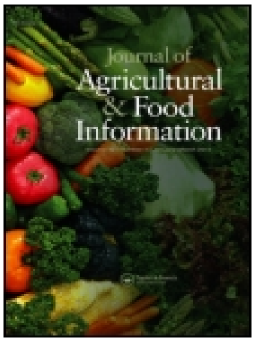

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Using ICT to Strengthen Agricultural Extension Systems for Plant Health

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ABSTRACT

Plant pests cause crop losses of 30–40%, contributing significantly to global food insecurity. The Plantwise program works alongside national agricultural extension services, who advise smallholder farmers on plant health issues and collect data on problems they face. In a 1-year pilot, Plantwise tested the use of information and communication technologies (ICT)—tablets and short message service (SMS)—with 60 Kenyan extension workers. They were able to assist more farmers with better advice, had significantly improved access to plant health information, valued being able to ask their peers for advice, and dramatically improved the quality and speed of the data they collected.

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Agricultural extension; plant health; ICT; mobile; plantwise

Introduction

Recent assessment of the Millennium Development Goal on hunger found that 167 million fewer people are undernourished today than they were a decade ago. The reality that 793 million people remain malnourished cannot, however, be ignored (Food and Agriculture Organization of the United Nations [FAO], 2015). In order to reach the new Sustainable Development Goal of zero hunger by 2030 (United Nations [UN], 2015), the impetus is to find practical ways to continue to reduce the number of people who are food insecure.

Agricultural pests and diseases are significantly undermining food availability by diminishing crop yields through both preharvest and postharvest losses. Pests and diseases cause yield losses of 30–40% (Oerke, 2006). The risk to food security is increased as populations tend to depend on just one or two crops for the majority

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of their diet (Strange & Scott, 2005). If those crops are impacted by a particularly virulent disease or devastating pest, the impact on food security can be disastrous.

Smallholder farmers rely on agricultural extension services for best-practice advice on how to prevent and manage the pests and diseases that undermine their food security. However, many agricultural extension services in developing countries are weak (Haug, 1999) and are often under underresourced (Anderson & Feder, 2004).

Plantwise (http://www.plantwise.org) is a global program, led by CABI, to increase food security and improve rural livelihoods by reducing crop losses. Working in close partnership with relevant actors, particularly extension services, Plantwise strengthens national plant health systems from within, enabling countries to provide farmers with the knowledge they need to lose less and feed more. This is achieved by establishing sustainable networks of local plant clinics, run by trained plant doctors, usually extension workers, where farmers can find practical plant health advice (Romney et al., 2013). These plant clinics are based on a similar approach to human health clinics and farmers come to receive advice on how to manage and prevent crop problems. Plant doctors learn methods to identify any problem on any crop brought to the clinics and provide appropriate recommendations guided by national and international best-practice standards to the farmers. Plant clinics are reinforced by the Plantwise Knowledge Bank (http://www.plantwise.org/knowledgebank), a gateway to online and offline actionable plant health information—including diagnostic resources, pest management advice, and front-line pest data for effective global vigilance (Leach & Hobbs, 2013). During the clinic the plant doctors also record their interaction with the farmer through a standardized "prescription form" collecting such information as farmer name, location of farm, crop grown, plant health problem diagnosed, and treatment advice given. A copy of the form is given to the farmer for reference and then the data from these forms are collated, digitized, and analyzed by in-country partners through a suite of tools available on the Plantwise Online Management System (POMS; Finegold et al., 2014).

Providing and collecting information to and from plant clinics, often in remote locations, presents many problems. Distributing all the relevant reference material, keeping it updated and maintaining it in good condition is difficult if relying on paper. Similarly, collecting, collating, and digitizing paper-based prescription forms is a complex process relying on postal services, accurate data collection, and the availability of staff for data entry. To try to get around such problems, the use of digital technologies has been piloted in Kenya as "e-plant clinics" to test whether systems such as electronic tablets and SMS (short message service) messaging could support the current Plantwise model. Plant doctors working in e-plant clinics were provided with, and trained on, tablets for use in their workflow. Through the tablets they had access to a wealth of preloaded plant health materials, could fill in an electronic version of the prescription form, and send their recommendations via SMS to farmers. During the pilot, the use of the tablets was carefully monitored with regard to specific hypotheses, to review their suitability for the purpose and to ensure that all key stakeholders, plant doctors, farmers, and Ministry officials were supportive of the technology and saw value in it.

