TECHNICAL REPORT

SOCIO-ECONOMIC IMPACT AND ACCEPTANCE STUDY OF DRONE-APPLIED PESTICIDE ON MAIZE IN GHANA

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Festus Annor-Frempong
Principal investigator and project manager, DAEE-UCC

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List of acronyms

ACP	African, Caribbean and Pacific Group of States
CTA	Technical Centre for Agricultural and Rural Cooperation ACP-EU
CSIR	Council for Scientific and Industrial Research
DAEE	Department of Agricultural Economics and Extension
EU	European Union
FAW	Fall armyworm
FFDs	Farmer field days
GHS	Ghana Cedis
ICT	Information and communications technology
IPM	Integrated pest management
MoFA	Ministry of Food and Agriculture
PPE	Personal protective equipment
PPRSD	Plant Protection and Regulatory Services Directorate
SARI	Savannah Agricultural Research Institute
SD	Standard deviation
TAM 3	Extended Technology Acceptance Model
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
UCC	University of Cape Coast

Executive summary

The general consensus among agricultural stakeholders is that smallholder farmers need to become more productive and profitable on a sustainable basis. Unmanned aerial system (UAS) – or drone-based system – services can contribute towards these goals by bringing some of the tools of digital agriculture to agribusiness enterprises, including large and medium-scale holdings, and associations of small-scale farmers growing the same crop on contiguous areas. In Africa, UAS services can be described as nascent and are usually provided by entrepreneurs who invest in the equipment and necessary skills to use the technology, and go on to conduct or sub-contract data analysis, interpret the findings and advise customers. Cutting edge use of specially designed drones allows the devices to be used for agrochemical application on crops.

Recognising the opportunities provided by UAS, CTA has been partnering with leading private sector operators in Africa since 2017. Their work has assisted information and communications technology (ICT) start-ups in over 21 African countries to acquire the capacities required to deliver UAS services. CTA has organised a series of activities including training on the operations of drones mounted with multispectral sensors, understanding of drone safety, privacy principles and regulations, management and processing of remotely-sensed data, development of UAS business plans, and networking opportunities. During 2018-19, CTA upscaled its activities to increase the number of countries and UAS operators covered across Africa. Via scientific, on-site research, CTA has also invested resources accordingly to assess social acceptance of the technology and its costs and benefits. These projects are framed within a larger intervention known as Transforming Africa's Agriculture: Eyes in the Sky, Smart Techs on the Ground.

UAS and UAV technologies have been recognised as a potential solution for on-farm pest control through pesticide application, which could be of particular importance for fall armyworm (*Spodoptera frugiperda*) (FAW) invasions in Africa. FAW has continued to threaten food security in a wide range of African countries, including Ghana since its emergence in 2016.

Through agencies including the Ministry of Food and Agriculture (MoFA) and the Plant Protection and Regulatory Services Directorate (PPRSD), the Government of Ghana, alongside smallholder farmers, is applying several management strategies including biological, chemical, cultural and traditional control methods. The methods include hand picking and crushing of FAW, intercropping maize with plants that could repel FAW, and avoiding planting of crops that could serve as an alternative host to FAW. However, most of these control methods are ineffective due to various factors, such as FAW's feeding behaviour and life cycle (which is mostly nocturnal), and a lack of compatible pesticides and application methods. There is therefore a need to adopt technologies that could be congruent with the feeding behaviour and other characteristics of FAW. In this context, the potential use of new application technologies such as UAVs seems promising. However, a number of actions have to be put in place prior to upscaling such technologies to commercial agribusiness enterprises and smallholder farmers within the maize value chain.

Bayer CropScience Division (subsequently referred to as Bayer), a globally-operating enterprise that works to shape agriculture through the application of breakthrough innovations, identified UAS development as a promising innovation to control FAW maize infestations in Ghana. As such, they designed and implemented a series of experiments to test the safety and efficiency of drone use in pesticide application, and the potential benefits for African farmers. The results of the project, which was jointly funded by CTA, are shared in this paper.

In partnership with the Department of Agricultural Economics and Extension of the University of Cape Coast (DAEE-UCC), Acquahmeyer Drone Tech Ltd and the Savannah Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR), Bayer conducted trials in the Northern Ghana communities of Mion, Tolon and the West Mamprusi Districts using UAVs to control FAW. The trials were conducted in mid-June and mid-July in the 2019 growing season. The main aim of the trials was to assess the efficacy of UAV-based pesticide application in maize versus manual application. Furthermore, the trials collected information in order to evaluate the safety of such application, and thus, engaged the regulatory authorities to define the conditions required in order to have 'drone application' mentioned on pesticide product labels in future.

However, acceptance of a new technology by a group of users is not just a question of technical features, but relies on socio-economic parameters that need to be assessed. SARI was responsible for the experiments, and selected and set the research experimental trial plots at Nyankpala in the Tolon District, Salankpang in the Mion District and Kukua in the West Mamprusi District of Northern Ghana. Departments of Agriculture in the districts where the experimental trials were set up randomly selected maize growing communities within a 5–10 km range for interviews and trial observations.

The project's purpose was to determine the socio-economic impacts of introducing to the market a contact pesticide applied via drone technology to maize crops to address FAW infestation. The project also intended to identify the potential market acceptance success factors for drone-applied pesticide.

More specifically, the objectives were:

- To assess farmers' FAW control practices;
- To examine farmers' preferred pest and disease control options for maize in the study area;
- To examine farmers' perceptions on the use of drone technology for pesticide application to control FAW;
- To determine the economics of drone pesticide spraying in the field;
- To compare the costs and benefits of farmers' FAW control practices (pesticide knapsacks) with drone technology FAW control – from a farmer's perspective;
- To examine the willingness of farmers to pay for drone technology to control FAW;
- To determine the factors associated with farmers' propensity to adopt drone technology for pesticide application to control FAW;
- To assess the economic efficiency of drone technology for FAW control at experimental and control plots;
- To recommend market acceptance factors for the uptake of drone technology for pesticide application to control FAW.

In order to achieve the objectives of the study, a repeated cross-sectional survey design with a mixed method approach involving quantitative and qualitative procedures was used for the socio-economic study. The qualitative procedure included in-depth interviews, field observations and focus group discussions, while the quantitative approach was mainly cross-sectional surveys conducted among maize farmers within the study sites.

Various sampling procedures and sample sizes of farmers were used to achieve the objectives of the research at different stages in the Mion, Tolon and West Mamprusi Districts. A total of 150 farmers were randomly sampled from a cohort of 301 farmers previously selected during the baseline survey. The sample comprised of 50 farmers from each of the three districts where the experimental plots were established. Data was collected from these same farmers at various stages of the research process.

Key findings are presented below

- Farmers have appreciable knowledge of FAW (known locally as *Zunzuya*, meaning 'worms'), and can detect the presence of these pests on their farms based on characteristic signs they have identified with the feeding habits of the pest;
- Farmers mainly use agrochemicals to control FAW and in some cases, local mixtures and/or bio-pesticides, but never integrated pest management (IPM);
- Farmers prefer using synthetic pesticides over biological control methods, bio-pesticides, chemical mixtures, cultural practices and IPM to control FAW;
- Few farmers had seen or heard of drone technology applications or had participated in agricultural programmes using drone technology before this study. Videos and live drone operations to apply pesticides on maize fields enabled the farmers to see and describe the operation of drones and their separate parts, including the propellers/wings, the pesticide tank/container, discharging nozzles and the remote control used by the pilot;
- Farmers perceived a high benefit of using drones to control FAW when compared to the traditional pesticide knapsack method. They indicated that drones could apply pesticides more accurately to kill the FAW caterpillar, with little or no chemical wastage – and at speed, making the use of drones effective, simple and efficient;
- The farmers considered knapsacks to be more affordable and readily available than the drone technology, but recognised the higher risks of chemical spillage to the sprayer when carrying and pumping the knapsacks, and also the increased energy and time taken in manually covering an entire field when using the knapsacks;
- Wide variations in maize productivity were recorded over the years across the study sites, with reductions attributed to FAW invasions;
- No significant differences were found across the study sites in terms of the total variable costs, total cost, total revenue, gross margin and benefit-cost ratio between the control, drone and knapsack plots, but there were wide variations among them. The return on investments were also different across the study districts regarding knapsack and drone technology usage;
- The behavioural intention of farmers to use drone technology for FAW control can be predicted based on five variables, namely: attitude towards use of the digital technology, result demonstrability, perceived usefulness, perceived enjoyment, and voluntariness. Attitude towards the use of drone technology was the best predictor of the farmers' intention to use the technology for FAW control;
- An overwhelming majority of the farmers were willing to pay for FAW control drone services in the study area.

Conclusions

The study concludes that farmers will use any effective synthetic pesticide introduced for the control of FAW. Farmers are aware of, and perceived a high benefit for, the use of drone technology to control FAW when compared to the knapsack method. Although farmers felt that the knapsack was more affordable and readily available, its associated demerits encouraged farmers to consider other options.

It was evident that the farmers intended to use drone digital technology for FAW control because their attitude towards the use of digital technology, the result demonstrability, perceived usefulness and enjoyment, and their voluntariness, were high. The farmers were also willing to pay for the FAW control drone technology services in the study area.

