluable resources for people seeking pest management information across the globe. From its inception in 2011, more than 2.1 million individuals have visited the online Plantwise Knowledge Bank, 1.2 million of whom were from non-Plantwise countries. In 2019, the majority of website and app users were women (constituting 55%). Equally active on the Plantwise Knowledge Bank website are the youth, with the majority of users being under the age of 35 years. Google analytics shows that user journeys to the Factsheet library grew from 195 774 to 745 162 between 2017 and 2019.

5 Repositories for pest data

One of the uses of pest data by countries in the coming years is likely to be in broader applications in pest forecasting and advisories to farmers. The linking of data sets like those created in the Plantwise programme can be an enabler for regular pest advisories and response, the latter using repurposed Pest Management Decision Guides to mitigate pest damage. The main kinds of data collected at plant clinics are those on the crops, places of production and the farmers, the diagnosed problems and the recommendations given to the farmers for managing the problems. The data is fed into a repository called the Plantwise Online Management System, which was developed specifically to help countries manage this data coming from the field. The Plantwise Online Management System is a restricted access area of Plantwise Knowledge Bank, due to the confidentiality of the data. Personal data protection policies and sensitivities around pest data mean that national institutions who own the data have the responsibility of deciding who can access it. Once in the Plantwise Online Management System, the plant clinic data can be cleaned and standardized (in a process called data harmonization) to make analysis easier. In some countries, the data is then also reviewed by in-country experts who check the validity of diagnoses and recommendations of individual records (in a process called data validation). Harmonization ensures that analyses are accurate and do not contain keying or spelling errors, while validation assesses the accuracy and appropriateness of diagnoses and recommendations. An illustration of a simple analysis of data in Plantwise Online Management System is shown in Fig. 2.

Plant clinic data in the Plantwise Online Management System forms an important technical reference for pest management and associated actions, such as general surveillance. The Plantwise Online Management System is therefore a tool that serves as an enabler for pest listing and hence pest risk

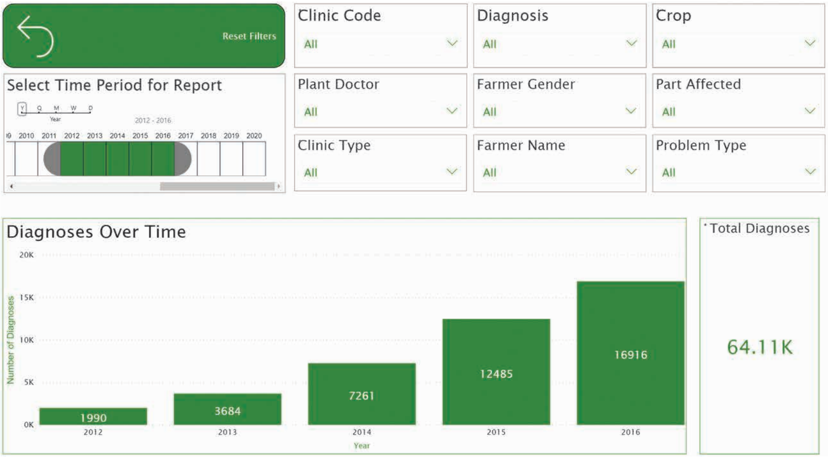

Figure 2 Plantwise Online Management System interactive visualization of plant clinic data.

analysis by countries. The data validation process described above is another major use of plant clinic data, providing a unique mechanism for monitoring quality of diagnostics and advice to farmers by plant doctors. This can be done centrally or locally in the operational areas of the plant doctors. The observations made during data validation are used to facilitate conversations during follow-up meetings where plant doctors and plant clinic supervisors discuss technical and operational issues associated with plant clinics (Danielsen and Kelly, 2010). During these meetings, a plant doctor self-assessment tool can be employed, with plant doctors reassessing the quality of their own diagnoses and recommendations to farmers. The results from these various assessments and discussions are used by Plantwise and the local implementing organizations to identify plant doctors' training needs.