Initial findings suggest that there are substantial advantages to integrating tablets into plant clinics. Most notable are the improvements of data speed and quality, the wealth of resources available for accurate decision making, and the opportunities for plant doctors to support each other through chat groups.

Materials and methods

Pilot site and implementation procedures

Plantwise has been working in Kenya since 2010 in partnership with the Kenyan Ministry for Agriculture, Livestock and Fisheries (MoALF). To date 93 clinics are established and have been running successfully using paper printouts of plant health materials from the Plantwise Knowledge Bank and collecting data on the farmer interviews on paper prescription forms which are keyed in country and then uploaded to the POMS where they are accessed by in-country partners.

The pilot began in March 2014 and uses an incremental implementation design in order to learn and adapt at each stage. This approach also minimizes disruption to existing clinic operations and data management systems. The steps of implementation used the following stages: developing and delivering appropriate technology, and in-country assessment, small pilot (stage 1), larger pilot (stage 2).

Developing and delivering appropriate technology

The developing and delivering appropriate technology stage consisted of the following:

1. Select a robust and locally supported tablet. The Lenovo a3000 (Lenovo Group Ltd., Beijing, China) was selected for the pilot.
2. Design and commission an Android application that would deliver key reference material from the Knowledge Bank. The "Plantwise Factsheets Library" was created, which displays all Plantwise pest management decision guides and factsheets for farmers in discrete country packs which, once downloaded, are available offline. This app is available for free on the Google Play Store (https://play.google.com/store/apps/details?id=org.cabi.pfff&hl=en_GB).
3. Identify a suitable Android application for collecting data. A commercially available platform (http://www.fulcrumapp.com) was used to create a bespoke Kenyan version of the prescription form.
4. Devise a process to send SMS messages from the tablet to farmers' mobile phones. A system was devised that sends an SMS noting the crop, problem, and recommendation to the simple type of phones used by 90% of the farmers.
5. Devise and deliver a training course to provide to plant doctors the knowledge, skills, and confidence to use the new technology. A 2-day intense course was created and used in face-to-face training of groups of plant doctors.

In-country assessment

Test and refine the tools with two plant doctors and implementation partners. Identify SIM and network providers and set up payment plans.

Stage 1

Begin with a small group and close follow-up to test implementation of the pilot and adjust as necessary.

Stage 2

Build a larger pilot with a representative sample of plant doctors to test the use of information and communication technologies (ICT) in Plantwise over a longer period.

Clinic selection

Stage 1 (March 2014–May 2014)

The first stage of the pilot aimed to understand the issues that would be faced in implementation, to validate the training materials, and to make any necessary adjustments before bringing a larger number of users into the pilot. This stage involved 10 plant doctors from five clinics (plant doctors work in pairs), who were selected based on proximity to the CABI office in Nairobi and clinics which were likely to be busy during the short pilot period, as this would allow Plantwise to remain in close contact with a group of relatively active users.

Stage 2 (May 2014–March 2015)

A further 50 plant doctors from 25 additional clinics were selected using a stratified model to balance spread between political and agroecological regions in Kenya. Stage 2 therefore gave a representative sample of the full diversity of plant doctors across Kenya. This diversity includes age, education, wealth, proximity to support, strength of mobile and network connectivity, access to electricity, etc.

Hypotheses

The following hypotheses about the use of ICT in plant clinics were tested throughout the pilot:

1. Access to and use of reference materials by plant doctors will increase as a result of having tablets in plant clinics.
2. The length and quality of recommendation may differ (positively or negatively) between typed and handwritten prescriptions.
3. The presence of tablets may affect (positively or negatively) farmer attendance.
4. Plant doctors' adoption of the technologies may be influenced (positively or negatively) by their age, sex, or education levels.

5. Plant clinic data will be received more quickly by the MoALF when collected via electronic prescription forms.
6. Plant clinic data will require less processing and cleaning when collected via electronic prescription forms.
7. Using the tablets to send photos of samples with the prescription form will aid data validation.