Recommendations

The following recommendations targeting various entities have been made based on the conclusions of the study:

Government of Ghana, Ministry of Food and Agriculture and Departments of Agriculture

- Farmers use a variety of FAW control methods, but place emphasis on the use of synthetic agrochemicals. The synthetic agrochemical developed by Bayer, and used in these trials, has been officially registered for knapsack use against FAW on maize since 2019 and is available on the market. The results of this study confirm similar FAW control efficacy when applied by drones. Ghana's Department of Agriculture staff must sensitise farmers to take up this specific agrochemical to effectively control FAW. The government should add it to the list of subsidised synthetic agrochemicals for use by farmers to effectively control FAW;
- Agriculture departments in the experimental districts should educate farmers to use appropriate personal protective equipment (PPE) at all times when using agrochemicals in the field. Farmers lack knowledge on the use of IPM, which is key for effective and sustainable pest control;
- The Department of Agriculture should double their efforts in assisting farmers with requisite information on the destructive characteristics of FAW, and the measures to put in place to control it. There should be concerted efforts to cut across the districts with interventions, such as mass spraying to reduce FAW numbers and crop impacts. Such efforts should consider the use of drone technology, especially based on the results of the experimental trials;
- The Department of Agriculture should promote the use of drone technology not only for FAW control in the study area, but also for other agricultural activities, such as crop health monitoring, yield estimation and soil analysis at farmers' fields;
- The farmers have shown a positive attitude towards use of the technology, but there is a need for alternative funding sources or cost mitigation of the drone services to enable greater uptake. The Ghanaian Government is currently partnering with Zipline, a private drone service provider to apply the technology for medical supply delivery in parts of Ghana. Similarly, through the Ministry of Agriculture, the government could adopt drones as a policy for agricultural development. The private sector could be provided with tax waivers by the government to encourage them to import more drones into Ghana for agricultural purposes;
- The Department of Agriculture should sustain farmer interest or turn their aspirations into reality by ensuring that drone services are made available for use on individual farms. Department staff will require training, most likely from the service providers themselves;
- This study has shown that farmers with positive attitudes towards the drone technology have a high behavioural intention to use it for FAW control – provided the drone can demonstrate results farmers can voluntarily perceive as useful and enjoyable. This finding should be the basis for any programme by the Department of Agriculture to encourage farmers to patronise drone service application in agriculture;
- A study on the training needs of extension staff for drone application in agriculture should be conducted.

Farmers

- Farmers must use synthetic agrochemicals that have been developed, tried and found to be effective for FAW control, such as the one being marketed by Bayer;
- Farmers should use appropriate PPE at all times when applying agrochemicals in the field;
- Farmers must strive to acquire knowledge on the use of IPM, which is key for effective and sustainable pest control;
- Farmers must work in groups to access available drone services so as to reduce the cost per person of FAW control.

Drone service providers

- Drone service providers should consider setting up offices in all districts to provide drone services for agriculture;
- The service providers should adopt cluster/group spraying services for farmers located within the same areas to reduce overhead costs of drone spraying services;
- The service providers should develop collaboration and cost-sharing proposals for drone spraying services with the District Assembly, the Department of Agriculture and the farmers, to roll it out to more districts and make it more accessible for farmers;
- Drone service providers, such as Acquahmeyer Drone Technology Ltd, should develop and present a proposal to the government to roll out the programme and provide drone services for agricultural development;
- Training and demonstration sessions should be held with farmers by would-be drone service providers to explain the benefits of drone technology, and enable farmers to exercise good judgement about choosing drone applications;
- The study revealed that farmers are very observant and easy to train regarding the use of drones. Drone service providers should fashion training courses in local areas to provide farmers or educated youth within their families with the skills needed to become drone operators;
- Drone service providers should organise demonstration events for farmers to showcase the advantages of drone-based spraying services. This will enable farmers to take informed decisions on whether to adopt such services or not.

Bayer

- The results of the study have shown that farmers prefer to use agrochemicals over other pest management methods, and that Bayer's agrochemical is efficacious in treating FAW invasions. Bayer should therefore double its efforts in releasing the synthetic agrochemical used in the study, and increasing its availability on the market.

DAEE-UCC

- This study is a first of its kind in Ghana with many useful recommendations. DAEE-UCC will need to share the results widely among service providers and other stakeholders to create awareness about the value and efficacy of drones for FAW control, and productivity enhancement. DAEE-UCC also needs to showcase the technology as the best option for controlling FAW to convince all Ghanaian farmers to call for such services;
- Farmers are likely to make more returns on investment using drone technology than knapsack sprayers. A benefit-cost analysis comparing the two methods should be presented to farmers in order to sustain their interest in drone technology adoption;
- Since DAEE-UCC has the capacity, it should seek financial resources to offer training to extension workers of the Department of Agriculture in the use of drone services;
- DAEE-UCC should support the Departments of Agriculture of the District Assemblies to develop proposals towards the application of drones in agriculture.

1. Project background

1.1 CTA-supported interventions

There is a general consensus that smallholder farming needs to become more productive, sustainable and profitable. UAS – or drone-based system – services can contribute towards these goals by bringing precision agriculture tools to producers, including large and medium-scale holdings and associations of small-scale farmers growing the same crop on contiguous areas. Typically, UAS services are provided by entrepreneurs who invest in the equipment and necessary skills to use the technology, and go on to conduct or sub-contract data analysis, interpret the findings and advise their customers. Cutting edge use of specially designed drones allows the devices to be used for agrochemical application on crops.

Recognising the opportunities provided by UAS, since 2017, CTA has partnered with leading private sector operators, and assisted ICT start-ups in 21 African countries to acquire the capacities required to deliver UAS services. CTA has also organised a series of activities, including training on the operation of drones and mounted multispectral sensors, drone safety and privacy principles and regulations, management and processing of remote sensed data, development of business plans and networking opportunities. In addition, CTA provided financial support to ICT companies for the acquisition of necessary equipment for the successful implementation of UAS-based advisory services in these countries.

In 2018–19, CTA upscaled its activities to increase the number of countries and UAS operators covered across Africa. CTA also invested resources to assess the social acceptance of the technology and its costs and benefits via scientific on-site research. These activities and this project are framed within the larger CTA intervention known as Transforming Africa's Agriculture: Eyes in the Sky, Smart Techs on the Ground.

1.2 The Ghana context

The threat of FAW to food security in a wide range of African countries, including Ghana, is an undeniable fact. Currently, FAW is the most devastating and destructive invasive maize pest in Ghana. Alongside smallholder farmers, the Ghanaian Government – through MoFA and PPRSD – is using several FAW management strategies, including chemical application (via knapsacks), cultural[1] and traditional control methods. However, most have been ineffective because of pesticide efficacy issues and the nocturnal feeding behaviour and life cycle of the pest.

Bayer is an innovative leading company in the field of health and nutrition, with a vision of 'health for all and hunger for none'. Through the company's CropScience Division, Bayer's vision is implemented via a globally-based research team, which works to shape agriculture through the application of breakthrough innovations. In Ghana, Bayer obtained registration for a promising FAW control insecticide for the 2019 maize growing

[1] Cultural control methods involve the use of natural and biological control methods that exclude organic or inorganic chemical usage. For example, hand picking and physical destruction of worms, intercropping maize with plants that could repel FAW, avoiding planting of crops that could serve as alternative host to FAW, and promoting the presence of insects and birds to biologically control FAW.

season. The product was approved for application via a knapsack sprayer. Manual pesticide application requires knowledge of good agricultural practices and awareness of correct PPE to ensure efficient protection of both the operator and the environment. This is particularly true in maize fields where the height and density of the crops could make spraying operations challenging.

In this context, the potential use of new application technologies such as UAVs seems promising. However, a certain number of actions need to be put in place prior to full deployment of such technologies.

Bayer, in partnership with the organisations as listed under 'The parties involved' below, conducted trials in farming communities in Mion, Tolon and West Mamprusi Districts of Northern Ghana using UAVs to control FAW. The trials were carried out during mid-June and mid-July in the 2019 growing season. The main aim of the trials was to assess the efficacy of UAV-based pesticide application versus manual application. Furthermore, the trials collected information regarding the safety of drone-based application, and engaged regulatory authorities to define the conditions required in order for 'drone application' to be mentioned on pesticide product labels in future.

However, acceptance of a new technology by a group of users is not just a question of technical features but relies on socio-economics parameters that needed to be assessed.

2. The parties involved

CTA funded the socio-economic study implemented by DAEE-UCC, whilst Bayer contracted Acquahmeyer Drone Tech Ltd to apply the pesticide using drones, and SARI to secure and prepare the land for experiment, apply pesticide using knapsacks, carry out crop husbandry practices, harvest the crop and keep records of all experimental plot data.

2.1 Bayer

Bayer has initiated a project in Ghana to define the technical conditions required for the safe and efficient use of plant protection products, and application by drones in maize fields. CTA and DAEE-UCC proposed to take advantage of the study trials to run, in parallel, a socio-economic study. The main contributions from Bayer were as follows:

- Design study plan to be used as a basis for the field trials;
- Coordinate locally and ensure consistency between the technical experiments executed by SARI and the socio-economic study;
- Support the researchers to get the needed contacts of all parties involved, and provide data for the socio-economic impact study;
- To ensure that conditions on experimental plots and during field visits by farmers and researchers are in line with Bayer's safety standards, including the provision of PPE.

2.2 DAEE-UCC

The DAEE-UCC is one of the five departments of the School of Agriculture, College of Agriculture and Natural Sciences at UCC in Ghana. DAEE-UCC contributes to teaching, learning, research and outreach in agricultural economics, agribusiness, extension education, and community development. The specific research agenda includes: ICT and precision agriculture, drone and sensor application in agri-food systems, innovations and adoption, entrepreneurship and agribusiness management, maize innovations for sustainable development, and gender and youth issues in Ghana.

