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SMART ARMYWORM SURVEILLANCE: PROJECT TECHNICAL REPORT

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Collaborators

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ROTHAMSTED RESEARCH

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1 EXECUTIVE SUMMARY

This project was designed to test three different technologies for monitoring the fall armyworm, a highly migratory moth pest of maize in Kenya. This insect is invasive and is estimated to have caused between US$200 and US$600 million dollars' worth of crop damage in Africa since it was first observed in western Africa in 2016.

The three technologies we piloted were entomological radar, digital pheromone traps and an image identification app. The hypothesis we set out to test was that high-altitude moth migrations are linked to pest incidence at ground level and the later impacts of feeding damage. Our objective was to install and launch all three technologies in the space of a year, with the aim of developing an integrated dataset that would provide an overview of near-ground and upper-atmospheric movements of fall armyworm. This data would be shared with multiple different stakeholders in real-time.

Over a 12-month period between March 2019 and February 2020, we installed the entomological radar, 20 digital pheromone traps and launched the Nondo app to test this hypothesis. Although there were several challenges, the outcomes after one year include:

1. **Preliminary radar data.** We were able to detect insects at heights up to 800m and the preliminary data would suggest these are targets of the appropriate mass to be classed as noctuid moths
2. **A network of digital pheromone traps.** We observed fall armyworm in almost all of the locations where the traps were installed and received daily automated updates, despite the traps being hosted in very rural parts of Kenya.
3. **An image detection algorithm for the fall armyworm and other maize pests.** This provided a very high level of accuracy for species where we were able to provide more than 100 images (>90% in some cases).

This project has profound potential for impact as it demonstrates the successful implementation of an "internet of things" approach to biological monitoring in very rural parts of Kenya. Indeed, one of the highlights of this project is the deployment of the digital trap network beyond the end of the project. **This is the first time such an ambitious, multi-layered monitoring network comprising radar, pheromone traps, machine learning and decision support apps has been established in Sub-Saharan Africa**. This project is a proof-of-concept that clearly demonstrates the potential of digital monitoring to deliver major impacts for farmers in Sub-Saharan Africa.

2 PROJECT OVERVIEW

2.1 Background

The fall armyworm, simply referred to as "FAW" in Kenya, is an invasive migratory moth pest. Native to the Americas, it was first detected in West Africa in 2016 and in the intervening years has spread across the world; invading India, China and most recently Australia [1]. Although the initial incursion into Africa may be the result of accidental transfer through trade, the FAW is also highly migratory. A single individual can fly several hundred kilometres in a night given the right wind conditions, and the species is well known to migrate in response to changes in seasonality and temperature. Although FAW are assumed to be at least partially migratory in South America, the migration is best documented in North America where it is an obligate migrant. In the USA, the species overwinters in Florida and Texas, migrating as far north as Canada in the spring and returning to the southern latitudes in the late autumn. It cannot withstand freezing and is far less active in cold climates where it struggles to survive [2].

Following its widespread discovery across Africa, the species has gone on to cause extensive damage to agricultural crops. The larvae are highly polyphagous, with more than 100 host plants, but most of the damage occurs in maize. A study by CABI based on a sample of 10 African countries estimated this insect caused an estimated annual losses in maize yield of 8.3-20.6 million tonnes (US$2,481M-6,187M), most of which occurred in 2017 when the pest was novel and farmers were unsure how to manage it [3].

2.2 Project aims and objectives

The aim of this project was to pilot different technologies that have the potential to detect and monitor FAW in real-time. The pilot study was designed to provide an early warning system across a large area of western Kenya and our hypothesis was relatively straightforward: high altitude moth migrations are linked to pest incidence at ground level and the later impacts of feeding damage. We intended to monitor this with three different technologies:

1. **Entomological radar:** Also referred to as vertical looking radar (VLR) this technology has been used to detect large scale insect migration events at 800m – 1,200m above ground level in countries such as the UK and Australia. Although the technology can detect smaller insect pests such as aphids or beneficial species like parasitoid wasps, it is best suited to larger insects such as locusts or noctuid moths, including FAW. The technology is described in detail by Chapman et al, 2003 [4], with reference to insect migration in Chapman et al, 2002 [5].
2. **Digital pheromone traps:** Pheromone traps are widely used to monitor the prevalence of insects. They use female sex pheromones to lure males into traps baited either with pesticides or sticky plastic, after which the number of insects caught is counted manually. Although they are relatively species specific, the lure in pheromone traps is usually attractive to several non-target insects as well as the pest species of interest. This can result in recording errors unless the user has been carefully trained in insect

identification. The innovation in this project was automating this process by using the digital pheromone traps provided by Trapview. These traps use image recognition software to count and identify the insects caught. Multiple traps can also be linked together to form a network that provides an area wide overview of pest prevalence. In addition to recording insect numbers, these traps also record temperature and humidity in real-time, and can send data remotely from anywhere in the world where there is a 2G network.

3. **Mobile phone app:** In collaboration with Waarneming.nl, Cosmonio have developed the mobile phone app ObsIdentify. This app can be used to identify a wide variety of animals, plants and fungi in Belgium and the Netherlands using image recognition algorithms. This includes many European moths and butterflies. In this project, we adapted this app and the underlying algorithm for use in Kenya, specifically focusing on developing image recognition algorithms for the top 20 lepidopteran pests of maize (Table 2). The app can identify both adult moths and caterpillars. It works by taking multiple pictures of a caterpillar or adult moth, following which the algorithm gives a species suggestion along with an indicated level of confidence in the identification. The Kenya-specific app is available on google play under the name Nondo, Swahili for moth.

Using these three technologies, our objective was to develop an integrated dataset that provided an overview of near-ground and upper-atmospheric movements of fall armyworm, made available to multiple different stakeholders in real-time. The specific aims of the project were as follows:

i) To provide the speed, direction, body alignment, and size parameters of individual moths from the radar that will inform the direction and height of moth migrations;
ii) Design an early warning system to advise growers of FAW incidence, which may derive information from any one, or all three, applications in real-time;
iii) An empirical-based experimental plan to develop future sampling protocols and thresholds.

2.3 Experimental design

The experiment, which we initially expected to be based in the north western part of Kenya, was designed to include the entomological radar at the centre of a network of digital pheromone traps, surrounded by growers who could report fall armyworm observations using their mobile phones. Our initial expectation was that the radar would be placed in the centre of a crosshair design, looking upward and scanning for migrant moths in real-time (Fig. 1a, red spot) to a height of 1200 m (Fig. 1b). Twenty digital fall armyworm traps would then be placed around the radar within a 1000km radius, giving an experimental footprint of >7000 km2 (Fig. 1a – blue spots). Growers and Kenyan field officers will be trained to use the app (Fig. 1d), automatically identify FAW caterpillars and adults, as well as three closely related species, and providing real-time georeferenced data of pest numbers in the surrounding maize crop (Fig. 1a, green stars).

Fig

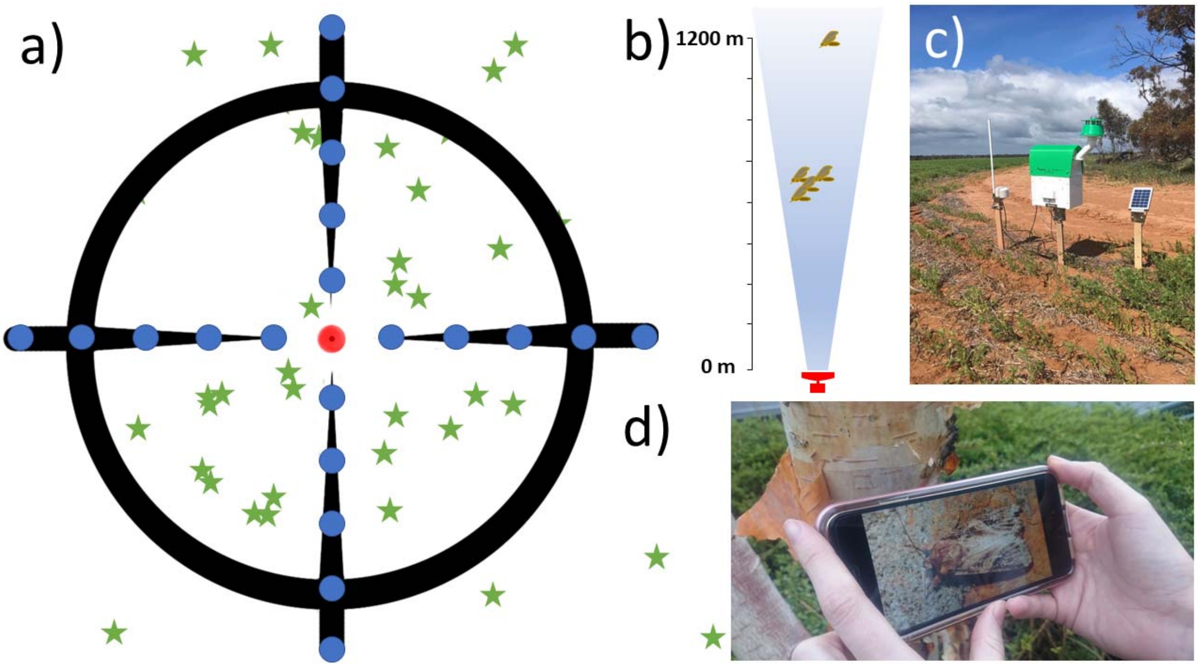

***Figure 1**: Experimental plan, including the new technologies or tools to be tested and deployed. a) vertical looking radar (red dot) at the centre of a "crosshair" of digital pheromone traps (blue dots) and surrounded by local growers and field technicians using the Nondo app (green stars); b) Illustration of the entomological radar and height bands at which it is operational; c) Digital pheromone trap, with solar panel and weather station; d) Image representation of the Nondo app.*