Collection of results

In order to assess the hypotheses, data were collected using a variety of research methods as follows: (a) surveys, (b) review workshop, and (c) analysis of the clinics data.

Surveys

Surveys incorporated the following:

- A monitoring and evaluation form filled in by support staff at clinic visits.
- Video interviews with plant doctors and farmers.
- Logs of e-mails, stories, and communications.

Review workshop

A participatory review workshop was held between Stages 1 and 2 in order to learn lessons from the first stage and to refine the approach and training for broader roll out. During the workshop, plant doctors participated in a variety of activities to share their experiences of the pilot and describe changes in the way their clinics operate. These were captured via a combination of workshop cards, flipcharts, and video, and later collated into a spreadsheet.

Analysis of the clinic data

For the statistical analysis of Hypotheses 2 to 4, plant clinic data collected between January 1, 2013 and November 31, 2014 were downloaded from the POMS database on February 25, 2015. In order to account for geographical and temporal differences, all paper forms collected in Kenya during this period were combined and the resulting average used as a benchmark. The data from the two pilots were pooled together and compared to this benchmark using a one-sample *t*-test. For Hypothesis 5, the nature of the *Tuta absoluta* invasion made it necessary to use a two-tailed test to assess processing time. For Hypothesis 6, data were only analyzed from January 1, 2014 to November 31, 2014 to account for changes to the harmonization process. Chi-squared tests were used to assess the proportion of plant doctors achieving the highest quality scores in validation (Hypothesis 2). Data were log transformed if they did not meet the criteria for normality and were analyzed using R (R Development Core Team, 2014).

Results and discussion

Hypotheses 1–7

Hypothesis 1: Access to and use of reference materials by plant doctors will increase as a result of having tablets in plant clinics

Forty monitoring and evaluation surveys were conducted at clinic visits. Plant doctors reported using their tablets to access a wealth of Plantwise and non-Plantwise resources such as the Plantwise Factsheets Library, the Plantwise Knowledge Bank, Infonet Biovision, e-books, Internet searches, and weather apps. By March 2015, the Plantwise Factsheets Library had been accessed over 41,000 times.

Some plant doctors were surveyed more than once, allowing their progress throughout the pilots to be understood. Initially plant doctors only used the tablet to access agricultural extension materials during Plantwise clinic sessions but, as the pilot progressed, they also began to use them at the office, at home, on farm visits and, as one plant doctor put it, "everywhere the need arises."

Automatic updates ensure that, when plant doctors refer to Plantwise materials like factsheets, they are looking at the latest version. If pesticide restrictions or best practice changes, updates can be made immediately, and users receive them automatically to their device. Plant doctors valued this up-to-date material and reported no problems in getting these updates through the Internet when they were able to connect.

The participatory review workshop found that one plant doctor had discovered that he could copy advice from the Plantwise Factsheets Library app and paste it into his recommendation for the farmer. This ensures that farmers get advice that is consistent with agreed best practice and also saves time. At their request, he has taught this method to other plant doctors and it has now been integrated into the training materials.

Hypothesis 2: The length and quality of recommendation may differ between typed and handwritten prescriptions

Recommendations given to farmers via the tablets are, on average, 56 characters longer than recommendations given to farmers on paper forms ($t_{34} = 4.32$, $p = < .001$; Figure 1). The longer recommendations written on tablets can be seen to include a broader range of control options and more detailed instructions. Data from the clinics were later reviewed on POMS by crop experts to examine the quality of the plant doctors' diagnoses and recommendations. This validation process showed that 16% more recommendations written on tablets ($\chi^2 = 6.81$, $p = < .01$) achieved the highest quality score.

The participatory review workshop revealed two explanations for the longer recommendations:

1. Paper forms are printed on one A4 sheet, limiting the size of the recommendation field, whereas the recommendation field on the tablet expands to fit the text, allowing them to write more.