A team of researchers from DAEE-UCC, namely, Festus Annor-Frempong (a socio-economist and the principal investigator), Selorm Akaba (agricultural development economist) and three postgraduate students (Isaac Kwasi Asante, John Kwesi Ocran and Selorm Omega) conducted the research into the socio-economic impacts and acceptance of drone-applied pesticide on maize in Ghana. The team reported their findings to CTA who commissioned the study.

2.3 Acquahmeyer Drone Tech Ltd

Acquahmeyer Drone Tech Ltd is a Ghanaian start-up company offering drone-based spraying services. Drones can be programmed for executing a particular mission on a given flight path. The drones for this experiment carried a tank of agrochemicals to apply to crops in a very precise manner, via very fine droplets, in order to reduce human intervention and risk exposure to the pesticide.

2.4 SARI

SARI is one of the 13 research institutes of CSIR. It was originally known as the Nyankpala Agricultural Experimental Station and operated as an outpost of the Crop Research Institute in Kumasi. In 1994, the station gained autonomy and was upgraded to a fully-fledged research institute. SARI is located 16 km west of Tamale in the Tolon District of the Northern Region of Ghana.

SARI's mandate is to provide farmers in the Northern, Upper East and Upper West Regions with appropriate technologies to increase their food and fibre crop production, based on a sustainable production system that maintains and/or increases soil fertility. Its mission is to develop and introduce improved technologies that will enhance overall farm-level productivity.

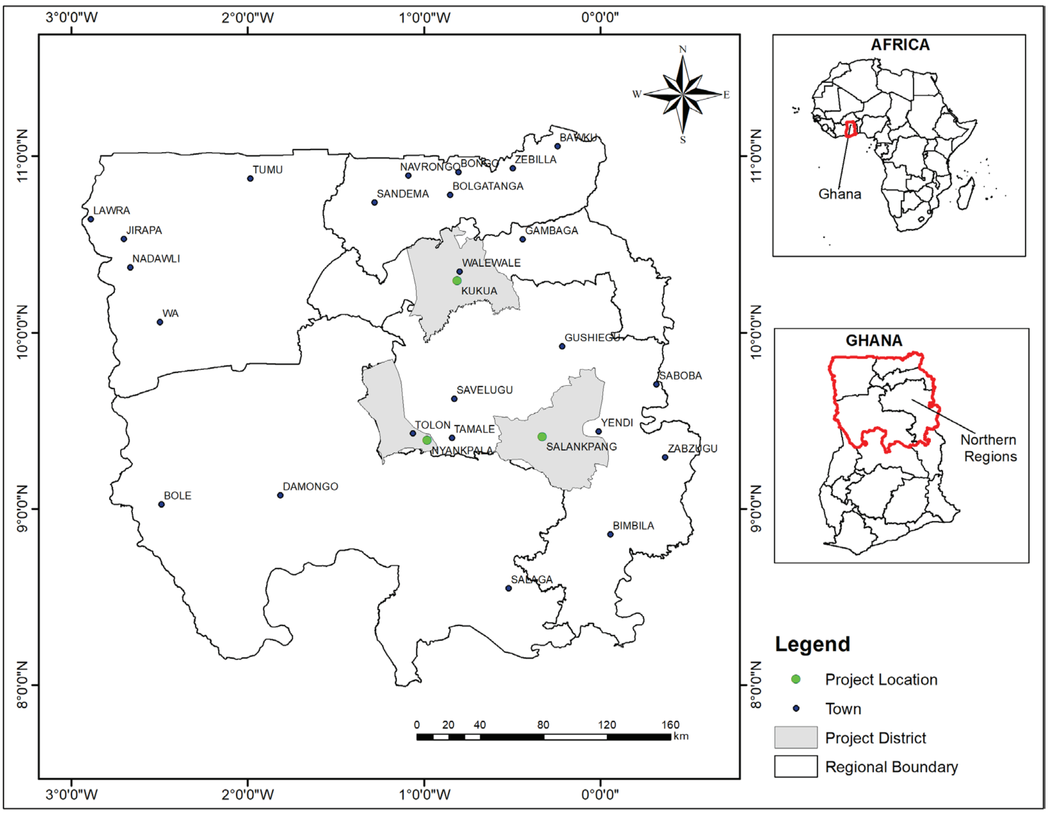
Abdulai Mumuni, chief research scientist at SARI, is also the institute's lead researcher on pesticide efficacy. With a team of research technicians, Mumuni set up and managed the project experimental trials.

3. Project location

SARI selected and set the research experimental trials at Nyankpala in the Tolon District, Salankpang in the Mion District and Kukua in the West Mamprusi Districts of Northern Ghana.

The Departments of Agriculture in the selected districts were contacted to randomly select maize growing communities within a 5–10 km radius of the selected villages. The socio-economic data were collected from farmers from Nyankpala and Kpalsogu in the Tolon District, Dijo, Kplijine and Salankpang in the Mion District and Kukua and Loagri in the West Mamprusi District.

Figure 1: Map of Ghana showing the study districts



4. Project purpose

The project's purpose was to determine the socio-economic impacts of introducing to the market a contact pesticide, to be applied via drone technology, to address FAW infestations in Ghana's maize crops. The project also intended to identify the potential success factors for market acceptance of drone technology for pesticide application.

4.1 Specific objectives of the research

- To assess farmers' FAW control practices;
- To examine farmers' preferred pest and disease control options for maize in the study area;
- To examine farmers' perceptions on the use of drone technology for pesticide application to control FAW;
- To determine the economics of drone pesticide spraying in the field;
- To compare the costs and benefits of farmers FAW control practices (pesticide knapsacks) and drone technology FAW control – from a farmer's perspective;
- To examine the willingness of farmers to pay for drone technology to control FAW;
- To determine the factors associated with farmers' propensity to adopt drone technology for pesticide application to control FAW;
- To assess the economic efficiency of drone technology for FAW control at experimental and control plots;
- To recommend market acceptance factors for the uptake of drone technology for pesticide application to control FAW.

4.2 Research questions

- How do farmers control FAW in the study area?
- Do farmers have preferred pest and disease control options in the study area?
- How do farmers perceive the application of pesticides using drone technology for FAW control?
- What are the field application economics of drones in spraying pesticide?
- Do the costs and benefits of farmers' practices (such as knapsack use) outweigh those of drone technology for pesticide application in FAW control?
- Are farmers willing to pay for drone technology to control FAW?
- What factors are associated with the propensity of farmers to adopt drone technology for pesticide application to control FAW?
- Are experimental plots more economically efficient for drone-based FAW control compared to plots benefiting from knapsack spraying or no spraying at all (control)?

5. Methodology

5.1 Research design

A repeated cross-sectional survey design with a mixed method approach involving quantitative and qualitative procedures was used for the socio-economic study. The qualitative procedure included in-depth interviews, field observations and focus group discussions while the quantitative approach was mainly cross-sectional surveys conducted among maize farmers within the study sites.

5.2 Population

The study population consisted of maize farmers in the Mion, Tolon and West Mamprusi Districts of Northern Ghana.

5.3 Sampling of respondents and sample sizes

Various sampling procedures and sample sizes of farmers were used to achieve the research objectives at different stages.

To assess farmer FAW control practices, and examine their preferred pest and disease control options, and propensity to adopt drone technology for pesticide application, a simple random sampling procedure was used to select a representative sample of farmers for interview. In view of the project's limitations in terms of time and resources, stakeholder discussions concluded that a sample size of 300 (100 farmers from each district) would be adequate to achieve the objectives.

The selected districts' Departments of Agriculture were contacted to randomly select maize growing communities within a 5–10 km radius of the selected villages where experiments were set up. A list of farmers based in close proximity to the villages where the experimental plots had been set-up in Nyankpala (Tolon District), Salankpang (Mion District) and Kukua (West Mamprusi District), was compiled by the respective agricultural departments. Table 1 shows the sample size of farmers from each of the study communities for the pre-survey.

Table 1: Sample size based on communities for the pre-survey

District	Communities where data was collected	Sample size
Tolon	Nyankpala	65
	Kpalsogu	45
Mion	Salankpang	25
	Kplijine	33
	Dijo	22
West Mamprusi	Kukua	60
	Loagri	51
	Total	301

Source: DAEE-UCC, field data, 2019

A total of 150 farmers were randomly sampled from a cohort of 301 farmers previously selected in the baseline survey. The final sample comprised of 50 farmers from each of the three districts where the experimental plots were established. Data was collected from these same farmers at various stages of the research process. There were different response rates during the various waves of data collection. Table 2 provides a breakdown of the sample size from each community.

Table 2: Sample size for field days in each of the communities

District	Selected communities	Sample size farmer field day survey I	Sample size farmer field day survey II	Sample size farmer field day survey III
Tolon	Nyankpala	34	26	22
	Kpalsogu	16	18	33
Mion	Salankpang	14	9	24
	Kplijine	23	16	22
	Dijo	12	12	2
West Mamprusi	Kukua	31	16	19
	Loagri	15	10	20
	Total	145	105	152

Source: DAEE-UCC, field data, 2019

5.4 Data collection, analysis and statistics

5.4.1 Interview schedule

Structured interview schedules were developed to include face-to-face interviews by trained enumerators for data collection. Four different survey instruments were used during different waves of the field data collection. The first survey included questions on the level of knowledge, awareness and incidence of FAW, farmers' management and preferred FAW control options, and characteristics of maize production farmers and their farms. The second and third interview schedules, used to collect data for the drone technology survey, were made up of questions regarding farmers' perceived awareness of drone technology, their perceived benefits of drone technology in FAW control (Figure 2), and cost and benefit comparison analyses of drone technologies and knapsack sprayers for FAW control. The fourth interview schedule was used to collect data on farmers' acceptance of drone technology, and their willingness to pay for drones in FAW control.