With plant clinics equipped with tablet computers and using the Plantwise Data Collection app, there is rapid data flow into the Plantwise Online Management System. This happens on a near real-time basis compared to the original paper-based system that used to take approximately 105 days (Wright et al., 2016). This rapid information flow is what is needed for swift response to pest problems that can otherwise quickly result in massive damage to crops. The Plantwise Online Management System has therefore a huge potential for use as a support tool to decisions on pests of economic importance that warrant prioritization for investments in major control measures by countries. However, use of the Plantwise Online Management System data for purposes such as decision to make investments in pest control measures still not widespread. This may typify the apparent low level of uptake of data-driven decisions in the area of pest management or plant health management practices in many developing countries. Examples from specific cases where data is identified as critical for traceability systems for risks due to pests or contaminants from pest control products affecting trade in plants and plant products (European Union, 2018, 2019) show that in most developing countries, this is not unique to Plantwise.

The data in the Plantwise Online Management System is available for analysis by country-authorized stakeholders thereby helping, for example, in identification of:

- i major crops on which farmers raise queries relating to pest management,
- ii pests of concern to farmers and their distribution,
- iii areas where further research is needed, for example, for effective management of emerging pest threats, and
- iv areas where information is lacking to support diagnosis and recommendations that can be given to farmers.

Through these processes, crops on which farmers tend to raise queries are easily identified from the data in the Plantwise Online Management System

Table 2 Top five crops with the highest number of queries at the plant clinics in a sample of Plantwise countries in Africa

	Top crops				
Country	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5
Kenya (n = 61 084)	Maize (17%)	Tomato (12%)	Kales (10%)	Coffee (10%)	Banana (5%)
Ghana (n = 43 326)	Maize (28%)	Cocoa (21%)	Chillies (6%)	Okra (5%)	Tomato (5%)
Malawi (n = 18 407)	Maize (44%)	Tomato (16%)	Beans (4%)	Cassava (3%)	Mustard (3%)
Rwanda (n = 15 873)	Maize (26%)	Cassava (15%)	Banana (8%)	Beans (8%)	Irish Potato (8%)
Uganda (n = 8 833)	Citrus (11%)	Banana (9%)	Cassava (9%)	Coffee (9%)	Maize (9%)
Zambia (n = 8 392)	Maize (46%)	Tomato (13%)	Rape (8%)	Mango (5%)	Cabbage (3%)

Numbers in parentheses are percentages of queries on the named crops relative to total queries (n) raised.

Table 3 Top problems based on % of all queries in five top crops in a sample of African countries' (Kenya, Ghana, Malawi, Rwanda, Uganda, Zambia) crops

	Problem 1	Problem 2	Problem 3	Problem 4	Problem 5
Maize (n = 49 288)	Fall armyworm (55%)	Maize stalk borer (12%)	Maize streak virus (6%)	Maize lethal necrosis disease (4%)	Weevils (2%)
Tomato (n = 16 464)	Bacterial wilt (11%)	Late blight (9%)	*Tuta absoluta* (8%)	Early blight (7%)	Red spider mites (7%)
Cocoa (n = 10 543)	Miri bugs (40%)	Cocoa stem borer (17%)	Black pod borer (12%)	Termites (8%)	Nutrient deficiency (2%)
Coffee (n = 7 518)	Coffee leaf rust (28%)	Coffee berry disease (12%)	Coffee stem borer (5%)	Thrips (4%)	Green scales (4%)
Cassava (n = 6 534)	Cassava mosaic virus (58%)	Cassava brown streak virus (16%)	Cassava mealybug (4%)	Cassava root rot (3%)	White flies (2%)

(as outlined with the examples in Table 2). Related examples for pests and the associated management recommendations are presented in Tables 3 and 4. For instance, fall armyworm (*S. frugiperda)*, tomato leafminer (*T. absoluta*), mango gall midge (*Erosomya mangiferae*), cocoa mirids *(Sahbergella singularis* and/ or *Distantiella theobroma*) and cocoa black pod *(Phytophthora palmivora*) are among those for which farmer queries in some African countries indicated the

Table 4 Categories of recommendations and their frequency of occurrence for five top pests in a sample of African countries (Kenya, Ghana, Malawi, Rwanda, Uganda, Zambia)