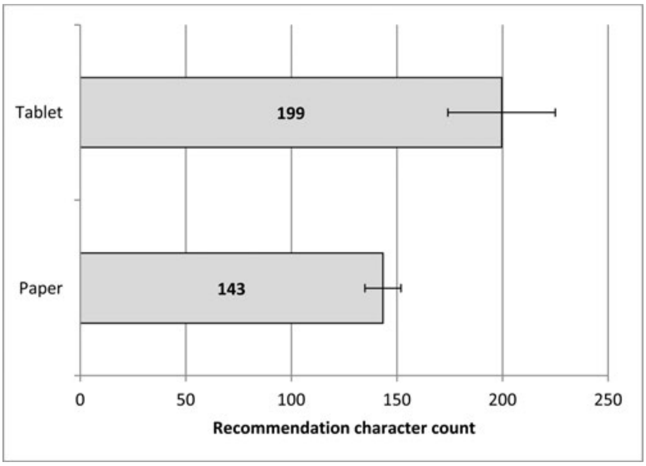

Figure 1. The Average (With 95% Confidence Interval) Word Count for Recommendations Written on a Tablet Is 199 (174, 225) Characters Compared to 143 (134, 151) Characters on the Paper Form ($t_{34} = 4.32$, $p = < .001$).

2. Plant doctors copy and paste recommendations from the Plantwise Factsheets Library app which are longer than those they write themselves.

Hypothesis 3: The presence of tablets may affect (positively or negatively) farmer attendance

Clinics with tablets submit significantly more forms on average than clinics using paper forms (Figure 2). A possible explanation for increased attendance is that some plant doctors SMS from the tablets to invite farmers to clinics. Plant doctors that sent invitations reported that an average of four more farmers came to the advertised clinic sessions.

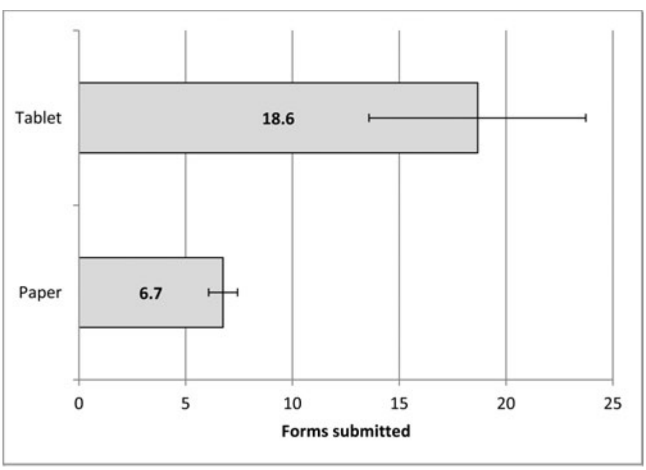

Figure 2. The Average (With 95% Confidence Interval) Number of Forms Submitted Each Month From Clinics With Tablets Is 18.6 (13.5, 23.7) Compared to 6.7 (6.0, 7.4) for Clinics Without Tablets ($t_{14} = 4.60$, $p = < .001$).

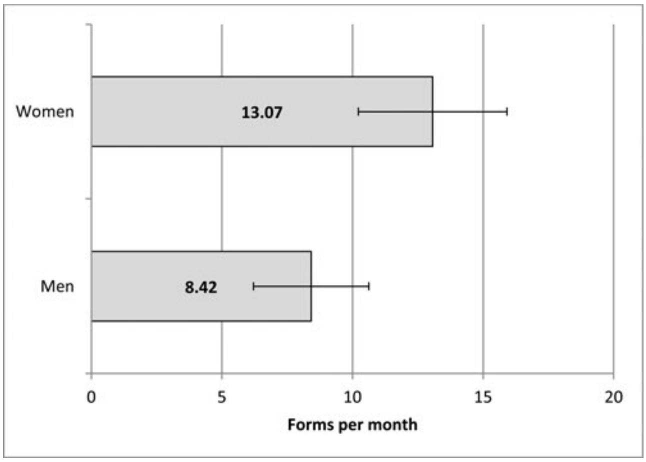

Figure 3. The Mean Number (With 95% Confidence Interval) of Forms Submitted on the Tablets Every Month by Male Plant Doctors Is 8.42 (6.21, 10.63) and 13.07 (10.22, 15.91) for Female Plant Doctors ($t_{24.20} = 2.53$, $p = .018$).