Figure 2: Data collection at Kukua

Credit: DAEE-UCC, 2019

The data collected was entered into the IBM-SPSS software data analysis programme to generate frequencies, percentages, means, standard deviations, Friedman rank, Wilcoxon signed rank tests, Pearson correlations and regression analyses to present the findings.

5.4.2 Farmer field days

Three farmer field days (FFDs) were organised at the experimental plots in Kukua in the West Mamprusi District, Kplijine in the Mion District, and Nyankpala in the Tolon District (Figure 3). The FFDs were carried out during the first and second rounds of drone spraying and during crop harvesting.

During the first pesticide application, a video captured by Bayer involving the use of knapsacks on one of the trial plots and drones on another trial plot was shown to the farmers. Data collected during the FFDs show that 145 (96.66%) out of 150 farmers participated in the first field day and responded to the survey questions afterwards.

Figure 3: Operation of drone with farmers watching attentively

Credit: Ayodele Kayode, Bayer

The second FFD, which was held two weeks after the first FFD, had 105 (72.41%) farmers participating. During this session, farmers had the opportunity to witness a live operation of both the drone and knapsack sprayer, but for safety purposes were not allowed to enter the trial plots. They were made to observe from within a safe perimeter defined and demarcated by Bayer and Acquahmayer Drone Technology Ltd.

The third FFD was held during maize harvesting from the experimental plots. Farmers were allowed to walk into the experimental plots to observe, first-hand, maize growth and yield from all the four experimental plots.

5.4.3 Key observations and reflections from FFD I

Each experimental location had three types of pesticide treatment: in treatment one, one maize plot was sprayed with pesticide via a drone (Figure 4); in treatment two, one maize plot was sprayed using a knapsack (Figure 5); for treatment three, no pesticide was sprayed to two maize plots – these were the control plots.

Figure 4: First application of pesticide using a drone in Nyankpala

Credit: Ayodele Kayode, Bayer, 2019

In all three experimental locations, the selected farmers were given ample opportunity to express their concerns and observations during the FFDs. The farmers' main concerns during FFD I regarded how the drone could manoeuvre its way past the trees in their maize fields, and also, how the pilot could tell when the pesticide in the tank had been used up. Some farmers wanted to know how the pesticides were measured and mixed before being added to the drone tank, whilst others were curious to know if individuals would be able to access the services, or whether they would only be available to farmer groups. The team leader explained the working of the drone in detail to the satisfaction of the farmers and assured them that the drone company would make the services available to every individual farmer expressing interest.

Figure 5: Operator applying pesticide to the emerging crop with a knapsack sprayer

Credit: DAEE-UCC, 2019

It became clear during discussions that the farmers had observed in Bayer's video the presence of appropriate PPE as worn by the knapsack operator and drone pilot. Additionally, all the farmers observed that the drone pumped the pesticide from a height above the maize plants directly onto the crops, making it effective, with little or no chemical wastage. After the video screening and discussions, farmers were taken in groups (to avoid overcrowding that could obscure effective farmer observation) to the field to observe the plants on the plots.

At Kukua, the key farmer observation was that the two control plots were highly infested with FAW, whilst the drone plot – where pesticide had been sprayed prior to FFD I – showed no sign of any FAW presence. They could tell that the knapsack plot had some level of infestation but not as severe as in the control plots. This observation was made based on visible signs of FAW attack on the plants, including damage to the emerging whorl and holes in the leaves, as well as the presence of caterpillar faeces (frass) on some of the leaves. Farmers at Kplijine made similar observations at the plots they visited. However, at Nyankpala, the farmers observed that the drone and knapsack plots were equally as infested as the control plots. This was due to the fact that the trial plots were surrounded by other maize fields that were heavily infested with FAW.

5.4.4 Key observations and reflections from FFD II

To address farmer queries and concerns from the first FFD on drone manoeuvrability and estimating pesticide levels in the tank, at the second FFD, the farmers were able to witness all the pre-flight preparations, the mixing and feeding of chemicals into the drone, and how the drone took off and maintained flight (Figure 6).

Figure 6: Farmers being debriefed before the second application of pesticide using a drone at Kukua

Credit: DAEE-UCC, 2019

In all three locations, the selected farmers were visibly fascinated by the live operation of the drone and raised further questions. Some wanted to know if it was necessary to wear the same PPE as the operators. The farmers applauded the ease and speed with which the drone applied the pesticide in the field.

5.4.5 Key observations and reflections from FFD III

The selected farmers were given the chance to observe the maize crops and plots in all locations before harvesting. They asked why all the plots were overgrown with weeds, some commenting that the overgrown weeds were likely to affect the maize yield. Some also admitted that the weeds were likely to affect their judgement in terms of the drone and knapsack impacts, as well as the agrochemicals applied on the various plots. SARI, the partner responsible for managing the plots, explained that because of the severe drought just after the maize had tasselled, controlling the weeds would have stressed the crops. In any case, the weed infestation was across all plots of the experimental fields.

5.4.6 Analytical framework

Table 3 below summarises the type of data, methods/designs and analysis required to achieve the study objectives.

Table 3: Type of data, methods and analyses applied to achieve objectives

Objective	Type of data required	Methods/designs	Data analysis and statistics
To assess the farmers' practice in the control of FAW	Methods, chemicals, rate of application, production sustainability (i.e. economic, social and environmental)	Cross-sectional survey, compared with benchmark practices and mixed methods	Descriptive and inferential statistics, t-test
To examine farmers' preferred pest and disease control options in the study area	Control methods, ranking of these methods, and farm and farmer characteristics	Cross-sectional survey, mixed methods, discrete choice model	Descriptive, multinomial (ordered logit), contingent valuation analysis
To examine farmers' perceptions on the use of drone technology for pesticide application for FAW control	Awareness, knowledge levels, perceived benefits, willingness to accept and recommend the technology; technology characteristics (relative advantage, compatibility, complexity, trialability, observability); farmer characteristics (age, education, gender, social status, and contact with extension/research); social factors (family and kinship groups), infrastructural access (credit, marketing, input supply, extension, roads, etc.), and environmental factors (land resources, climatic conditions)	Repeated cross-sectional survey, mixed methods	Descriptive, Friedman rank tests, TAM 3
To determine the economics of drone-applied pesticides in the field	Costs, benefits, labour savings (man hours), chemical savings, sustainability (economic, social and environmental)	Field survey, experimental observation	Gross margin

Objective	Type of data required	Methods/designs	Data analysis and statistics
To compare farmers' perceived costs and benefits of their own FAW control practice (knapsack) with the drone technology FAW control practice	Perceived effectiveness, coverage, number of pests killed, killing capacity, time (labour) saving, chemicals saved, affordability, and environmental sustainability	Cross-sectional survey	Benefit-cost analysis
To examine the willingness of farmers to pay for drone technology to control FAW	Attributes of the various choices available for the spraying (knapsack and drone), and socio-economic characteristics of farmers	Survey/discrete choice experiment	Stated preference approach
To determine the factors associated with the propensity of farmers to adopt drone technology for pesticide application	Intention to use, effort expectancy, openness to change, trust in science, social/peer influence, associated benefits, willingness to pay for drone services	Theory of planned behaviour	TAM 3
To assess the economic efficiency of experimental and control plots for the application of drone technology to control FAW	Yield, farm size, labour, agrochemicals, seed and seed types, cultural practices		Land productivity

Source: Authors' construct, 2019

6. Key findings

This section reports on the key findings according to the objectives of the project.

6.1 Farmer practice in the control of FAW

The farmers in the study communities were very much aware of the incidence of FAW. The FAW larva (caterpillar) was described as green when young, and light brown when grown. The FAW moth was also correctly described as having a brown colour at the tip of the wing and/or grey forewing, and a noticeable white spot near the extreme ends of the wings. In the farmers' local languages (Dagbani and Mamprusi), FAW is called *Zunzuli* (singular) or *Zunzuya* (plural), which literally translates as 'worms'.

The farmers used five main signs to detect FAW presence on their maize farms: destruction of new emerging leaves, presence of frass, physical presence of worms on surrounding grasses, presence of white strips on maize leaves, and the presence of brown spots on maize leaves. The majority of farmers first noted the presence of FAW on their farms in 2016, when FAW was widely reported in Ghana. During the study, FAW infestations were most severe during June and July, which coincides with the start of the planting season in Northern Ghana.

The data, as analysed from 301 respondent farmers, indicated that FAW maize attacks were most severe from dawn (72.1%) between 4.30 and 5.30am, early morning (77.4%) between 5.31 and 7.30am, late at night (66.4%) between 7.31pm and 4.30am, and in the evening (53.5%) between 5.01 and 7.30pm. Most respondents (92.7%) indicated that FAW attacks take place during the vegetative stage of the maize plant.

Farmer interviews revealed that FAW totally destroyed the entire maize farms of some farmers in the study area. About two out of every five respondents indicated that, since 2016, they had not harvested any maize of economic value from their farms due to FAW attacks. More than 60% of respondents reported that their farms were totally attacked or destroyed by FAW within 3 to 21 days if not controlled. Most respondents (94.0%) also reported that the incidence of FAW affected all farms in their communities.