Pest/Disease	Pesticides (%)	Cultural (%)	Biological (%)	Other (%)
Fall armyworm (n = 49 497)	48.0	47.5	2.5	2.1
Aphids (n = 17 101)	49.2	45.2	4.4	1.2
Mirid bugs (n = 6 247)	50.9	48.7	0.1	0.3
Powdery mildew (n = 5 027)	48.1	47.9	1.8	2.2
Anthracnose (n = 4 315)	42.6	53.4	1.6	2.3

need to prioritize the development of methods for effective management to be disseminated more broadly, through complimentary extension campaigns.

6 Conclusion

A sustainable agricultural production system should be considered as one that takes into account all three dimensions of sustainability viz. environmental, economic and social aspects (Rose et al., 2019). However, this is always affected by underlying factors, such as equity in access to opportunities for participation and cooperation and the level of knowledge, which influence farmer's decision-making processes. In developing countries, farmers' immediate concerns typically consist of improving crop yield, increasing crop diversity, and increasing income rather than concern for the environment (Uziak and Lorencowicz, 2017). In smallholder production systems, input costs and the value of the crop would be typically the major drivers in decisions in allocating resources to pest management. When faced with pest problems and presented with a mix of options, farmers are more likely to choose those that are affordable, practical, and offer quick and visible results (Parsa et al., 2014). This can be a barrier to IPM adoption and a threat to sustainable practices such as the use of biological control in smallholder agriculture. The study by Parsa et al. (2014) found that the most frequently cited obstacle to IPM adoption in developing countries was 'insufficient training and technical support to farmers'. This underscores the importance of information delivery to rural communities.

Agriculture advisers therefore not only require systems that enable rapid dissemination of accurate information, but also a suit of effective solutions if they are to earn the confidence of their clientele when promoting sustainable solutions. It is essential that they have information that is reliable and as current as possible on solutions with minimum adverse environment and health effects when dealing with rapidly changing pest situations. Innovations related to ICT tools and applications can greatly help the effort made by these advisers and farmers to access pest management information. Besides serving as decision-support systems, the tools also bring efficiency in critical steps to effective pest response, as seen in Sri Lanka where photos of an unidentified pest (which turned out to be banana skipper) posted by a plant doctor on a Telegram chat group triggered a system-wide response (CABI, 2019). The tools more or less automate the processes of collecting, organizing, integrating and analysing various kinds of data required to make decisions on pest threats and enable data use to drive decisions on pest management. Some of these uses, for example, in pest surveillance and provision of advisory services on various crops have been demonstrated in India (Vennila et al., 2012). Thus, the potential to advance the scope of using such tools as developed under Plantwise is great and needs to be explored further in the context of many crops or in partnership with other similar initiatives. For instance, the quick transfer of data through the Plantwise Data Collection app and the pest-specific management information available in the open access Plantwise Knowledge Bank can assist work flows of plant protection institutions in pest advisories for prompt response actions that are needed to save crops from damage.

Under Plantwise, the use of social media, such as WhatsApp and Telegram, has also gained popularity with plant doctors for day-to-day peer support. Many of them post photos of problems encountered and ask each other for diagnostic support or solutions to problems they have encountered. Some of these groups also include technical experts from local institutions and occasionally seek support from CABI's experts on more challenging cases. At least 27 Plantwise countries had established digital support groups by plant doctors by the end of 2019 and shared over 6000 photos in seeking support for diagnosis (CABI, 2019). In a few of these countries, plant doctors and subject-matter specialists now conduct lectures on pest-related issues via social media to address identified training needs. Plant doctors also use social media to invite farmers to extension activities on specific pests of concern and in trialling virtual plant clinic sessions. Additionally, information gathered through these networks has been used to map the occurrence of certain pests, for example, fall armyworm when it first appeared in East Africa.