3 PROJECT IMPLENTATION OF THE ENTOMOLOGICAL RADAR

3.1 Outcomes and Outputs

The vertical-looking radar (VLR) was installed at icipe's Mbita site on the shores of Lake Victoria on the 12th June 2019. The VLR is capable of identifying noctuid moths flying at heights up to 1,200m [4], and was installed on the assumption that we would be able to identify insect movement suggestive of northward noctuid migration toward the Kenyan maize belt. However, due to numerous technical and administrative challenges, the radar was only operational for a week-long period between the 18th and 23rd June 2019. During this time we detected 23 insect targets that fitted the profile of noctuid moths flying at altitudes between 150m and 337m at multiple times of day. Preliminary analysis of the data showed that we were detecting good quality targets with an R^2 value above 90 but only in the lower height bands and not at the volume we would expect (Figure 3). We were also detecting targets with the appropriate mass in much higher numbers up to 800m, but the return signal from the radar was weak, with an R^2 below 90 (the accepted standard for good quality targets). We believe this is due to a combination of noise and low levels of return power to the radar receiver. These issues could be resolved by installing a bandpass filter and increasing the sensitivity of the receiver (see below), but without a radar technician it proved difficult to resolve these issues in situ. Instead we made the decision to ship the radar back to the UK in March 2020 for servicing and an upgrade.

Figure 2: *The vertical looking radar installed at ICIPE Mbita, on the shores of Lake Victoria.*

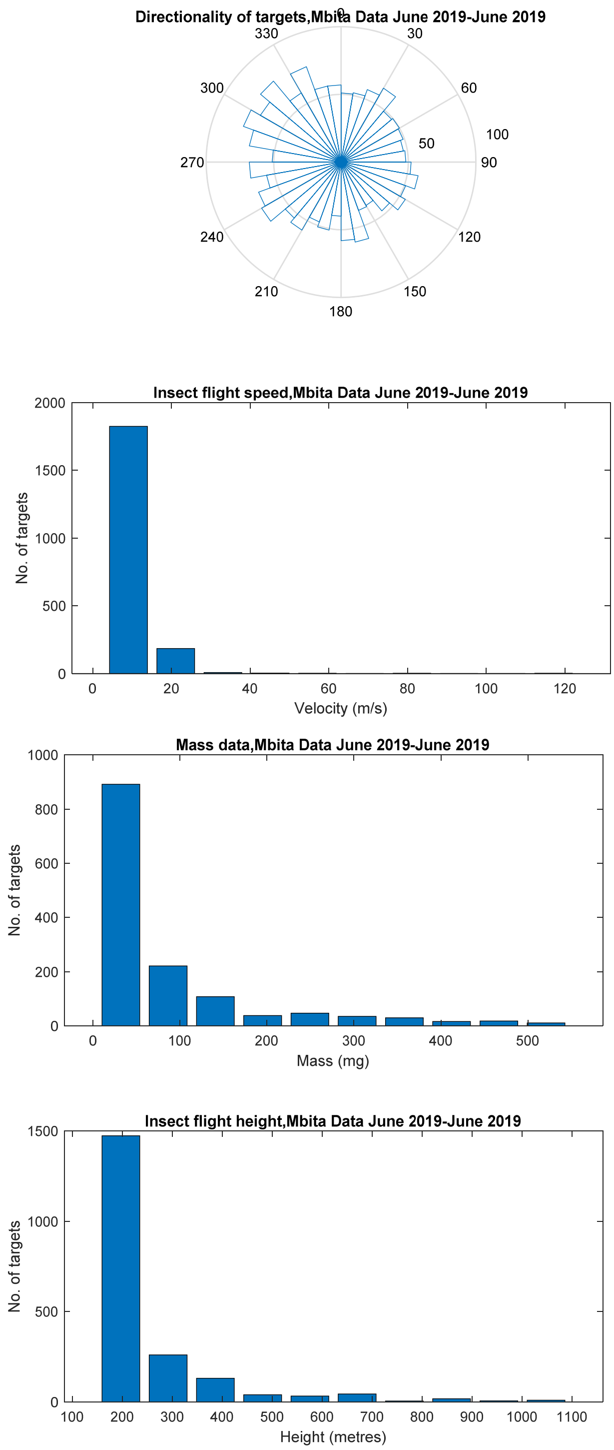

Figure 3: *Preliminary results from the vertical looking entomological radar for the period from 18th – 23rd June 2019, during which time we detected 34,705 insect targets. The data shows (a) directionality, (b) flight sped, (c) mass and (d) height of 2,021 targets with a correlation co-efficient greater than 0.80. The standard for "good" targets is 0.90 but, due to technical issues resulting in a loss of power, we have used a correlation coefficient of 0.80 in these figures ("less good" targets) to show potential as well as valid targets (Chapman 2002).*

3.2 Technical and administrative challenges:

Radar import:
Rothamsted Research has deployed the entomological radar all around the world, including in the USA, China and Europe within the last 5 years. As such we were aware of the challenges required to progress the vertical-looking radar through Kenyan customs, as well as the need to secure a site for its deployment. Although we began the permit process in August 2018, and submitted all necessary paperwork by the following September, the radar was only cleared from customs and released for deployment on in June 2019. We could not have anticipated this unprecedented delay, which was beyond our control and partially due to complex internal political issues in Kenya at the time [6].

Radar site:
Initially we planned to install the radar at the KALRO site in Kitale. This field station is in the primary maize growing region of Kenya and has many links with smallholders and extension officers in local area. Logistically however, this proved challenging. KALRO have collaborated closely with us throughout the project but are not official project partners. This led to complications around licencing and import restrictions, as well as invoicing the site fees and internet connectivity. Ultimately the decision was taken to install the radar at ICIPE's campus in Mbita. This was further south than we ideally would have wanted, but still surrounded by smallholder maize. The site at Mbita has a fast and reliable internet connection, as well as a knowledgeable team of IT specialists and electronic engineers who oversaw the radar while it was in operation. The radar itself is surrounded by ICIPE's maize trials and within 25m of the local weather station. We installed a digital pheromone trap at the same site.

Staffing and technical issues:
As the VLR technology is over 20 years old, in 2015 Rothamsted took the decision to overhaul and upgrade the whole system. After a full re-design, the radar was piloted in the USA between 2016 and 2018, and then sent back to the UK for servicing and repair before we shipped it to Kenya. On its return to the UK, the radar had two known issues: (1) low return power to the receiver, and (2) noise in the return signal. Both of these issues had been detected in other VLRs with the same technical specification, and we expected to resolve them once the radar arrived in Kenya by (1) installing a bandpass filter to reduce the noise in the return signal, and (2) installing an additional resistor, which would increase the amount of return power detected by the receiver.

However, because the import the radar was so severely delayed, our trip was cut short and the radar installed by a local team without these components. Although we initially expected to return to Kenya and make this upgrade in March 2020, the radar stopped operating two weeks after it was installed and we were unable to access it remotely to diagnose the problem. This issue was partially resolved after we established a permanent remote access link, but we could not upgrade or repair the parts that led to the failure (stalling of the radar motor). This explains the short time period of data that is available for reporting. Ideally, we would have had a radar engineer present in Kenya to address these issues, but as that was beyond the scope of the project and the decision was made to ship back to the UK.

3.3 Conclusion

Insect migration transfers millions of tonnes of nutrients and biomass across the globe every year. This phenomenon has a profound impact on agriculture and biodiversity, and understanding insect movement has profound potential for informing conservation strategies and the sustainable intensification of agriculture [7].