It also appears that plant doctors with tablets are recording a higher proportion of the advice they give to farmers during their general work, as they are only working as plant doctors for a maximum 1 day per week, performing other extension duties for the rest of the time. In addition to recording prescriptions given during clinic sessions, these plant doctors also submit prescription forms from field days, farm visits, and farmers that drop in to the office. The plant doctors report that the size and portability of the tablets allow them to carry them everywhere, using them in all of their activities. They further report that, since the electronic prescription form is quicker to complete, time is less of a barrier to filling in the forms than with the paper version.

It was also clear that farmers were not put off by the new technology. Interviews showed they appreciated the extra information the plant doctors could provide by having access to a wide variety of reference material. Farmers also preferred having the information presented to them as SMS rather than on paper, as they carried their phone with them at all times and could check on the advice as and when needed. They could also easily forward the advice to friends and family. The few farmers who did not have phones were provide with a written recommendation.

Hypothesis 4: Plant doctors' adoption of the technologies may be influenced by their age, sex, or education levels

Of the 60 plant doctors trained on the tablets, 31 are male and 29 female. The female plant doctors have taken to the tablets exceptionally well and, on average, submit four more forms per month than their male counterparts (Figure 3). There was not enough variation in plant doctors' age and education levels to identify any significant effects from these variables.

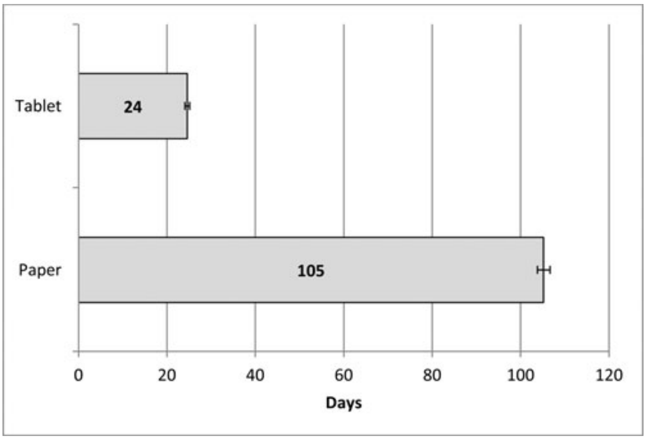

Figure 4. The Average Time (with 95% Confidence Interval) for Data Transfer From Clinics to POMS is 105 (103, 106) Days for Paper Forms and 24 (24, 25) Days for Forms Collected on the Tablets ($t_{4561.64} = 110.79$, $p = < .001$).

No tablets were lost or stolen during the course of the pilot and all functioned well at the clinics. All plant doctors were able to use them and submitted clinic data through the tablet system.

Hypothesis 5: Plant clinic data will be received more quickly by the MoALF when collected via electronic prescription forms

For the data collected in clinics to be most relevant and useful, it needs to be made available as soon as possible. Clinic data collected on tablets is transmitted in near-real time and requires far less processing. It is available to stakeholders via the Plantwise Online Management System (POMS) within an average of 24 days, a dramatic improvement on the previous average of 105 days (Figure 4). This time will be reduced further as a result of recent updates to POMS allowing data to be posted daily rather than being dependent on 2-week updates. This will result in data being available within 2 days.

The importance of having data available for analysis as near to real time as possible is clearly highlighted through a case study of tomato leaf miner (*Tuta absoluta*), a new problem pest in Kenya in 2015. *Tuta absoluta* can decimate tomato crops and has major trade implications. For new pests like this, comprehensive monitoring and rapid communication are key to an effective government response. The tablets have helped in this battle against *Tuta absoluta* in a number of ways:

- Records of *Tuta absoluta* collected on tablets are available on the POMS with minimal delay, allowing the government to identify, monitor, and respond to the threat more quickly. Data on *Tuta absoluta* is available 65 days earlier when data is collected on tablets compared to paper (Figure 5).
- Plant doctors used the chat groups to request management information and share photos and advice about the problem.
- Plant doctors can show farmers pictures of the devastation the pest is causing.