The Plantwise Data Collection app is a useful tool for plant clinic operations in facilitating data capture and transmitting recommendations for pest management to farmers with potential for application beyond the current Plantwise processes. By 2019, over 3400 plant doctors in 28 countries had been trained in electronic capture of plant clinic data, and collectively had submitted over 60 000 plant clinic prescription forms and 12 000 photographs of various symptoms. The use of the Plantwise Data Collection app has enabled near real-time transmission of plant clinic data to the Plantwise Online Management

System, thereby reducing the time between initial pest detection and advisory on appropriate response actions. Thus, the potential of using a tool like the Plantwise Data Collection app and Plantwise Online Management System in pest surveillance systems is very high, provided the uptake is embedded in country systems for managing plant health.

The impact of ICT tools in pest management should mainly arise from their contributions to surveillance programmes through capture of pest information from farmers' fields, transferring it to centralized databases and enabling basic analytics needed for pest advisories to farmers (Vennila et al., 2012; Awuor et al., 2019). However, fundamental to this is the linkage of these ICT tools and systems with agricultural advisory services, agro-input supply systems and farm-produce traceability requirements. With an enabling regulatory environment and linkage to other production and agricultural supply systems, ICT tools can make a significant contribution to pest management thereby improving farmer livelihoods and profitability of agri-enterprises.

7 Future trends

From the developments in the past decade, it is evident that the transformation of smallholder agriculture needs to cope with increasing demand for food and that this would rely heavily on the use of innovative technologies, processes and ICT tools. Although these tools may introduce innovations that alter the traditional approaches to agricultural development by enabling information- and knowledge-based approaches, they must be considered as part of the continuum in evolving needs for sustainable agriculture. Thus, their applications should be expanded to holistically deal with all farming needs (FAO, 2013).

In particular, for pest management, the use of innovations should aim to increase resource-use efficiency in the face of climate change. ICT-mediated early warning system is a rapidly growing area of work in agricultural development and is one of the areas where the tools developed under Plantwise can be further deployed**.** The move of agri-enterprises towards ICT-based tools should increasingly anchor plant health management as a priority issue in regular practices for sustainable agriculture. Addressing plant health will be more effective if it is done through data-driven processes as described in this chapter. The drivers for ICT use in plant health should be based on the potential for scaling working concepts and innovations beyond the purposes for which they have been developed.

Functional ICT-based tools for pest and disease management should:

i enable proper planning of monitoring activities,
ii be adaptable to different cropping systems and conditions,
iii enable data inter-operability and integration,

iv ensure accurate pest detection, that is, backed by good diagnosis and identification support system,
v be easily fitted within feasible surveillance programmes and easily handled in the fields,
vi be linked to efficient communication on pest advisories and response systems,
vii facilitate farmers in taking and executing optimum decisions by providing geo-mapping, crop planning, individual farm plans and farm automation customized for each farmer based on weather, soil, pest and crop data on an almost real-time basis, and
viii improve the efficiency of access to inputs and pest management information.

In deploying ICT-based tools, where there is opportunity to consolidate existing tools, the above attributes should be considered.

Demonstrating the use of ICT tools and applications for te management of pests should be prioritized by governments and international organizations as these are becoming essential requisites for agricultural development. The uptake of technology (technology acceptance) by users is influenced by many factors including technology moderators (complexity, purpose), user’s circumstances (individual moderators) and organizational moderators (voluntariness of technology use) (Sun and Zhang, 2006). As a result, user engagements, throughout the development process, become a necessity, particularly where there is need to identify systems requirements for such tools (Ochilo et al., 2019).

Ownership of ICT-based tools should be anchored in public-private partnerships, with governments providing policy support to private entrepreneurs as tech developers/users. Government policy and provision of an enabling environment, especially in developing countries, should be encouraged to facilitate enterprises promoting such tools.