Our conclusion from this project is that entomological VLR technology has an important role to play in the monitoring and forecasting of insect movement but faces two primary challenges. The first is a lack of investment and the second is integration with dual-polarised weather radar. The radar technology used in almost all entomological VLR's was developed in the 60s and 70s. Outside of this niche subject, radar engineering has "gone digital" and even finding component parts need to repair and replace the existing radar infrastructure has been a challenge. In recent years, Rothamsted have begun to address this by developing **digital millimetre wavelength radar,** which is suitable for monitoring smaller insects such as aphids and lacewings up to a height of 200 meters [8-10]. We would like to see similar efforts being made with the centimetre wave band VLRs, which currently suffer from a chronic lack of research development and deployment despite their obvious potential.

Secondly, vertical looking radar has the most potential for impact in locations where it can be linked with dual polarised weather radar [11, 12]. Combining these two technologies would give detailed information on the diversity and large-scale movement trajectories of pest and beneficial insect species, as well as provide estimates of bio-flow which are essential for conservation and sustainable intensification purposes. For this reason, we suggest that the best place for research development of the existing vertical looking radars is in countries which operate a dual-polarised weather radar network. Most of these countries are those with a well-maintained meteorological infrastructure, primarily Europe and America. There are several countries in Africa (Rwanda, South Africa, Mali and Kenya) who have invested in dual-polarised radar, but these are not always well maintained or operational. In Kenya, two S-band radar stations (near Nairobi and Malindi) were installed in 2005 but are currently inactive. Similarly to national weather networks, the impact from these technologies is most likely to come from investment in entomological radar and pest forecasting at a national level. The development of this technology requires an interdisciplinary team of biologists, engineers and meteorologists. To this end Rothamsted have now engaged with experts at University College London (UCL) and Cranfield university (two prominent UK centres of excellence for radar studies), as well as research colleagues in the United States, to progress the technical challenges identified.

3.4 Project Data:

The summarised radar data is published alongside this report, with the raw data made available on request. Full descriptions of each variable can be found in Chapman 2002 [4], with further information in Chapman 2003 [5]. A brief summary of each variable is given below.

ID:	Unique identifier for each observation
Date:	Date of observation
Direction:	Direction of movement for each observation (degrees)
Velocity:	Velocity of each observation as it travelled through the beam (m/s)
Cross-section a0:	Output of the Fourier transformation; describes the target's radar reflectivity and used in the calculation of the radar cross-section
Cross-section a2:	Output of the Fourier transformation; describes the target's radar reflectivity and used in the calculation of the radar cross-section
Cross-section a4:	Output of the Fourier transformation; describes the target's radar reflectivity and used in the calculation of the radar cross-section
Body Alignment (beta):	The heading of the target (degrees)
Gate number:	The radar gate number in which the target was observed
Position:	The position of the target (beam widths), used to calculated sensed volume
Angle:	The angle of the target (beam widths), used to calculate sensed volume
Correlation coefficient:	Output from the iterative analysis used in target classification. Signals that are successfully solved are divided into three classes: >0.9 ('good' targets), ≤0.9 but >0.7, ('less good') and those below 0.7 ('poor').
Range:	The range of the radar gate in which the target was detected.
sigmaxx:	Principal scattering cross-section term of the target (cm^2)
sigmayy:	Principal scattering cross-section term of the target (cm^2)
mass:	Target mass, calculated as per Chapman, 2002[4]
rmax:	Maximum range of detection within each range gate
R1	Lower boundary of the range gate.
R2	Upper boundary of the range gate.
Aerial Density:	Target aerial density (per 10^7 m^3)
Day number:	Numeric day of the year, ranging from 1-365 (366 in a leap year)

4 PROJECT IMPLENTATION OF THE DIGITAL PHEROMONE TRAPS

4.1 Outcomes and Outputs

When designing this experiment, we planned to host 20 digital pheromone traps within 1,000km of a radar site in Kitale. Once we made the decision to move the radar to Mbita however (see Section 3.2 above), this experimental layout was no longer valid as Mbita borders Lake Victoria (Figure A.13). Instead the decision was taken to situate traps across the various maize growing regions of Kenya, installing 20 digital pheromone traps during a three week campaign in March and April 2019 over an area which stretched from Kitale in the north to Mbita in the south-east and the coastal region in the south-west (Figure 4, Table 1). Most of the traps were located at sites that fell within the Mbita-Kitale-Nanyuki-Nairobi western quadrant, with 4 traps in the southeast along a transect from Machakos to the coast, near Mombasa that were more isolated. This large-scale network was made possible by working closely with small, medium and large scale farmers as well as a wide range of collaborators from industry (Cropnuts/ Agventure), government (KALRO and KEFRI) and non-governmental organisations (One Acre Fund) as well as international research organisations (University of Helsinki's Kenya field station). We started detecting fall armyworm across the network almost immediately. In April 2019, at the request of KALRO and other collaborators, we began communicating the size of the catches on a weekly basis via a WhatsApp group. Although our digital traps host valuable commercial components such as sim cards, weather stations and solar panels and needed to be securely located, we only lost a single solar panel and the network ran for the full 12-month duration of the project almost without disruption. This gave us the opportunity to significantly improve the image detection algorithm used differentiate fall armyworm from non-target species, increasing the accuracy from 75% at the start of the project to 85% as a result of detection and rejection of false positive samples by the project team.

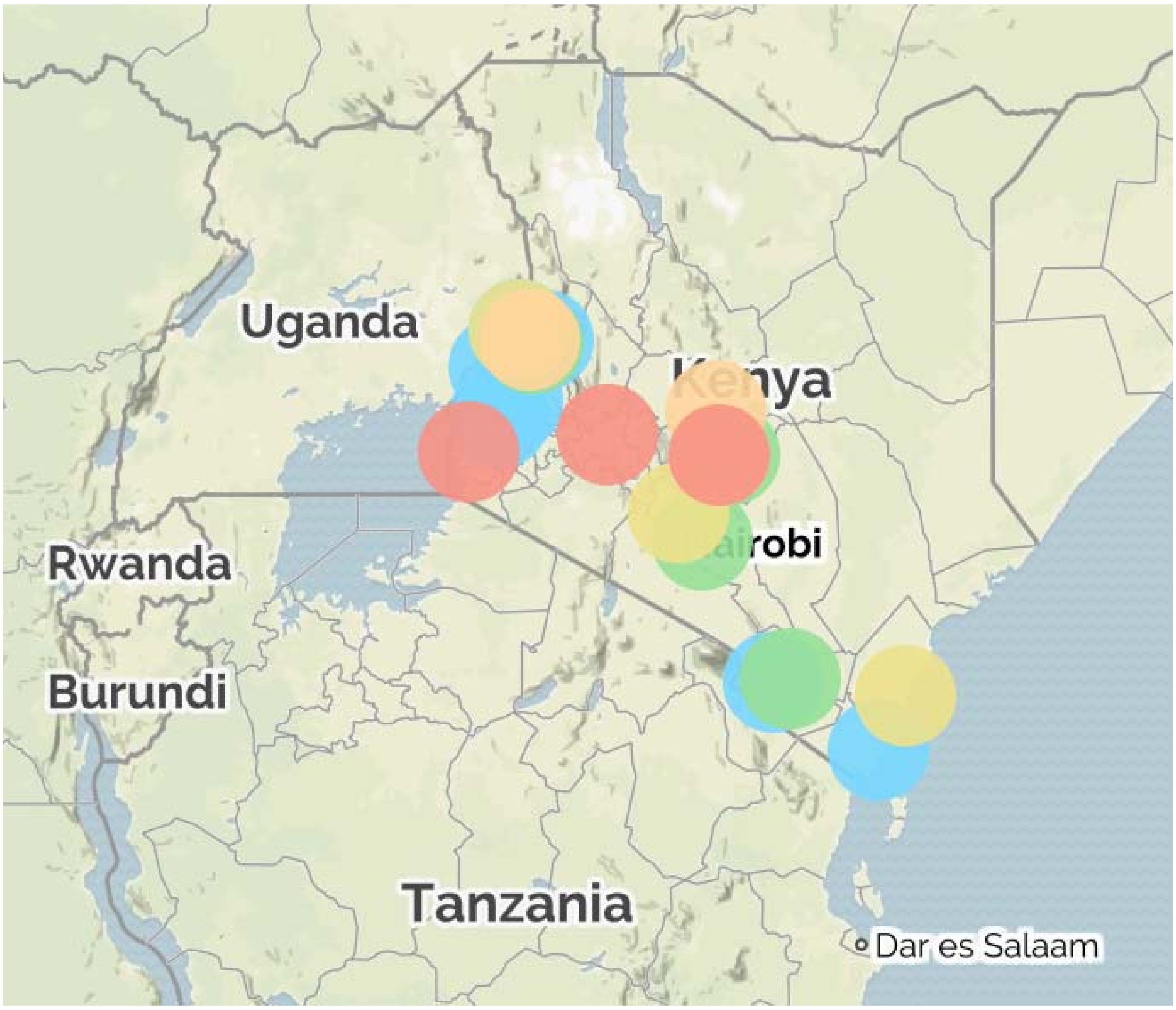

Figure 4: *Location and accumulated pest pressure of digital pheromone traps across maize growing regions in Kenya. See Table 1 for associated locations and pest numbers.*