Most respondents (85.4%) have attempted to control FAW on their farms in the past. Out of the 277 respondents who have tried, 144 (52%) were males whilst 133 (48%) were females. The women farmers employed men to spray agrochemicals on their farms. Few of these men were family members and were more often youths who work as service providers in the communities as by-day labourers, rendering their services for a fee. The youths charge a fee of between Ghana Cedis (GHS) 10 and GHS25 (€2.50 to €4.00) per acre, depending on the distance to the field and their ability to negotiate with the farmer. There are occasions when the sprayers charge for both providing the chemicals and the spraying labour. This costs between GHS30 and GHS50 (€4.75 to €7.91) per acre, depending on the type of chemical, and again, client negotiations.

The majority of farmers (83.7%) used synthetic agrochemicals, whilst 20.3% and 14.9% used local mixtures and plant extracts, respectively, to control FAW. It is worth noting that only a few farmers used IPM to control FAW.

6.2 Preferred farmer options for pest and disease control in the study area

Data in Appendix 1 presents detailed results of the farmers' preferred options for the control of FAW. In general, 180 (59.8%) farmers preferred the synthetic control option followed by cultural control 87 (28.9%), bio-pesticides 13 (4.3%), biological 15 (5.0%), cocktail/mixtures 11 (3.7%), and IPM 4 (1.3%). The mean results of the data were categorised on a scale of one-six, with one indicating the most preferred option, and six the least preferred. The synthetic control option recorded the lowest mean (mean = 1.61, standard deviation (SD) = 0.95), whilst IPM recorded the highest mean (mean = 5.78, SD = 0.81).

The Friedman rank test (Appendix 2) confirmed that farmers preferred the synthetic control option in their localities for the control of FAW (mean ranked = 1.62).

The study results also showed that there is a significant difference between the farmers' preference of synthetic FAW control and that of cultural, bio-pesticides, biological, cocktail/mixtures and IPM control options – at 0.05 alpha level (χ^2 = 958.63, degrees of freedom (df) = 5 and significance = 0.00). This confirms the finding that farmers prefer synthetic pesticide FAW control options over other control methods.

The Wilcoxon signed rank test (Appendix 3) revealed that there is a negative significant difference between the farmers' preferred choice of synthetic control and all the other control methods, at 0.05 alpha level. This result implies that at all times, the farmers will prefer synthetic FAW control over cultural, bio-pesticides, biological, cocktail and IPM control methods.

6.3 Farmers' perceptions on the use of drone-applied pesticides for FAW control

The findings show that only 26 (17.9%) out of the 145 farmers who participated in the first field day were aware of drone technology. Of the 26 farmers, 61.5% of them had seen or heard about drone technology for spraying agrochemicals; 46.2% knew about drone technology for taking pictures, and 42.3% for film making. Others were also aware of drone technology being used for monitoring and security surveillance in the sectors of oil, gas and mineral explorations, medical supplies, and land surveying and remote sensing. The results further revealed that the farmers became aware through TV (38.5%), attending ceremonies such as weddings, festivals and funerals where drones were used (34.6%), and through security agencies using the technology for activities in the area (26.9%). Only four (2.8%) of the farmers had participated in an agricultural programme where drone technology had been used, highlighting that most were experiencing drone technology application for the first time (97.2%). The four farmers had participated in programmes organised by non-governmental organisations, the Department of Agriculture under the MoFA and research institutions.

The farmers' descriptions of the spraying drone were also surveyed. The findings indicate that after watching the spraying video during the field day, the farmers recognised that the drone carries a tank/container to store pesticides (100%), nozzles for discharging the pesticides on the field (99.3%), propellers/wings to fly over the field (96.6%), stands/legs to land safely (95.2%), and that the drone is remotely controlled (92.2%).

The study results also reveal that, in general, the farmers rated the benefits of drone technology for FAW control to be very high (composite mean = 7.57, SD = 1.86) (Appendix 4). The six top benefits of the drone technology, as perceived by the farmers after watching the video, are as follows: it saves time, makes pesticide application easier, requires less labour, enhances pesticide application effectiveness, is superior to other pesticide application methods known to the farmers and reduces the negative impact of pesticides on the environment.

6.4 Comparison of the costs and benefits of the farmers' practice (knapsack) and the drone technology in applying pesticide for FAW control, from the farmers' perspective

Farmers' perceptions on the benefits of the drone sprayers for FAW control were analysed in terms of the efficiency of the technology, its performance, ease of use, consistency with current FAW control practice, flexibility in its use, consistency with farmers' needs to control FAW, and reliability to deliver additional benefits to the knapsack sprayer control method. Farmers perceived the cost of using the drone, in terms of the amount of capital required for the equipment, the service cost for pesticide application, maintenance costs and the costs associated with acquiring the skills and knowledge needed to operate the drone sprayer, to be higher than costs associated with the knapsack sprayer (Appendix 5). Further, the farmers considered that the benefits of the knapsack sprayer were greater than those of the drone in terms of equipment and labour availability, affordability, and availability of support systems in their communities.

On the other hand, the farmers stated that the costs of using the knapsack sprayer for FAW control are higher than those of the drone technology in terms of energy exertion during pesticide application – especially when considering the weightiness of the equipment – safety risks to the health of the sprayer, duration of time taken to apply the pesticides per plot, and frequency of pesticide spillages (Appendix 6).

6.5 Farmers' willingness to pay for the drone service to control FAW

The results of the study show that most of the farmers (94.7%) in the study area are willing to pay for the drone technology services to control FAW. Of the farmers (94.7%) who are willing to pay for drone-based spraying services, there was a negligible difference between gender in favour of men (man 95.6%, women 93.4%) (Appendix 7).

A total of 144 farmers were willing to pay a minimum of GHS5/acre (€0.75/acre), and a maximum of GHS60/acre (€9.5/acre) for the drone application of pesticides to control FAW. The study also revealed that at least 8 out of every 10 farmers (83.4%) were willing to pay between GHS10/acre (€1.58/acre) and GHS39/acre (€6.16/acre). The mean amount the farmers were willing to pay was GHS19.43/acre (€9.4/acre) with an SD of GHS12.28/acre (€1.94/acre). This does not include the cost of the chemicals applied. The chemical should be provided by the farmer; however, the drone service provider can also provide the chemicals for spraying at an additional cost.

The farmers were asked the maximum amount they were willing to pay for the drone services in controlling FAW. The results show that the minimum and maximum amounts the farmers were willing to pay were GHS5 (€0.75) and GHS70 (€11.06) per acre, respectively. More than two thirds (68.8%) of the farmers were willing to pay a maximum of between GHS20 (€3.16) and GHS70 (€11.06) per acre for the drone FAW control service. The mean maximum amount the farmers were willing to pay was GHS25 (€3.95) per acre with an SD of GHS15.11 (€2.37) per acre. There is a significant difference between the amount farmers want to pay and the maximum amount they are willing to pay for an acre of drone spraying services in the study area ($t = 9.57$, $df = 151$, $p = 0.00$).

A test of significance was computed between the amount farmers were willing to pay per acre for the drone spraying services and the amount charged by drone service provider Acquahmeyer (Appendix 11). The mean amount the farmers were willing to pay was GHS20.50 (€3.32) per acre, which is 57.37% less than the amount charged by Acquahmeyer at GHS45.58 (€7.38). The result of the one-sample t-test shows that there is a significant difference ($t = 25.717$, $df = 143$, $p = 0.00$) between the mean maximum amount the farmers are willing to pay for the drone per acre, and the amount charged by the drone service provider. The mean maximum amount the farmers are willing to pay for the drone spraying service is GHS26.90 (€4.36) per acre, which is 40.98% less than the amount charged by the drone service provider. The result of the one-sample t-test also indicates that there is a significant difference ($t = 15.752$, $df = 143$, $p = 0.00$) between the amount farmers are willing to pay and the amount charged by the drone service provider.

The main reason (57.2%) the farmers are willing to pay the Acquahmeyer fee is that they would not have sufficient resources at their disposal for subsequent production activities without using the drone services to tackle FAW infestation. The other reasons provided for paying the said amount include speed of the drone (15.8%), effectiveness (14.5%), reduced labour (8.6%) and increased safety (3.9%).

6.6 Factors associated with the propensity of farmers to adopt drone-applied pesticide to control FAW

(i) Farmers' acceptance of drone technology for FAW control

To explain the attitude of farmers towards accepting and making use of drone services for controlling FAW in the study area, the TAM 3, formulated by Venkatesh and Bala (2008), was used (Appendix 8). The TAM 3 construct included perceived usefulness, perceived ease of use, computer self-efficacy, perception of external control, computer playfulness, computer anxiety and perceived enjoyment. The other model variables are subjective norms, voluntariness, image, job relevance, output quality, result demonstrability, attitude towards use and behavioural intention.

1) The results of the study show that, on a scale of 1 to 10, the five variables most highly rated by the farmers for drone-applied pesticide in FAW control are perceived enjoyment (mean = 7.60, SD = 1.65), perceived ease of use (mean = 7.51, SD = 1.51), computer self-efficacy (mean = 7.50, SD = 1.83), perceived usefulness (mean = 7.48, SD = 1.61) and subjective norms (mean = 7.42, SD = 1.57).

2) The variables that were rated least highly by the farmers are perception of external control (mean = 7.17, SD = 1.55), computer playfulness (mean = 7.17, SD = 1.91) and computer anxiety (mean = 6.69, SD =2.16).

(ii) Behavioural intention of the farmers to use drone technology for FAW control

The Davis convention for describing the magnitude of correlation coefficients was used to interpret the result of the correlation between the behavioural intention of the farmers to use drone technology for FAW control, and the related variables (Appendix 9).