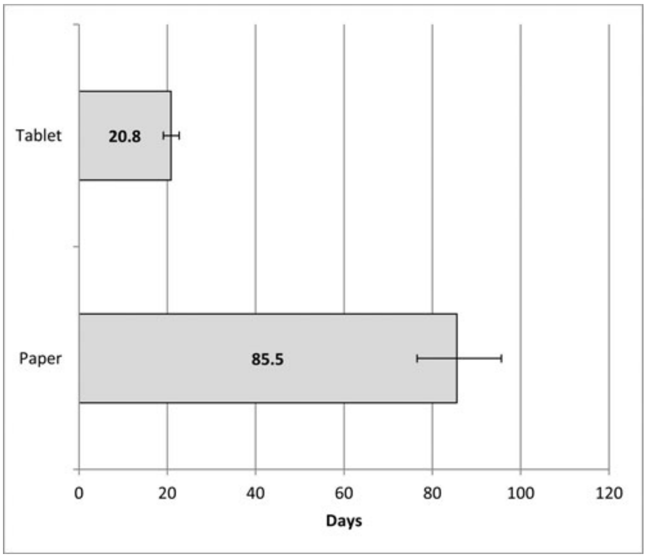

Figure 5. The Number of Days (With 95% Confidence Interval) It Took for Electronic Clinic Records of *Tuta absoluta* to Become Available on POMS Was 20.8 (19.1, 22.7) Days, on Average, Compared to 85.5 (76.5, 95.6) Days for Paper Forms ($t_{110.34} = 19.68, p = < .001$).

- As the government developed information materials on the pest, they were circulated quickly and easily to the plant doctors.

Hypothesis 6: Plant clinic data will require less processing and cleaning when collected via electronic prescription forms

Prior to being analyzed, plant clinic data pass through a process of data cleaning and harmonization to ensure that they are tidy and use consistent terminology. This can require considerable resources. Data collection on tablets allows drop-down menus to be used instead of free text for many questions. As a result, data submitted are much cleaner, requiring an average of half the harmonization time per data set as data collected on paper forms. This both reduces the amount of staff time required to run a data management system and contributes to improvements on how quickly the data become available. Plant doctors found the drop-down menus easy to use and intuitive and were able to request changes and additions that could be incorporated into new versions of the data collection app, which were then rapidly distributed.

Hypothesis 7: Using the tablets to take photos of damaged crops in the clinics will aid data validation

The tablets allow plant doctors to submit a photo of the farmer's sample with the prescription forms. To date 2,500 photos have been submitted. These photos assist the group of experts that carry out quality assurance checks on the data ("data validators") in checking the diagnoses the plant doctors have made. The photos can be viewed alongside the data during validation, allowing reference to them in addition to the written descriptions when deciding if a diagnosis appears correct or not. Validators report the photos are of substantial value in this process. The photos also provide a source of images for use in future extension materials.

Unanticipated effects

In addition to the changes identified in our initial hypotheses, we observed a number of additional changes to clinic operations.

Improved communication

At the plant doctors' request, Plantwise installed an instant messaging app on the tablets. They use this to communicate with each other most days. Plant doctors post photos of problems, ask each other for diagnostic support or treatment recommendations, forward resources on new or challenging problems, and update each other on their activities. This improved communication and access to diagnostic support is one of the most prominent benefits for the plant doctors.

Direct use of recommendations from reference materials

We had anticipated that plant doctors would use the tablet to look up information in a variety of reference materials, but expected this to happen mostly when they encountered an unfamiliar problem. Since they discovered that they can copy and paste best-practice recommendations directly from factsheets, this has become the default approach of many of the plant doctors. Plant doctors at e-plant clinics now refer almost constantly to Plantwise reference materials and proactively demand more factsheets and increased coverage.

Local ownership

Several plant doctors rapidly became proficient with the tablets and took the initiative to provide informal support to their colleagues during the learning process. As a result, they have now been trained as trainers and are responsible for training new cohorts of plant doctors as they join the pilot.