Device no.	Location	Accumulated pest pressure
S04570	Private Farm, Nakuru	257
S04515	ICIPE, Mbita	253
S04668	Delta Trap, KALRO, Embu[1]	45
S04539	Funnel Trap, Embu	36
S04551	Private Farm, Nanyuki	30
S04557	KALRO, Kitale	30
S04564	Private Farm, Endebess	26
S04543	ICIPE, Nairobi	24
S04569	Private Farm, Kilifi	20
S04565	Taita Research Station, Wundanyi	19
S04545	KALRO, Machakos	17
S04538	Private Farm, Kitale	14
S04531	Private Farm, Embu	11
S04542	Private Farm, Cherangani	5
S04568	Private Farm, Chwele	5
S04549	KEFRI, Maseno	4
S04544	Private Farm, Maktau	3
S04547	Private Farm, Kakamega	3
S04562	Private Farm, Endebess	2
S04535	ICIPE, Muhaka	0
S04546	Slit Trap, KALRO, Embu[2]	0

Table 1: *The device number, location and accumulated number of insects caught at each site hosting a digital pheromone trap for the period between 01 February 2019 and 17 March 2020 (project duration).* [1]*Installed in June 2019.* [2]*Not operational from January 2020.*

4.2 Technical and administrative challenges:

Phase 1a (February – June 2019): Replacement of faulty trap components

During the first phase of the project, the number of insects caught was much lower than we were expecting in almost every location. During the first phase of the project (February – June 2019) we were confident that this was due to faulty pheromone lure, which was later confirmed by Kenya Biologics. This was accompanied by degradation of the sticky rolls that are placed inside the pheromone traps (figure 5), which affected the automation of the traps. These issues were rectified in June 2019 when we revisited the entire network, upgrading to a multi-component Chemtica lure which has been very successful in the FAO FAMEWS project and replacing all the sticky rolls with an amended product.

Figure 5: *Defective sticky roll taken from the trap in Mbita. A combination of high temperatures and humidity caused the glue on several of the sticky rolls to degrade. The motor could not turn to replace the upper surface, which was no longer adhesive, affecting the operation of the digital pheromone traps.*

Phase 1b (June 2019 – March 2020): Troubleshooting

Despite these amendments, the numbers of insects caught were still much lower than we expected in the second phase of the project. Although the drought meant fall armyworm numbers were generally low across the country, we knew this because we were able to compare our digital funnel trap catches (0 – 5 insects caught in an average week) with standard delta traps (0-10 insects caught in an average week) and bucket traps (50+ insects caught in an average week) operated by KALRO at the sites in Kitale and Embu. With help from Dr Nyasani, a KALRO research scientist who has also been closely involved in CABI's PRISE project, we were able to some basic troubleshooting and this helped us eliminate several different reasons for the discrepancy. These included:

1. **Changing the colour of the funnel.** The bucket traps have a yellow funnel, while the funnel on the digital pheromone traps is green. We were able to swap the two and monitor the trap for several weeks to see if this resulted in an increase in the average number of insects caught. This seemed to have no effect on the average number of insects caught.
2. **Testing different pheromones.** After changing to the Chemtica lure, we became concerned about its longevity in the field. Specifically, we wanted to know if it was still valid after a month of operation. This is the period recommended by the manufacture but hasn't been tested in Kenya. We were able to test this by placing a used pheromone in a bucket trap a month after it had initially been installed in the funnel trap. This attracted a relatively large number of male moths (40+) in a single night, so we are confident that the Chemtica lure does last under field conditions for a full 30 days.
3. **Testing different trap designs:** Approximately halfway through the project, Trapview provided us with two different trap designs: a delta trap and a slit trap, which we were able to compare with the funnel trap at the KALRO site in Embu (Figure 6). These were installed approximately 25 – 30m apart and we were able to compare data from the three different designs. Unfortunately the solar panel was stolen from the slit trap, but in the second phase of the project (June 2019 – March 2020), it was clear that the delta trap was performing much better than the funnel trap.

Our overall conclusion from this work was that, although none of the digital trap catches are as high as conventional bucket traps, the digital delta traps do appear to be roughly equivalent to the standard delta traps used to validate CABI's PRISE model. Although still very preliminary, these data were enough to encourage us a project team to trial a six month no cost extension of the delta traps using the Chemtica lure (see conclusions).

Figure 6: *Examples of a digital funnel trap (top left), digital delta trap (top right) and digital slit trap (bottom left (not site-specific photographs). The delta trap and slit trap were placed within a 25m of the funnel trap at the KALRO site in Embu in June 2019. The slit trap was only operational for a period of five months following theft of the solar panel, but we continued to operate the delta trap until the project close in March 2020.*

Operation and maintenance:

In addition to the low numbers of fall armyworm, we encountered several challenges with operating the trap network. By far, the biggest problem was knowing if the operators had changed the pheromone. We send out monthly reminders but, as not all the operators had smart phones, we had no way of knowing for certain that they had received the message and changed the pheromone. This is another benefit to using smart delta traps, as the pheromone change is evident in the trap image. In addition, we had problems with wasp nests in almost all the traps we installed and also occasionally caught snakes, birds and lizards, which crept in through the trap openings and got stuck to the sticky surface. As all the trap components had to be imported from Europe, we had tremendous difficulty replacing some of the spare parts.

This was mainly because shipping costs could be prohibitively expensive if sending only a few small parts and the customs clearance was often very time consuming.

4.3 Conclusion

The pheromone traps were catching insects and sending daily updates to farmers via social media within weeks of the network being established. This proof of concept has profound potential for widespread impact as it demonstrates the successful implementation of an “internet of things” approach to biological monitoring in very rural parts of Kenya, where there is a limited 2G network. One of the highlights of this project is that the project team, in collaboration with KALRO and several private farms, have decided to continue trialling a reduced network of 9 delta traps over the intervening six-month period between March and November 2020. These delta traps are easier to monitor remotely, and the trap catch data more reliable, especially when recording zeros.

However, more work is needed to determine the effective scale of this network, including calculating the proportion of the maize crop in the landscape, the prominence of the trap relative to the maize canopy and how these smart traps can be complemented with standard traps to engage a wider and more diverse farming community.

4.4 Project Data:

Trap location, insect abundance and weather data for the full project duration are provided in three separate csv files. These are described below:

Trap Assignments:

This dataset describes the locations of the traps (which were occasionally moved during the project) and their operational dates. It also includes the location name, the pheromone manufacturer, the type of trap, and any notes. The column headings are described below

trap_number	The unique identifier for each trap (issued by Trapview)
start_date	The date the trap was installed in a given location, and start date of the monitoring period
end_date	The end date of the monitoring period for a given location
latitude	The latitude of the trap during the monitoring period
longitude	The longitude of the trap during the monitoring period
location	The name of the location where the trap was installed
pheromone	The pheromone used during the monitoring period
trap_type	This is the type of trap in operation (funnel trap, delta trap or slit trap, see Figure 6)
recording_period	The phase of the project during which the trap was operational (phase 1a: initiation, February – June 2019, phase 1b: updates to the trap network, June 2019 – March 2020)
notes	Any additional notes relating to the monitoring period

Pest Data:

This dataset describes the pest abundance reported by the digital pheromone traps for the duration of the project. Heading descriptions are as follows:

date:	The date the image was taken. Images were taken at 5am, and transmitted at 6am East Africa Time (EAT) every day.
pests_in_trap:	The number of pests in the image.
pest_difference:	The difference between the number of pests in the current image and the previous image (24-hour trap catch).
user_reviewed:	Describes if the image was reviewed and the number of insects confirmed by a member of the project team (yes/ no).
event:	One of four possible actions which could be automated or recorded in the Trapview system. (1) *count:* an automated count of the number of insects in the image; (2) *change of sticky plate:* the sticky plate at the bottom of the trap was changed/ replaced. Refers only to the delta trap at KALRO in Embu (4668) and the funnel trap in Nakuru (2570), where we had to temporarily replace the sticky roll with a sticky plate; (3) *replace of sticky roll:* sticky roll replaced at the start of phase 1b of the project (see section 4.2); (4) *sticky roll tweak:* instruction sent to the trap to automatically rotate the sticky roll, presenting a fresh surface. Count is assumed to start at zero for any insects detected in the following image.
trap_number:	The unique identifier for each trap (issued by Trapview)
latitude	The latitude of the trap during the monitoring period
longitude	The longitude of the trap during the monitoring period
location	The name of the location where the trap was installed
pheromone	The pheromone used during the monitoring period
trap_type	This is the type of trap in operation (funnel trap, delta trap or slit trap, see Figure 6)

Weather Data:

This dataset contains the temperature and humidity data from each of the digital pheromone traps, recorded in five second intervals. As the dataset is so large, there is an individual file for each trap labelled with the trap number. Location history can be taken by combining this data with information from the trap assignment file. Column names are as follows:

UTC:	The time of the observation in Universal Coordinated Time (UTC)
local_time:	The local time of the observation, East Africa Time (EAT)
temp_c	The temperature in degrees centigrade
humidity	The relative humidity (%)
temp_F	The temperature in degrees Fahrenheit
trap_number	The unique identifier for each trap (issued by Trapview)

Missing values:

In all three datasets, missing values are denoted with a forward slash (/) as per Trapview convention. In the weather and pest data, this is usually related to missing data as a result of signal failure (there wasn't a strong enough 2G connection to transmit the image and/or weather data), but may also represent an NA value. In the trap assignment data it relates to NA values. For example, where the current monitoring period is still in operation, the end date is denoted with a / to represent an NA value.

5 PROJECT IMPLENTATION OF THE NONDO APP

5.1 Outcomes and Outputs

During the first phase of the project, we collected and validated several hundred images, creating the reference image library needed to run the image detection algorithm. This was incorporated into an app, Nondo (Figure 6), which we launched on Google Play on 5th June 2019. The app has the capacity to automatically identify and differentiate 20 common moth spices found in maize in Kenya, including FAW caterpillars and adults. To test the applicability of app in the field, we held two farmer training days held between 3rd and 24th June 2019, one in Maseno and the other in Embu. We had also scheduled a training day in Kitale, but this had to be cancelled due to the import delay for the radar (see section 3.2). During this trip, we collated enough feedback from the farmer training days to address some back-compatibility issues (see below) and collect more images which were used to further improve the training algorithm. This allowed us to re-run the statistical models in the second phase of the project, increasing the overall algorithm, achieving a predictive capacity as high as 90% for species where we were able to collate a large number of images (Table 2).

Having trained the farmers in the use of the app, we returned in February 2020 to collate feedback (Appendix 2). From this, it became obvious that most farmers could identify the fall armyworm larvae without the use of the app, a testament to the large-scale communication efforts in Kenya over the last two years. However, several farmers mentioned that both the app and the training were most useful for differentiating between fall armyworm and stem borer, suggesting that there is a need for insect identification. This will become particularly relevant if growers are encouraged to use species specific biopesticides and management practices.

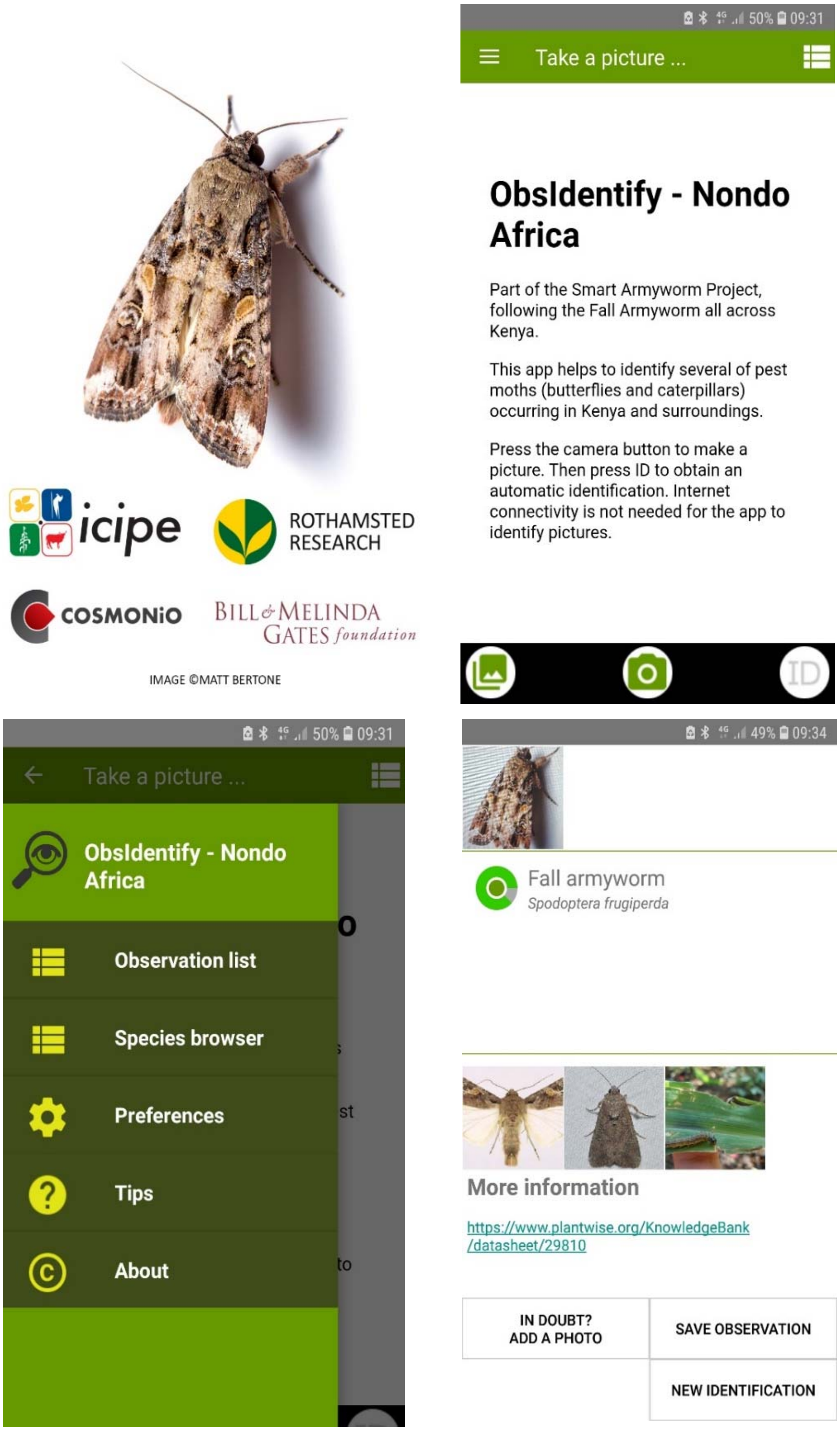

Figure 7: *Screenshots from the Nondo app, designed to differentiate between 20 different species of lepidopteran maize pests in Kenya (see table 2).*

		Total number of images		Precision (June 2019)		Precision (March 2020)	
Common name	**Scientific name**	**Adult**	**Larva**	**Adult**	**Larva**	**Adult**	**Larva**
False codling moth	Thaumatotibia leucotreta	19	11	1.00	0.00	1.00	0.00
Taro caterpillar	Spodoptera litura	51	23	0.60	0.00	1.00	1.00
Cotton leafworm	Spodoptera littoralis	47	19	0.00	0.40	0.75	0.33
Fall armyworm	Spodoptera frugiperda	138	443	0.57	0.56	0.84	0.94
African armyworm	Spodoptera exempta	110	77	0.00	1.00	0.73	0.88
Greater sugarcane borer	Sesamia cretica	37	14	1.00	1.00	0.80	1.00
African pink stemborer	Sesamia calamistis	24	65	0.50	0.00	0.00	1.00
Variagated cutworm	Peridroma saucia	93	50	1.00	0.67	1.00	0.75
Banana moth	Opogona sacchari	23	18	0.75	1.00	0.67	1.00
Rice armyworm	Mythimna unipuncta	71	55	1.00	1.00	1.00	0.71
Legume pod borer	Maruca vitrata	25	12	1.00	1.00	0.75	1.00
African white rice borer	Maliarpha separatella	2	0	0.00	-	0.00	-
Cotton bollworm	Helicoverpa armigera	71	50	1.00	0.71	0.78	0.63
Cotton tipworm	Crocidosema plebejana	67	4	0.88	0.00	1.00	0.00
Millet stemborer	Coniesta ignefusalis	6	1	0.00	-	0.00	-
Golden twin-spot	Chrysodeixis chalcites	69	29	1.00	0.67	1.00	1.00
Spotted stemborer	Chilo partellus	7	126	0.50	0.00	0.50	0.75
Maize stalkborer	Busseola fusca	10	92	1.00	0.00	0.50	1.00
Turnip Moth	Agrotis segetum	113	27	0.88	0.50	0.90	0.33
Black cutworm	Agrotis ipsilon	83	36	0.83	0.33	0.78	0.50
		Life history average		**0.68**	**0.49**	**0.70**	**0.71**
		Overall average		**0.59**		**0.71**	