1) The results show that there is a positive and very high correlation between the behavioural intention of farmers to use drone technology for FAW control, and attitude towards its use (r = 0.762, p = 0.00), and perceived usefulness (r = 0.717, p = 0.00) of the drone technology, at 0.01 alpha level. The results imply that the positive attitudes of farmers towards the use of drones, and perceptions of usefulness of the drone technology, could increase their behavioural intention to use drones for FAW control.

2) Also, there is a positive and substantial relationship between behavioural intention to use drone-based spraying services for FAW control and computer anxiety (r = 0.688, p = 0.00), result demonstrability (r = 0.661, p = 0.00), perceived ease of use (r = 0.653, p = 0.00), computer self-efficacy (r = 0.647, p = 0.00), perceived enjoyment (r = 0.598, p = 0.00), subjective norms (r = 0.590, p = 0.00), output quality (r = 0.588, p = 0.00), image (r = 0.579, p = 0.00), computer playfulness (r = 0.572, p = 0.00), perception of external control (r = 0.565, p = 0.00) and job relevance (r = 0.564), at 0.01 alpha level. In other words, the behavioural intention of farmers to use drone technology for FAW control improves with increasing perceived ease of use of the technology, self-efficacy, result demonstrability, perception of external control, playfulness, enjoyment, output quality, subjective norms, image, and job relevance. The anxiety construct indicates that farmers who were neither scared, nervous, uncomfortable, nor uneasy in using technology, tend to have a high propensity towards the adoption of drone services for FAW control.

3) Furthermore, there is a positive but moderate association between behavioural intention of farmers to use drone technology for FAW control and their voluntariness (r = 0.480, p = 0.00) to use the digital technology, at 0.01 alpha level. This implies with increasing voluntariness to use digital technology, behavioural intention to use drone technology for FAW control is also improved.

(iii) Best predictors of farmers' behavioural intentions to use drone technology in FAW control

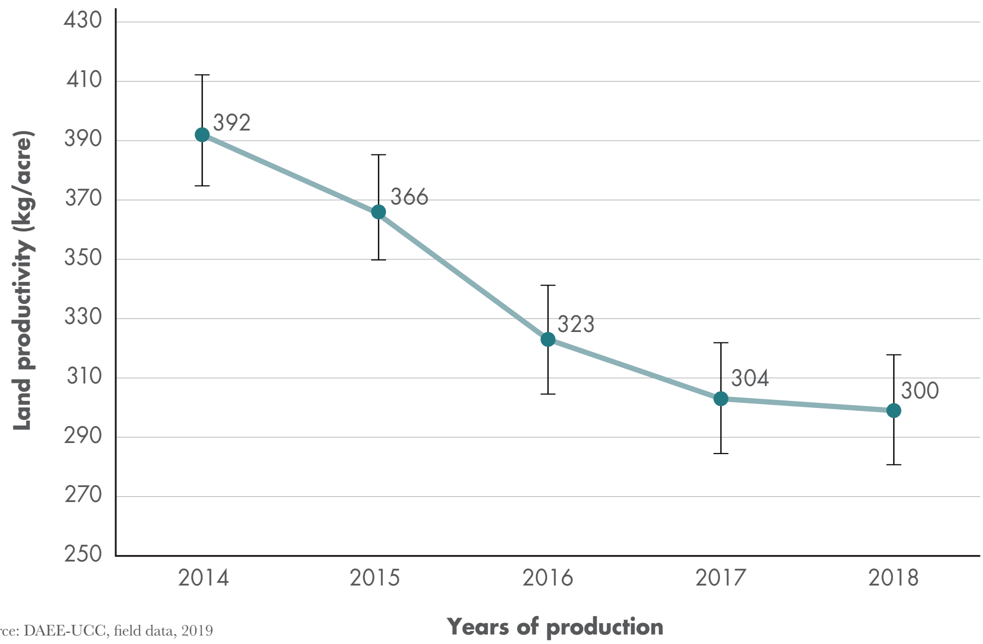
1) The results of a stepwise regression of the farmers' behavioural intention to use drone technology for FAW control, with related predictor variables, is presented in Appendix 10. The adjusted R-square value for the behavioural intention of the farmers to use drone technology for FAW control in the study area is 0.748, indicating that about 75% of variations in farmers' behavioural intention to use drone technology for FAW control is explained by their attitude towards use of the digital technology (58.1%), result demonstrability (9.9%), perceived usefulness (5.9%), perceived enjoyment (1.1%) and voluntariness (0.8%). The negative beta coefficient of X4 and X5 indicates that every unit standard increase in the perceived enjoyment and voluntariness is expected to result in a (-0.15 and -0.12) standard change in behavioural intention of the farmers in the study area. The analysis of variance test of the regression model was significant at alpha level 0.05, which indicates that the variables in the model significantly explained the composite effect of the farmers' behavioural intention to use drone technology for FAW control in Northern Ghana.

6.7 Economics of drone-applied pesticide in the field, and economic efficiency of the experimental and control plots for drone-applied pesticide in FAW control

6.7.1 Effects of FAW on productivity

There has been a gradual reduction in productivity in terms of yield per land area for the past five years in Northern Ghana. This has mostly been attributed to FAW invasion and the inability of farmers to effectively control this invasive species (Figure 7). Mean yields per acre since 2014, and especially those after the incidence of FAW since 2016, have been less than 50% of the national average.

Figure 7: Annual productivity trend of maize (kg/acre) in the study area 2014–2018



Source: DAEE-UCC, field data, 2019

Differences in cropping season productivity during the past 5 years

Results of the yearly paired samples statistics of mean annual productivity of maize among the respondents are presented in Table 4. The results show that the mean yield of maize per acre of land in the study sites was 392.03 kg in 2014, and 366.20 kg in 2015. The annual land productivity of maize in 2016, 2017 and 2018 were 323 kg/acre, 303.93 kg/acre and 299.89 kg/acre, respectively. There were high SDs across the years, indicating wide variations in productivity within the years at the various study sites.

A dependent sampled t-test statistic revealed that the mean annual productivity of maize in 2014 was significantly higher than all other estimates from 2015 to 2018. The result further indicates that the annual productivity of maize in 2015 was significantly different to that of 2016, 2017 and 2018. There were however no significant differences between the annual productivity of 2016, 2017 and 2018. This result implies that although there was a reduction in the productivity of maize from 2014 to 2018, the reduction from 2016 to 2018 was not significant. It should be noted that the first incidence of FAW was reported in 2016 and has become more widespread since then. This could be one of the factors accounting for the significant fall in productivity since 2016.

Table 4: Dependent sampled t-test for maize productivity from 2014 to 2018

Years	Mean	N	SD
2014	392.03a	210	229.23463
2015	366.20b	210	226.51938
2016	323.20c	215	193.25638
2017	303.93c	217	181.45696
2018	299.89c	217	199.27831

Source: DAEE-UCC, field data, 2019

a, b and c indicate that there is a significant difference in the means

Composite economic indicators of the three treatments in all districts

The results of the study on the composite economic indicators of the treatments in the study sites are presented in Table 5. The results show that the total mean variable cost for the treatments in the three districts was GHS493/acre (€79.79) (SD = GHS104.85 or €16.97); the total mean cost was GHS704.11/acre (€113.96) (SD = GHS104.02 or €16.84); and the total mean revenue was GHS2,184.68/acre (€353.59) (SD = GHS1,364 or €220.76). Also, the total mean gross margin for the three treatments from the three sites was GHS1,691.2/acre (€273.69) (SD = GHS1,309.67 or €211.86), whilst the mean benefit-cost ratio was GHS3.09/acre (€0.50) (SD = GHS1.92 or €0.31).

The results indicate that there was no significant difference between the three treatments (control, drone and knapsack plots) on the five economic indicators employed in the analysis i.e. total variable costs, total cost, total revenue, gross margin and benefit-cost ratio. Thus, the findings indicate that the total variable cost of the control plot was not significantly different from that of the drone and knapsack plots. Similar findings can be reported on the total cost, total revenue, gross margin and benefit-cost ratio. However, there were wide variations among the study sites considering the SDs of the corresponding mean values of all the indicators in the three areas. The study therefore went further to segregate the results within the various sites for any significant differences; the findings of which are presented in Table 6.

Table 5: Composite economic indicators of the three treatments in all districts

Economic indicators	Treatments	N	Mean (GHS)	SD	Std. error	F	Sig.
Total variable cost	Control	3	429.37	19.67	11.36	.804	.491
	Drone	3	523.37	126.93	73.29		
	Knapsack	3	527.97	134.85	77.86		
	Total	9	493.57	104.85	34.95		
Total cost	Control	3	614.34	31.00	17.90	2.031	.212
	Drone	3	746.70	109.77	63.38		
	Knapsack	3	751.30	117.48	67.83		
	Total	9	704.11	106.02	35.34		
Total revenue	Control	3	1825.58	1300.97	751.11	.211	.816
	Drone	3	2621.72	1946.13	1123.60		
	Knapsack	3	2106.75	1216.33	702.24		
	Total	9	2184.68	1364.59	454.86		
Gross margin	Control	3	1396.51	1282.43	740.41	.185	.836
	Drone	3	2098.35	1874.14	1082.03		
	Knapsack	3	1578.78	1142.80	659.80		
	Total	9	1691.21	1309.67	436.56		
Benefit-cost ratio	Control	3	3.16	2.48	1.43	.068	.935
	Drone	3	3.38	2.48	1.43		
	Knapsack	3	2.73	1.48	.86		
	Total	9	3.09	1.92	.64		

Source: DAEE-UCC, field data, 2019

Differences in the economic indicators of Kukua, Nyankpala and Salankpang districts

The economic indicators of the three locations are presented in Table 6. It should be noted that within all the economic indicators considered, the Salankpang site figures were the lowest. This is due to lapses in the application of agronomic practices which affected output from the plots.