There is need for coordination at the national, regional and international levels by embedding technological advances in what is already happening under similar initiatives. An example of this is the Food and Agriculture Organisation of the United Nations (FAO)-led multi-organization effort to develop the Fall Armyworm Monitoring and Early Warning System (FAMEWS). This tool was created in response to the invasion and rapid spread of *Spodoptera frugiperda* in Africa, and subsequently Asia, beginning in 2016. The FAMEWS feeds data from an app for smartphones into several platforms that are used to make decisions about fall armyworm (FAO and CABI, 2019). It provides exact locations of the source of the information. Field data on FAW is collected from infested crop plants or pheromone traps. In each country, the data goes to a national platform, for review and approval, and thence to a global platform. The data is used by decision-makers to set priorities informed by a good understanding of the pest. Ultimately the FAMEWS-generated data will be freely available for use by farmers, agriculture advisers, government officials and donors. It will also be a key input in a risk model, and possibly other models, on fall armyworm. Another example demonstrating this aspect of coordination can be seen in the efforts made to manage desert locust in Eastern Africa, where there have been devastating outbreaks and spread since 2019. In Kenya, the Ministry of Agriculture, Livestock, Fisheries and Cooperatives has formed a multi-institutional technical team to strategize and guide the management of desert locust in the country. The team comprises individuals drawn from various institutions including government agencies: the National Plant Protection Organization (NPPO), the National Agricultural Research System (NARS), the FAO, the Desert Locust Control Organization for Eastern Africa (DLCO-EA), international agricultural research centres (CABI and the International Centre of Insect Physiology and Ecology (ICIPE), and private sector (technology providers for pesticides, including biopesticides). At a regional level, the FAO augments national efforts by supporting surveillance as well as aerial and ground spraying in the affected countries.

Building on the experiences and lessons learned over the years, evolving Plantwise by incorporating facets to enable countries to develop efficient pest surveillance and response systems has become necessary. Such systems require accurate predictions of imminent pest outbreaks to enable timely action to prevent or reduce the magnitude of damage on crops. As a result of ICT use, farmers would become more resilient to climate change with positive benefits also contributing to sustainable production practices that are climate-smart. Likewise, consumers would have improved access to safer food as a result of production practices that minimize risks such as contamination of agricultural products with pesticides. However, uptake of these practices will require that government policies in many countries prioritize sustainable agriculture and embrace the development and use of ICT-mediated systems.

Upscaling of the Plantwise innovation is largely determined by the level of ownership of the approach by programme beneficiaries. They seek to sustain the elements that are relevant and appropriate for them through their regular development funding, through other bilateral agricultural development projects, or through inter-linked businesses. Steps taken by some countries to sustain certain elements of Plantwise, such as plant clinics and data management, include integration of these innovations in countries' policy and implementation plans for agricultural extension and crop protection services. These are then budgeted for at national and sub-national levels (e.g. County Integrated Development Plan (CIDP) in Kenya). Country partner institutions are equipping their own staff to serve as trainers for new additional plant doctors. Under Plantwise, partners are also exploring ways of integrating the knowledge bank concept with country data and knowledge management systems (e.g. the Green Control subsidy programme in the Beijing, China (CABI, 2020)).

In addition, various interest groups see the value added and economic benefits of these Plantwise innovations and tools, and these can be repurposed for certain business interests. Since all tools and innovations under Plantwise have been developed using donor funds, they are freely accessible to all current and potential beneficiaries. This will ensure equitable access by relevant stakeholders in the agriculture sector in each country.

8 Where to look for further information

The following articles provide a good overview of the subject:

Boa E, Franco J, Chaudhury M, et al. (2016) Plant health clinics. *What works in Rural Advisory Services* 81.

Cameron KH, Somachandra K, Curry CN, et al. (2016) Delivering actionable plant health knowledge to smallholder farmers through the Plantwise program. *Journal of Agricultural & Food Information* 17: 212–229.

Danielsen S, Mur R, Kleijn W, et al. (2019) Assessing information sharing from plant clinics in China and Zambia through social network analysis. *The Journal of Agricultural Education and Extension*: 1–21.

Dougoud J, Cock MJ, Edgington S, et al. (2018) A baseline study using Plantwise information to assess the contribution of extension services to the uptake of augmentative biological control in selected low-to lower-middle-income countries. *BioControl* 63: 117–132.

Finegold C, Oronje M, Leach MC, et al. (2014) Plantwise Knowledge Bank: Building sustainable data and information processes to support plant clinics in Kenya. *Agricultural Information Worldwide* 6: 96–101.