Table 2: *Species list, total number of images and precision of the image detection algorithm at the launch of the app (June 2019) and on completion of the project (March 2020)*

5.2 Technical and administrative challenges

Back-compatibility and data storage issues

Although the app supports all the actively maintained versions of android, almost half the farmers couldn't download the app, primarily because they didn't have a compatible version of the android software. In the second phase of the project, the app was changed to accept v5.0 Lollipop (circa 2014 issue) and newer versions, and this has improved accessibility but remains a challenge for farmers in rural areas with older mobile phones. For those who did have a compatible version of android but *still* couldn't operate the app, this was usually because they didn't have enough storage space on their device, either for the app or the new images.

Limitations to building a comprehensive reference library

Although we were actively looking for insects in the field, we found relatively few pests in the crop. This was primarily due to a drought in the early part of 2019, which meant most maize hadn't been planted. We searched again in June 2019 and were more successful, but only a subset of the species we were interested in were present. For this reason, we had to rely largely on museum collections and laboratory cultures to build the image library. This was reasonably successful but limits the applicability of the app in field situations as, ideally, we would have images that are similar to photographs taken by growers in the field. For this reason, the app is also very accurate fall armyworm when it is used to identify a late instar larva on a green, white or brown background, but the predicative ability declines rapidly for early instar larvae or when the background colour changes.

Short season rains

For those farmers who could install and use the app, very few of them took many pictures. According to the feedback we received (Appendix B) this was mainly because the rains were very heavy shortly after planting, which several of the farmers told us "washed away" the fall armyworm. Damage in the season between June 2019 and February 2020 was minimal, and many farmers simply did not feel the need to use the app or adopt crop protection measures because the insect wasn't present in large numbers.

5.3 Conclusion

Given the relatively small size of the reference image library, the accuracy of the app demonstrates the potential of this algorithm. Technology such as this has tremendous applied value, for example when linked to biological control strategies or insurance schemes. There is huge potential when it is adopted on medium and large scale farms, but our conclusion was that smallholders are unlikely to be able to afford access to the technology, preferring instead to be trained by local extension officers and often then sharing that knowledge with family, neighbours and friends (see Appendix B).

5.1 Project Data:

The algorithm itself has not been published as it is built on existing intellectual property belonging to Cosmonio. Any requests for details on the algorithm or further collaborations should be directed to Laurens Hogeweg, via Cosmonio: https://www.cosmonio.com/contact/

A subset of the reference images used to train the algorithm are published alongside this report. For copyright purposes, only those images which were taken as part of the project, or where we have express permission to share publicly, are included in the image library. Each image is labelled with the species' scientific name, followed by the life history stage (adult/ larva) and a unique number for each species-life history stage combination. For example, all fall armyworm images are labelled:

Spodoptera-furgiperda_adult ([1-138])
Spodoptera-furgiperda_larva ([1-443])

A full list of species can be found in table 2.

APPENDIX A. LOCATION DESCRIPTIONS AND FEEDBACK FROM DIGITAL TRAP OPERATORS

Western Kenya

Kitale, KALRO

Location

The trap on the KALRO Kitale site was placed next to an acre of maize, which was planted in a larger field and surrounded by other field trials.

On collecting the trap, we discovered that there were a lot of moths on the bottom of plastic box and in the roof, near the electronics. These insects evidently entered the trap but weren't counted because they hadn't come into contact with the sticky roll which is photographed and used for recording. We couldn't tell if these insects were all fall armyworm as many of them had decomposed. The aerial had also been knocked sideways, but this was in no way interfering with the operation of the trap. This is one of the traps which we exchanged for a delta trap.

Figure A. 1: *Aerial image of the site at KALRO, Kitale. © Google Earth*

Figure A. 2: *Field site at KALRO, Kitale*

Private Farm, Cherangani

Location

Cherangani is a KALRO affiliated farm, owned by Esleen Meli and her family. It is another medium scale farm, and the trap was placed between approximately an acre of maize, and her son's irrigated vegetable garden. The mobile phone signal in this location is poor and this is one of the locations where we did struggle sending and receiving data, losing at least one image most weeks. However, as the moth numbers rarely changed significantly, this didn't affect our ability to report from this trap: we could tell the number of moths caught each week, but not always the exact date on which they were captured. This trap stopped operating in January 2020, and when we return in March 2020, we found the cable between the solar panel and the trap had been cut, so the solar panel was no longer connected. The solar panel however hadn't been stolen, so the assumption was that this might have happened accidentally while cutting back the weeds that had grown around the trap.

Feedback

"We only plant long season maize here, so the crop was harvested in September. We planted 25 acres and got 200 bags. There were no fall armyworm problems last year. We saw a few, but not so many. Perhaps about 10% infestation, which we managed with pesticides. Stalk borer were present when we were harvesting, but there were heavy rains and they weren't so many. The biggest problem was the drought when planting."

Figure A. 3: *Aerial image of the site at a private farm in Cherangani. © Google Earth*

Figure A. 4: *Field site in Cherangani*

Private Farm, Chwele

Location

The trap in Chwele was managed by Professor Kafu and his wife, both KALRO affiliated farmers. They too have a medium scale mixed farm, where they grow multiple horticultural and arable crops both for sale and to feed their family. The trap was placed in the middle of a fenced off vegetable garden to ensure its safety. In total the farm planted about 4 acres of maize, with additional acres in neighbouring fields.

Feedback

"We changed the pheromone every month on the first day of the month, as requested. We planted about 4 acres of maize in March, but we didn't see any fall armyworm. There was no stem borer either, so we didn't treat the crop at all. We harvested in September and didn't do so well. From this area, we got about 40 bags of maize. Usually in a good year we would get 60 bags. A lot of farms are having a bad harvest. The rains are mostly light, with showers and no heavy rain. In September we only planted one acre of short season maize as the harvest is usually much lower. We would only ever expect little rain in the short season, so it is not usually worth planting, and we use a different variety."

Figure A. 5: *Aerial image of the site at a private farm in Chwele. © Google Earth*

Figure A. 6: *Field site in Chwele.*

Private Farm, Endebess

Location
This trap was placed on the medium scale farm, at the edge of a maize plot which measured approximately 5 acres. It was managed by Wesley Kibet who is a KALRO affiliated farmer. We initially had problems with this trap. Shortly after we installed it one of the for cameras broke so we could only see a quarter of the image. With help from Dr. Patrick Kalama at KALRO, we were able to eventually replace the camera, but this was a protracted process. We needed to import the spare parts from Europe, and customs clearance can be a very slow process in Kenya.

Feedback
Unfortunately, Wesley wasn’t available to meet with us when we came to collect the trap, so we weren’t able to get his feedback. We generally got the impression that he was frustrated by low trap catches, as well as the technical issues we experienced.

Figure A. 7: *Aerial image of the site at a private farm in Endebess. © Google Earth*

Figure A. 8: *Field site in Endebess.*

ICIPE, Maseno

Placement

This trap was initially placed in the compound outside KEFRI, where ICIPE also have an office. The field station has a lush garden planted with trees. We installed the trap in this garden, about 40m from a large field which we initially expected to be planted with maize.
As trap catches from this site were incredibly low, and in the end the field was not planted with maize, we decided to move it to the home of one of the local farmers, Allens Metho. Allens installed the trap in the garden of his home, close to the border of his maize field. The trap reminded in this location until we collected it in March 2020.

Feedback

“I had a very good harvest. I saw a few fall armyworm at the beginning of the season but they disappeared due to too much rain. There were fall armyworm but these were all is my standard maize, I did not have any in my push-pull maize. I have eight or nine bags in total so far, but we are still harvesting, and I have sold five. This is from about ¾ of an acre, using the Pioneer 2809 variety.”