The results show that there was no significant difference between the total mean variable cost of the Kukua plot and the Nyankpala plot, or between the Nyankpala plot and the Salankpang plot. In terms of the total mean cost at all three locations, no significant difference was found. The results of the total mean revenue from the three locations indicate no significant difference between the Kukua and Nyankpala plots. However, there was a significant difference in the gross revenue when comparing Kukua and Nyankpala with the Salankpang plots. A similar result was found in the gross margins – no significant difference was found between Kukua and Nyankpala, while Salankpang had a significantly lower gross margin than the other two sites.

For the benefit-cost ratio, Nyankpala was significantly higher than Kukua, which was also significantly higher than Salankpang. The Nyankpala site was very close to where the researchers were based in the field, and thus, those attending the plots likely carried out adequate crop husbandry in Nyankpala. Less care was potentially provided to the Kukua and Salankpang plots, which are located further from the staff's place of residence.

Table 6: Economic analysis of the fields in the three locations

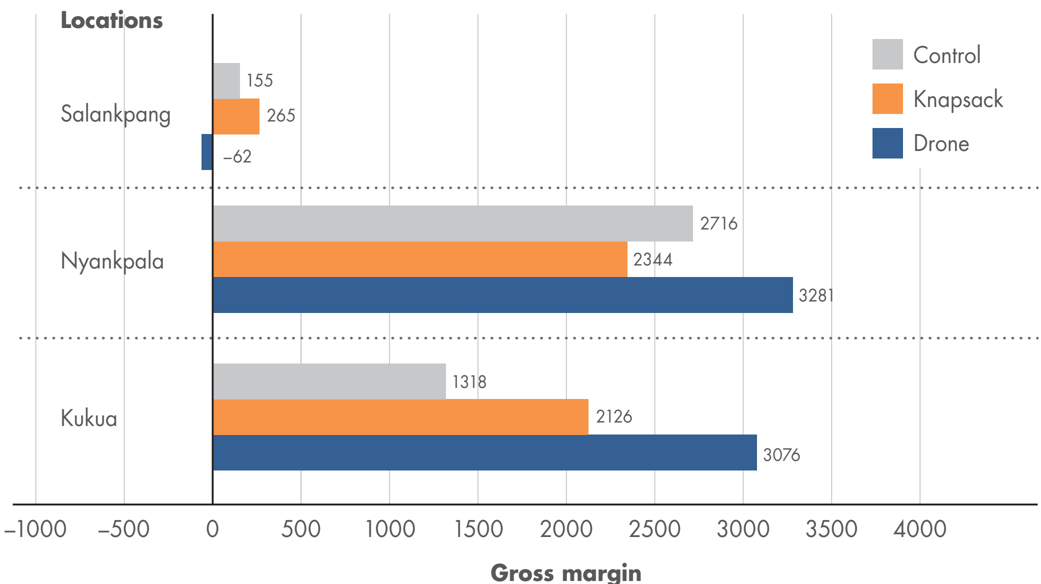
Economic indicators	Locations	N	Mean (GHS)	SD	Std. error	F	Sig.
Total variable cost	Walewale	3	596.37a	138.10	79.73	3.763	.087
	Nyankpala	3	457.33ab	11.55	6.67		
	Mion	3	427.00b	17.32	10.00		
	Total	9	493.57	104.85	34.95		
Total cost	Walewale	3	796.34a	138.16	79.77	2.297	.182
	Nyankpala	3	669.00a	77.94	45.00		
	Mion	3	647.00a	17.32	10.00		
	Total	9	704.11	106.02	35.34		
Total revenue	Walewale	3	2769.98a	995.42	574.71	14.997	.005
	Nyankpala	3	3238.14a	473.02	273.10		
	Mion	3	545.93b	164.38	94.90		
	Total	9	2184.68	1364.59	454.86		
Gross margin	Walewale	3	2173.64a	879.76	507.93	17.098	.003
	Nyankpala	3	2780.81a	471.51	272.22		
	Mion	3	119.19b	166.74	96.27		
	Total	9	1691.21	1309.67	436.56		
Benefit-cost ratio	Walewale	3	3.42b	.80	.46	24.091	.001
	Nyankpala	3	5.00a	.97	.56		
	Mion	3	.85c	.25	.12		
	Total	9	3.09	1.92	.64		

Gross output margin from the experimental plots in all three locations

The gross output margin results from the experimental plots in the three districts are presented in Figure 8. The results show that Nyankpala's experimental plots produced the highest gross margin followed by Kukua and Salankpang. Results from the drone plots show the gross margin for Nyankpala and Kukua (GHS3,281.32/€531.0, and GHS3,076.21/€497.88, respectively) were higher than those of the knapsack and control plots in these locations. However, the results from the Salankpang drone plot was GHS62.47 (€10). This finding is attributed to the poor maintenance of all the experimental plots in Salankpang. The weeds which had overgrown the maize crops are likely to have affected yields across all the plots. The technicians at SARI explained that because of the severe drought just after the maize had tasselled, controlling the weeds would have stressed the crops further.

It is worth noting that at Nyankpala, the control plot had a higher gross margin (GHS2,716.1/€439.6) than the farmer practice field (GHS2,344.99/€ 379.54), indicating that crop performance is better without knapsack pesticide application if crop husbandry is adequate. The results of the analysis as presented in Figure 8 show that in the cases of Kukua and Nyankpala, drone spraying resulted in the highest gross margin when compared to knapsack spraying and no pest control at all. On the other hand, in Salankpang, where the crops were affected by poor crop husbandry and extreme dry weather conditions, the higher investment for drone-based spraying resulted in a negative gross margin, and a minimal incremental margin of knapsack spraying versus no pest control at all.

Figure 8: Yield gross margin from experimental plots in the three locations



Source: DAEE-UCC, field data, 2019

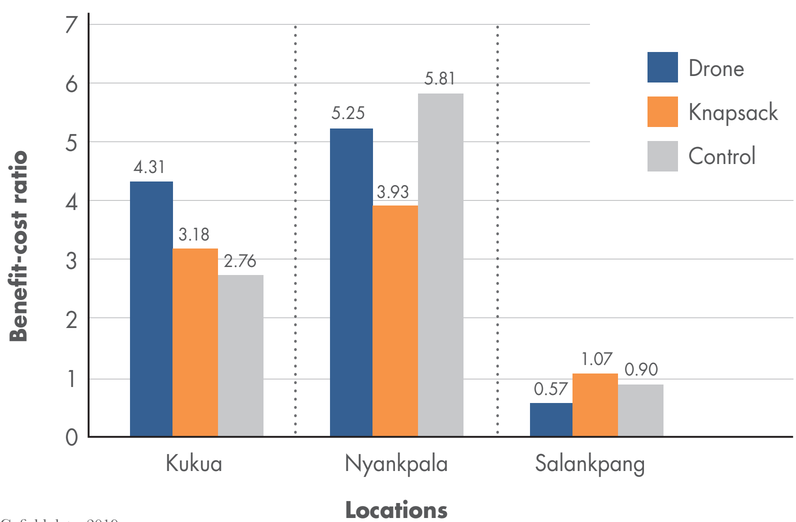
Benefit-cost ratio of the three treatments across the three locations

Figure 9 presents the results of the study on the benefit-cost ratio calculated as detailed in Appendix 12. The results show that Nyankpala had the highest benefit-cost ratio of all three treatments followed by Kukua and Salankpang. The benefit-cost ratio for all the plots in the three different locations, apart from the drone and control plots in Salankpang, were more than one. This indicates that the present value of the benefits is better than the present value of the costs. At the Nyankpala location, the control plot had the highest benefit-cost ratio (5.81), followed by the drone plot (5.25), and the knapsack plot (3.93). The results imply that if a Nyankpala farmer invests €1 to control FAW through the use of drone or knapsack, he/she will make a return of €5.25 or €3.93 respectively. At Kukua, results indicate that the benefit-cost ratio was highest for the drone plot at 4.31 followed by the knapsack at 3.18 and then the control at 2.76. The results imply that if a farmer invests €1 to control the invasive species, he/she will gain a return of €4.31 from the drone and €3.18 from the knapsack.

The Salankpang results indicated that the knapsack field showed the highest benefit-cost ratio at 1.07 (although it is not significantly different from 1), followed by the control at 0.90 and then the drone plot at 0.57. The low benefit-cost values achieved from the Salankpang experimental plots were due to the extreme weather conditions of severe droughts in addition to poor maintenance of the experimental plots by the SARI technicians. Having a benefit-cost ratio of approximately equal to one indicates that the present value of benefits is equal to the present value of costs. For a project with benefit cost ratio equal to one, you can expect that the project would neither generate any profit nor would run under any losses.

The result of the benefit-cost ratio for the Nyankpala plot was significantly different from the results of both Kukua and Salankpang. There was also a significant difference between the Kukua plot and the Salankpang plot. The results imply that farmers are likely to make more return on their investments in Nyankpala than farmers in Kukua and Salankpang. Since the benefit-cost ratios at Salankpang are not significantly different from 1, such investments at this community are not advisable. However, investing in maize production enterprise in this area will mean that all the good agronomic practices must be strictly adhered to, more especially in timely weeding of the plots.