Kansiime MK, Mugambi I, Migiro L, et al. (2020) Farmer participation and motivation for repeat plant clinic use: Implications for delivery of plant health advice in Kenya. *Cogent Environmental Science* 6: 1750539.

Lamontagne-Godwin J, Williams F, Bandara WMPT, et al. (2017) Quality of extension advice: a gendered case study from Ghana and Sri Lanka. *The Journal of Agricultural Education and Extension* 23: 7–22.

Majuga JCN, Uzayisenga B, Kalisa JP, et al. (2018) "Here we give advice for free": the functioning of plant clinics in Rwanda. *Development in Practice* 28: 858–871.

Mugambi I, Williams F, Muthomi J, et al. (2016) Diagnostic support to Plantwise plant doctors in Kenya. *Journal of Agricultural Extension and Rural Development*8: 232–239.

Musebe R, Mugambi I, Williams F, et al. (2018) Gender differences in the use of plant health information services: A case of plant clinics under Plantwise Program in Kenya. *African Journal of Agricultural Research* 13: 2862–2871.

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Romney D, Day R, Faheem M, et al. (2013) Plantwise: putting innovation systems principles into practice. *Agriculture for development*: 27–31.

Silvestri S, Macharia M and 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* 11: 301–315.

Tambo JA, Aliamo C, Davis T, et al. (2019) The impact of ICT-enabled extension campaign on farmers' knowledge and management of fall armyworm in Uganda. *PLoS ONE* 14.

Tambo JA, Uzayisenga B, Mugambi I, et al. (2020) Plant clinics, farm performance and poverty alleviation: Panel data evidence from Rwanda. *World Development* 129: 104881.

Tambo JA, Williams F, Jenner W, et al. (2018) *Profiling of Plant Clinic Users*. *Research Brief Series*. CABI.

Toepfer S, Kuhlmann U, Kansiime M, et al. (2019) Communication, information sharing, and advisory services to raise awareness for fall armyworm detection and area-wide management by farmers. *Journal of Plant Diseases and Protection* 126: 103–106.

Williams FE and Taron A. (2020) Demand-led extension: a gender analysis of attendance and key crops. *The Journal of Agricultural Education and Extension*: 1–18.

Key research in this area can be found at the following organizations:

Centre for Agriculture and Bioscience International (CABI) (https://www.cabi.org/).

International Plant Protection Convention (IPPC) (https://www.ippc.int/en/).

European Union Notification System for Plant Health Interceptions (EUROPHYT) (https://ec.europa.eu/food/plant/plant_health_biosecurity/europhyt_en).

Rapid Alert System for Food and Feed (RASFF) (https://ec.europa.eu/food/safety/rasff_en).

The World Bank (https://www.worldbank.org/).

The Technical Centre for Agricultural and Rural Cooperation (CTA) (https://www.cta.int/en).

International Maize and Wheat Improvement Centre (CIMMYT) (https://www.cimmyt.org/news/blast-and-rust-forecast/).

9 Acknowledgements

CABI is an international intergovernmental organization, and we gratefully acknowledge the core financial support from our member countries (and lead agencies) including the United Kingdom (Department for International Development), China (Chinese Ministry of Agriculture), Australia (Australian Centre for International Agricultural Research), Canada (Agriculture and Agri-Food Canada), the Netherlands (Directorate-General for International Cooperation) and Switzerland (Swiss Agency for Development and Cooperation). See http://www.cabi.org/about-cabi/who-we-work-with/key-donors/ for full details. CABI and its partners also recognize the contributions from the Directorate-General for International Cooperation and Development of the European Commission (DG-DEVCO), the International Fund for Agricultural Development (IFAD), Irish Aid (Ireland) and the Koppert Foundation. Others that have supported the programme, for example, through the use of tablet computers at plant clinics and/or spin-off projects, include the UK Space Agency, Corteva Agriscience and the contribution from the St Andrews Prize for the Environment. We are also grateful to all our collaborating partners in Plantwise countries. The authors also thank CABI staff involved in Plantwise implementation, particularly Mr. Fredrick Mbugua for his contribution to analyses of quantitative data.

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