Plantwise program in context

Other papers have reviewed the role of ICT in agricultural extension (Bell, 2011, 2015; Vignare, 2013a, 2013b). These reviews outline three best-practice guidelines: (a) knowing the audience and using multiple channels to reach them; (b) emotionally connecting with the audience to build trust, meeting their needs, and responding to their feedback; and (c) providing actionable products (Bell, 2015). These three guidelines have been identified as necessary components in promoting the behavior change necessary to facilitate the successful implementation of ICT in extension. The introduction of ICT within the Plantwise program ensured the integration of these components in the following ways:

1. Knowing the audience and using multiple channels to reach them.

- The tablet applications developed were tested with users before release through the "in-country assessment" phase of the pilot.
- Review workshops allowed users to give feedback on the applications as the pilot progresses.
- Plant doctors assisted in refining the training materials between pilot Stages 1 and 2.
- Applications were deployed through face-to-face training workshops and then supported with a dedicated helpline and through instant messaging.

2. Emotionally connecting with the audience to build trust, meeting their needs, and responding to their feedback:
   - 10% of the 2-day training and review workshops is allocated to icebreakers and team building at the start to create a safe environment for honest feedback.
   - The review workshop used exercises which were specially designed to allow participants to easily share negative feedback without embarrassment or worry.
3. Providing actionable products.
   - Tailored training and close support of plant doctors ensured that the applications were highly suitable for their environment.

The successful use of the tablets by plant doctors confirms these best practices as being key to the positive acceptance of ICT in extension work.

Conclusions

Key findings

The pilot showed that the use of ICT in the plant clinics could improve the capability of the plant doctors to deliver good advice on plant health matters to smallholder farmers. Notably:

- Stakeholders receive the data far more quickly, allowing them to rapidly respond to threats.
- Plant doctors give higher quality recommendations, using updatable reference materials installed on their tablets.
- Chat groups enable plant doctors to ask each other for advice.
- Plant doctors collect more data on plant pests and diseases.
- More advice is given to farmers per clinic session.
- Plant doctors are coming up with innovative new uses for the tablets.
- Plant doctors use the tablets in all aspects of their extension work.
- Participatory design approach has created strong local ownership.
- Tablets streamline the data collection and resource delivery process.

Challenges and lessons learned

For many of the plant doctors, using tablets is a completely new skill and some struggled initially. Based on their feedback, we adapted the training materials to give the plant doctors the space to explore the tablets together without the supervision of trainers, as they feel more at ease to experiment and make mistakes, though this may vary in different cultural contexts. It is important to train all of the plant doctors from any given clinic, as they work together very closely and help each other learn. Despite this, however, five out of the 60 plant doctors still struggle and have submitted fewer than 10 forms.

The capacity of some plant doctors to pick up and use the new technology outstripped that of their colleagues. By using them as champions for the system, locally based support and training could be assured. This resulted in greater capacity development for all, with the new trainers building their skills and the other plant doctors being more comfortable with local colleagues as trainers.

Feedback from the trainees could be rapidly worked on and new solutions deployed. As this was the first pilot, such improvements were of great value in facilitating the success of the use of ICT in future.

Monitoring and close contact with the plant doctors has yielded important insights into plant doctors' use of tablets. Further qualitative work will be needed to understand how and why this might vary in different contexts, as Plantwise looks to pilot e-plant clinics in some of the additional 33 countries where the program currently runs.

Next steps

Initial results are generating enthusiasm and strong demand from plant doctors and coordinators across Plantwise. It will be important during these pilots to manage expectations. Working together with the Kenyan government, Plantwise is looking at further expansion across Kenya, perhaps to the level where all plant clinics are converted to e-plant clinics. Initial studies indicate that the cost of delivering and collecting information using tablets can be brought down to the level of the costs of paper and that the benefits of using ICT are considerable. Nevertheless, sustainability of the ICT system will need close analysis and attention. Supplementing expansion in Kenya through additional third-party funding will be explored, as will persuading county governments to use their own (non-Plantwise) funds. The initial focus remains on learning how tablets are used in different contexts and the effect this has on plant clinic operations. An investigation is also underway into building a custom app for data collection which will better meet the needs of plant doctors.

The results indicate that introducing appropriate ICT technologies to the Plantwise plant clinics is a powerful means of strengthening agricultural extension systems. It can provide smallholder farmers with access to up-to-date, best-practice advice on how to prevent and manage pests and diseases and hence enable them better to protect their food security from the threats posed by plant health problems.

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