Figure A. 9: *Aerial image of the site at ICIPE, Maseno. © Google Earth*

Figure A. 10: *Field site at KEFRI, Maseno*

Private Farm, Kakamega

Placement:

The trap in Kakamega was hosted by Jane Mudukiza, who owns a medium scale farm just outside of Kakamega town. She was introduced to us by the Project Office at One Acre Fund, as one of their affiliated farmers. The trap itself was situated in a small garden close to the house. There were several maize fields within the vicinity, the closest approximately 30m away.

Feedback:

"I planted about one and a half acres, from which we harvested 15 bags. After you last came [June 2019] there was some fall armyworm, but the damage was small. I saw some fall armyworm in the corn, eating the leaves and inside the ears. Maybe about 10% of plants were infected, but I did not use pesticides. I think it was similar for all my neighbours."

Figure A. 11: *Aerial image of the site in Kakamega. © Google Earth*

Figure A. 12: *Field site in Kakamega*

ICIPE, Mbita

Placement:
Mbita has two maize seasons, one planted in March and harvested in July/ August, and another planted in September/ October and harvested in January/ February. The trap there is installed next to one of the long-term maize trials, part of which is continuous maize and the remainder used to study push-pull. The trap is operated by Aloice Ndiege, a field technician who also looks after the trials.

Feedback
"In the first season we had heavy infestation with about 30% of crops infested by fall armyworm – maybe 20% in the push-pull plots but as high as 45% - 50% in the non-push pull trial. Despite the drought this is an irrigated crop and we saw heavy losses from fall armyworm. This wasn't true in the push-pull maize, but in the permanent maize trial it was very bad. The yields across the different treatments varied from a minimum of 1.5 t/ha in the control plots to a maximum of 4.5 t/ha in the push pull plots. We are currently harvesting the second season maize. This is the short rainy season so we would expect lower yields. Also because of the unreliable rainfall.
Farmers in the area seem to be controlling fall armyworm better and the numbers are much lower. They tackle the problem as soon as they see an infestation."

Figure A. 13: *Aerial image of the site at a private farm at ICIPE, Mbita. © Google Earth*

Figure A. 14: *Field site at ICIPE, Mbita.*

Central Kenya

ICIPE, Nairobi

Placement:
The trap was placed on the edge of the push-pull plots at ICIPE's campus in Nairobi, where it was maintained by the ICIPE project staff. Kasarani, the area of Nairobi in which ICIPE is situated, is a fairly developed area. There is little or no smallholder maize in this area, and this trap was installed primarily for demonstration purposes. This proved useful, as several visitors from other countries who were also interested in fall armyworm visited the ICIPE during the project and we could demonstrate how the trap works and is maintained. There is only a single season of maize planted in Nairobi.

Feedback:
This trap was managed by the project team, so there is no location specific feedback on hosting or maintaining the trap. In terms of fall armyworm prevalence, much of the maize had already been planted in Nairobi when we installed the trap. Late instar fall armyworm larvae were present in about 10% – 20% of the plants on the non-push pull plots. We didn't find any fall armyworm in the push pull maize, but there was a small amount damage which could have been attributable to fall armyworm or any other stem boring larvae. Unfortunately, we probably missed the opportunity to link trap catches with in-field damage at this site as most of the damage occurred while we were using the faulty Kenya Biologics lure.

Figure A. 15: *Aerial image of the site at ICIPE, Nairobi. © Google Earth*

KALRO, Embu:

Placement

For security purposes, the three traps hosted by KALRO in Embu were placed in an enclosure where KALRO grow irrigated vegetables. This site is bordered by their larger trials of rainfed maize, with approximately 20 – 50m between the trap and the maize.

Feedback:

"Fall armyworm was present and infestation levels were much higher in the long season than short season maize, but drought has been the primary concern. We did use pesticides as part of the trials, where the positive control was Ampligo (lambda-cyhalothrin and chlorantraniliprole), manufactured by Syngenta."

Figure A. 16: *Aerial image of the site at KALRO, Embu. © Google Earth*

Figure A. 17: *Field site at KALRO, Embu.*

Private Farm, Embu

Placement:
This is a private farm belonging to Henry Ngare. The trap was placed in the middle of a maize field close to his home, and this site had two harvests in the space of a year. We also had a challenge initially with the Kenya Biologics lures, which need to be kept in a fridge. Mzee Ngare doesn't have a fridge, but we were able to find a local shop who stored them for him. This was less problematic with the Chemtica lures, which can be stored for six months at room temperature according to the manufacturer. Henry Ngare is older than most of our farmers and neither he nor his wife have WhatsApp. For this reason, it was often difficult for us to contact him and we can't be sure how regularly the lure was changed. The zeros in this trap may represent an expired lure rather than an absence of fall armyworm.
As an interesting aside, while we were visiting Ngare in June, his wife took the opportunity to pick fall armyworm out of the plants. Covering approximately an acre took her an hour, when fall armyworm was present in every 3-5 plants. According to Dr Nyasani, the KALRO recommendation is for smallholder farmers to do this at least once a week.

Feedback:
"The first crop was harvested in September. This was a good harvest, and fall armyworm was present but our biggest concern was the droughts, not the fall armyworm. In the second season, which we are harvesting now (March 2020) we had very heavy rains in December. This reduced the number of fall armyworm, knocking the insects off the stems. Fall armyworm was present, but the attack was negligible. Many people reduced spraying for that reason, and we did not use pesticides in the long season (February – September) or short season (October – March) crops. This short season harvest was one of the best harvests in a long time, but because of the rains not fall armyworm."

Figure A. 18: *Aerial image of the site at a private farm in Embu. © Google Earth*

Figure A. 19: *Field site at the private farm in Embu.*

KALRO, Machakos

Placement:
This trap was placed on the edge of a 2-acre maize trial at the KALRO site in Katumani, near Machakos. This, along with Embu and Kitale, is another of the sites where they have previously collected validation data for CABI's PRISE project. The trap was maintained by Dr Daniel Mutisya. There is only a single season of maize in this region.
Feedback:
"The maize in the initial trial plots failed. These plots are not irrigated, and the whole of Kenya experienced a very heavy drought in the early part of 2019, resulting in several crop losses such as this one. We continued to operate the trap as normal, but the numbers were very low."

Figure A. 20: *Aerial image of the site at a private farm at KALRO, Machakos. © Google Earth*

Figure A. 21: *Field site at KALRO, Machakos.*

Private Farm, Nanyuki

Placement:
The trap was placed on a large commercial farm, which primarily produces seed potatoes. The trap was placed on the edge of a maize variety trial, in a field with multiple other crops (barley, wheat, sunflowers, beans). Nanyuki has a single cropping season, so there was maize in the trial from March to September 2019, after which it was left fallow. The trap was hosted and managed by David Jones, an agronomist with CropNuts/ Agventure.

Feedback:
"Fall armyworm numbers and damage this year were very low, especially compared to the rest of the country. This is possibly because Nanyuki is very high in altitude and, as a result, much cooler. In addition to low trap catches, there was never any fall armyworm damage in the crop and we only used one preventative spray all season. Regularly replacing the pheromone has been a challenge. I have clients across the rift valley and I'm not always at Kisima on the day it needs changing."

Figure A. 22: *Aerial image of the site at a private farm near Nanyuki. © Google Earth*

Figure A. 23: *Field site at Nanyuki.*

Private Farm, Nakuru

Placement
This trap was placed on a large commercial farm near Nakuru, run by Agventure. The trap itself was situated on the edge of a variety trial, which was very similar to that in Nanyuki. The trap was managed by the Farm Manager, John Ochieng.
In addition to the digital trap, Agventure have a network of standard delta traps across the farm, which are used to monitor fall armyworm. Similarly, to the troubleshooting work in Embu, we weren't able to formally compare the different traps, but they were useful for giving us a baseline comparison. These traps, supplied by FarmTrack, use the same Chemtica lure and Agventure kindly supplied us with some initial pheromones for testing. In addition, we knew from comparison with the delta traps that the digital funnel trap was under-reporting. We have now replaced the digital funnel trap at Nakuru with a digital delta trap, and this will continue operate until November.

Feedback:
"There was a severe attack of fall armyworm in our commercial maize at the start of the season. We considered three spray applications and carried out one. The first spray was at five leaf stage, when we used Thunder (Imidaclopride + Betacyfluthrine) to control for vectors of maize lethal necrosis disease (MLND). The second spray was when we detected the presence of fall armyworm. This was about one and a half months after planting, when we applied indoxacarb. The third spray we considered when the plant was at silking. Every cob had at least one caterpillar (stem borer as well as fall armyworm) and we considered using Emamectin bezonate, but decide against it as the pesticide was unlikely to penetrate the canopy and reach the pest. At this time, the pest feeds on the very soft tissues and only destroys the top of the cob. The maize is sold for seed, so even though the cob is damaged we can still sell what remains for seed. We think the fall armyworm source population comes from the neighbouring farms.
We have now begun planting the new season of maize, although it is heavily delayed by the rains. During this time, we have seen many fall armyworm and this is matching with our (standard) delta trap catches."


Figure A. 24: *Aerial image of the site at a private farm in Nakuru. © Google Earth*


Figure A. 25: *Field site at Nakuru.*

Eastern Kenya and the Coast:

Private Farm, Kilifi

Placement:
This trap was situated at the ICIPE Fruit Fly Learning Farm in Kilifi. The farm is managed by Joseph Maramba, who also hosted and managed the trap for us. The Fruit Fly Learning Farm is a large mango plantation, although Joseph and his family also grow a small amount of maize for their own use and consumption. This trap was situated on the edge of a maize plot of about an acre. This field wa surrounded mostly by mango trees, as well as their personal dwellings.

Figure A. 26: *Aerial image of the site at a private farm in Kilifi. © Google Earth*

Figure A. 27: *Field site at Kilifi*

ICIPE, Muhaka

Placement:
This trap was placed at the ICIPE site at Muhaka, situated within the compound but within approximately 20 meters of a large 5-acre maize field. The trap was managed by Beatrice Elasani.

Figure A. 28: *Aerial image of the site at a private farm at ICIPE, Muhaka. © Google Earth*

Figure A. 29: *Field site at ICIPE, Muhaka.*

Taita Research Station, Wundanyi and Private Farm, Maktau

Placement:
Trap 4565 was hosted by the University of Helsinki, at Taita Research Station in Wundanyi. The trap was placed in the gardens of the research station, which is surrounded by several smallholder maize farms; the closest field about 25m from the trap. As the research station is at quite a high altitude, there is usually only one season of maize in this region.

The second trap, 4544, was placed on a small mixed farm growing maize, cassava, pigeon pea and cowpea. The trap was placed on the edge of a maize plot covering an area of about an acre. This trap was at a much lower altitude, where there are two cropping seasons a year. Both traps were maintained by Mwadime Mjomba, who works at Taita Research Station.

Feedback:
We weren't able to get feedback from farmers local to Taita, but Mwadime gave us feedback from his own farm:

"For the first harvest (July 2019) we got 2-3 bags of maize. There were very high levels of fall armyworm, with 4-5 larvae per cob. The second harvest (January 2020) was better. There was no fall armyworm and we got 10 bags of maize. In addition to my crops, I also keep bees. I want to reduce pesticides and encourage my neighbours to do the same, so I can sell the honey. The warning system is good, but we also need better pesticides. The [pesticide] information from David (CropNuts agronomist, see Nanyuki) was useful for managing fall armyworm, but the pesticide was still not beneficial for bees."

At the end of the project we collected the two traps from Wundanyi and Maktau, but Mwadime wanted to continue monitoring for fall armyworm. We gave him the contact details for FarmTrack (www.farmtrack.co.ke), who provide the delta traps used for monitoring at Nakuru. He contacted them, hoping to purchase several for his farm, but the supply was interrupted by Covid19.

Figure A. 30: *Aerial image of the site Taita Research Station, Wundanyi. © Google Earth*

Figure A. 31: *Field site at Taita Research Station*

Figure A. 32: *Aerial image of the site at a private farm in Maktau. © Google Earth*

Figure A. 33: *Field site in Muhaka*

APPENDIX B. NONDO USER GROUPS

Embu Farmer Group

Agnes Kariuki:

"I planted about 2.5 acres, and from this harvested 15 bags of maize. This is enough for food. Fall armyworm was present and I estimate the damage was about 20% of plants. I used Escort (emamectin benzonate) once when the maize was about 1m high. It was effective. There was fall armyworm and stalk borer in this maize, and I would have liked to use the app to differentiate but the app refused to open. After you left, I tried to open it with a CABI extension worker, but we could not get it to work. This is the same phone as we first installed it on, and it was working before. After the training from Dr Nyasani during your first visit, I could tell the difference without the app so it was okay."

Miriam Gitonga:

"I used the app one or two times, but not often because there were not many fall armyworm. The prevalence of the pest was quite low, especially when the rain came. The infestation was not alarming, and the rains were favourable. When the rains are plenty, it tends to suppress the pest and the advice is to use pesticides as a last option. I thought I knew fall armyworm, but the app helped me to tell the difference between fall armyworm and stalk borer. There were very few diseases. They were mostly suppressed by the rains in most crops, but not absent. I lost some beans to rotting early in the season."

Agreffina Muriuki:

"I didn't download the app because I wasn't present at the first training session. I think the main pest I have had in my maize is stem borer, but there has been very low pest pressure. Mostly I have used cultural control. I put a mix of hot chilli, tobacco, detergent and marigold. It is not ideal, but I got 30 – 40% control this way."

Joseph Nyamu:

"I couldn't get the application to work or install on my phone because it is not compatible. I now have a new phone to install it on, and I appreciated the field training. When the rains were good, the pest incidence went down. About 20% of plants infected. I used Mach (Lufenuron) and put dust in the whorls. Overall I had a good maize harvest."

Naomi Wamuyu:

"The training was very useful for differentiating between stemborer and fall armyworm, and after training I continued scouting. I did this with my grandchildren and taught the young

children to distinguish between the different species. The infection was not uniform and there were heavily infected patches. I found more stem borer than fall armyworm. To control them I used tobacco snuff every fourteen days, which I bought from the market. I applied this four times in total and it works well, but it is more effective for stem borer than fall armyworm. The challenge with this approach is knowing how much to apply. It is not like a normal insecticide, so there is no label to inform you. About ¾ of my farm was infested before I started spraying, and the tobacco only became effective when I started using a knapsack sprayer. At first I was putting the mix in the whorls of the plant, but this was not effective. I used 200g in a 16l knapsack sprayer, and combined it with corn flour to help it adhere. After this I did not see fall armyworm again."

Elizabeth Mdwiga:

"Last year I planted very little maize. There was some fall armyworm. When I noticed it, I controlled it by mixing ash and tobacco and put this in the whorls. This helped control maybe 50% of the insects."

This feedback session was also attended by three students from the local agricultural college; Jacob Mwendwa, Irene Murangi and Anrita Njeru.

Maseno Farmer Group

Charles Apeli:

"This season has been successful, but we had problems with the weather. There was too much rain and I had bad water logging which reduced my production. In total I got four 90kg bags from the half acre I planted. The app was not bad, and I would have liked to use it, but there was not any fall armyworm."

Rose Magana:

"This season I had a good harvest. I could not load the app on my phone so I could not test it. There was no fall armyworm either."

Allens Melli:

"I had a very good harvest. I saw a few fall armyworm at the beginning of the season but they disappeared due to too much rain. On my phone there are three [pictures], two fall armyworm and one stem borer [correctly identified]. I took very many pictures of fall armyworm and sent them to the WhatsApp group. These were all is my standard maize, I did not have any in my push-pull maize. I have eight or nine bags in total so far but we are still harvesting, and I have sold five. This is from about ¾ of an acre, using the Pioneer 2809 variety."

Rose Adiambo:

"I couldn't load the app as it wouldn't work on my phone. It is giving me the same problems as when you were here to install it. My harvest was good, I got 4 sacks from a ½ acre. I am using push-pull so there was no fall armyworm."

Grace Kageha:

"I also could not load the app on my phone. But I used push-pull and got 2 sacks from ¼ an acre."

Maureen (Agnes) Ambubi:

"I couldn't get the app on my phone before, but it is loaded now. I tried to use it once or twice and I had three images which are correctly identified, but I didn't know what to do with them. The fall armyworm was there in the beginning but then when the rains come, they disappear. I got 3 bags from a ¼ acre, and when I was harvesting there were many weevils and some stem borer, but no fall armyworm."

Tito Otene:

“I wanted to use the app, but it doesn’t load onto my phone. There was very little fall armyworm, but some stemborer. I was able to get 3 bags from ¼ acre.”

Rodgers Oliech:

Rogers is an extension worker, who helped co-ordinate the meeting. While in the field, he occasionally used the app and had three pictures: one of a correctly identified fall armyworm, one identified as variegated cutworm where the picture was too indistinct to be certain of the species and a third image identified as a black cutworm. This was not a black cutworm, but not fall armyworm either.

John Ochieng:

“I installed the app and tried to use it, but I couldn’t get a breakthrough.” On watching John use the app on his phone, I realised that he wasn’t selecting the tick box for processing the images. Once we’d shown him what to do, it worked fine.

APPENDIX C. REFERENCES

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