Figure 9: Benefit-cost ratio of the three treatments at the three locations



Source: DAEE-UCC, field data, 2019

7. Summary of key findings

The following summaries were made based on the results of the study.

Summary

1. Farmers have appreciable knowledge of FAW and could correctly describe the morphology of the insect. The local name given to the FAW, *Zunzuya*, is indicative of the inability to separate this invasive species from other worms, however, farmers were able to differentiate the feeding behaviour and destructive nature of FAW from other pests. Farmers reported that the invasion of FAW started in 2016. The destruction is especially devastating on the pre-tasselling stage (vegetative stage), which occurs between June and July.

2. Farmers mostly used synthetic pesticides compared to other control options such as the use of cultural practices, bio-pesticides, biological control methods, and cocktails of chemical mixtures, but they do not employ IPM to control FAW. Most farmers have experienced FAW invasion, with some losing everything on the farm within 3 to 21 days of attack if the pests were not controlled.

3. Most male farmers have attempted to control FAW on their farms. Female farmers tended to employ local youths to spray agrochemicals on their farms at a cost of between GHS10 (€1.62) to GHS25 (€4.05) per acre of farm land.

4. Generally, the farmers prefer the use of synthetic pesticides as control methods, followed by cultural, bio-pesticides, biological, cocktail mixtures and IPM, in that order. At all times, farmers will opt for synthetic chemical control methods over other options.

5. Few farmers were aware of the use of drone technology in agriculture prior to their participation in the study. The few who were aware had seen the application of drones in monitoring and security, and for other sectors such as oil and gas and mineral explorations, medical supplies, land surveying and remote sensing. TV programmes and attendance to various agricultural projects and ceremonies such as weddings, festivals and funerals were major sources of farmers' drone awareness.

6. After watching a drone spraying video during the project's field days, all the participating farmers could accurately describe the various parts of the drone, and what they can be used for during the spraying process.

7. The farmers perceived time saving, ease of pesticide application, reduced labour, and enhanced pesticide application effectivity to be the key benefits of drone technology in FAW control.

8. Farmers' perceptions on the benefits of the drone and knapsack sprayer in FAW control in terms of efficiency were compared in the study area. The drone technology was rated highly in terms of its performance, ease of use, flexibility in the handling of drone, consistency with the farmers' FAW control needs and its reliability. In all cases, the drone outperformed the knapsack sprayer, relative to the perceived benefits. Farmers perceived the drone costs for FAW control to be higher than that of the knapsack sprayer. Further, in terms of availability (labour and equipment), affordability and local support systems, the knapsack sprayer was perceived to have advantages over the drone.

9. Farmers perceived the costs of the knapsack sprayer to be higher than those of the drone technology in terms of the energy exerted during pesticide application, the effect of the equipment weight on the operator, riskiness (safety) to the health of the operator, the time taken for pesticide application per plot, and occurrence of pesticide spillage during spraying.

10. The study results reveal that most of the farmers (94.7%) were willing to pay for the drone FAW control services in the study area. There was a negligible difference between genders in their willingness to pay for the drone-based spraying services, slightly favouring men (men 95.6%, women 93.4%) The farmers are willing to pay a minimum of GHS5 (€0.81) and a maximum of GHS60 (€9.71) for the drone-based pesticide application service per acre of land. The majority of farmers are willing to pay between GHS10 (€1.62) and GHS39 (€6.31), with an average of GHS19.43 (€3.14). More than two thirds (68.8%) of the farmers are willing to pay a maximum amount of between GHS20 (€3.24) and (GHS70 (€11.33) per acre for the drone pesticide service. Farmers are willing to pay the said amount because they perceive that such investment will result in higher returns, allowing them to invest such resources into other essential farming practices. Other factors that contributed to their willingness include the speed of the drone, its effectiveness and less laborious nature, and the perceived health and safety benefits of using the drones.

11. The factors that determine farmers' intention to accept and use drones for FAW control in the study area are: perceived enjoyment, ease of use, self-efficacy, usefulness and subjective norms of the drone technology for pesticide spraying. Perceived external control, computer playfulness and computer anxiety were the least important considerations in determining behavioural intention to use the drones.

12. Positive farmer attitudes towards the use of drones and their perceived usefulness of the technology could increase their behavioural intention to use the digital technology for the control of FAW.

13. The behavioural intention of farmers to use drone technology in FAW control improves with increasing perceived ease of use of the technology, self-efficacy, result demonstrability, perception of external control, playfulness, enjoyment, output quality, subjective norms, image, and job relevance. Those farmers who were neither scared, nervous, uncomfortable, nor uneasy about the technology tended to have higher propensities to adopt the drone services for FAW control. Furthermore, as the farmers' voluntariness to use the digital technology increases, their behavioural intention to use the technology for FAW control also increases.

14. Annual maize productivity in the study areas has significantly reduced since the first incidence of FAW in 2016.

15. Results from the experimental plots indicate that pesticide application to control FAW shows a higher competitive advantage over not applying pesticides. However, this benefit was not significantly different when considering the use of knapsack spraying when compared to no pesticide application. Thus, with proper agronomic practices, farmers in the study areas could benefit more from the use of modern technologies, including drones, over traditional knapsack spraying for FAW control.

8. Conclusions

The following conclusions were made based on the results of the study:

1. Farmers are aware of FAW and its capacity to destroy maize farms if not controlled.

2. Farmers preferred synthetic pesticides compared to other options and never employ IPM to control FAW; and will use the synthetic control of FAW at the expense of all other methods.

3. Male farmers tend to personally control FAW on their farms whilst female farmers employ the services of youths to spray agrochemicals on their farms at a cost of between GHS10 (€1.62) and GHS25 (€4.05).

4. Few farmers were aware of the use of drone technology in agriculture prior to their participation in this study.

5. Farmers could describe parts of the drones and their operation after watching a video of drone spraying during one of the field days.

6. The farmers perceived high benefits of drone technology use in the control of FAW.

7. The farmers considered the drone's efficiency, its performance, ease of use, consistency with FAW control practice, manipulation flexibility, consistency with farmers' FAW control needs and its reliability, to outperform the benefits of the knapsack sprayer.

8. Farmers perceived the financial costs of using the drone for FAW control to be relatively higher than those of the knapsack sprayer. However, in terms of other costs such as its laborious nature, the time involved in spraying, energy exertion, health and safety, and pesticide spillages, use of the knapsack sprayer was perceived to incur higher costs when compared to the drone technology.

9. Farmers are willing to pay for drone technology services for FAW control in the study area because of its speed, effectiveness, less laborious nature and perceived safety. The farmers are however concerned about their limited resources, which can serve as a barrier to acquiring the drone services.

10. Enjoyment, ease of use, self-efficacy, usefulness and subjective norms of drone technology for pesticide spraying are key factors that determine farmers' intention to accept and use drones for FAW control in the study area.

11. Farmers have positive attitudes towards the use and perceived usefulness of the drone technology; this could increase their behavioural intention to use the digital technology for the control of FAW.

12. The intention of farmers to use drone technology for FAW control improves with increasing perceived ease of use of the technology, self-efficacy, result demonstrability, perception of external control, playfulness,

enjoyment, output quality, subjective norms, image, and job relevance. Also, farmers who were neither scared, nervous, uncomfortable, nor uneasy in using the technology tended to have a higher propensity towards adoption of drone services for FAW control.

13. The farmers' voluntariness to use digital technology increases their behavioural intention to use drones for FAW control in the study area.

14. Annual productivity of maize in the study areas has significantly reduced since the first incidence of FAW in 2016.

15. With proper agronomic practices, farmers in the study areas could benefit more from the use of modern technologies, including drone usage, for FAW control.

8.1 Recommendations

Based on the results and the conclusions of the study, the following recommendations are made:

1. Farmers are aware of the presence of FAW in the study area because it is affecting every farm. Since FAW was first detected in Ghana in 2016, it has been pervasive in the study districts. Therefore, any effective information and strategies to control FAW will be accepted by farmers because if left uncontrolled or not properly managed, FAW infestations can lead to huge yield losses with implications for food security and livelihood sustainability. The approach adopted by the Government of Ghana is to provide free pesticides to farmers through the agricultural departments. However, the pesticides are inadequate in most cases, and the farmers are expected to purchase them using their own resources, which rarely happens due to the expense. The study recommends a concerted, holistic effort that cuts across all districts at the same time, such as mass pesticide spraying to reduce the FAW numbers and crop effects. The use of drones and appropriate pesticide for spraying could help reduce the levels of devastation.

2. Farmers mainly controlled FAW with agrochemicals, and in some cases local mixtures and/or bio-pesticides, but never IPM. They prefer synthetic pesticides to control FAW compared to other options such as cultural practices, use of bio-pesticides, biological control methods, chemical mixtures and IPM. Bayer should double its efforts to release the synthetic agrochemical used in this study since results have already shown that it is efficacious. Farmers in the experimental districts should be educated by agents of the various agricultural departments on the use of appropriate PPE whenever they use agrochemicals in the field. Additionally, the use of IPM in FAW control should be introduced and encouraged since it has proven to be an effective and sustainable pest control method. The field level extension agents of the Department of Agriculture should educate farmers on this.

3. Farmers witnessed the speed, efficiency and effectiveness of drone technology for FAW control at the experimental plot and the video demonstration. The interest of farmers in use of the technology remains very high. The Department of Agriculture, Acquahmayer Drone Technology Ltd and/or other relevant service providers should sustain their interest and turn farmers' aspirations into reality by ensuring that the drone services are made available for use at individual farms. These stakeholders should also look to extend these drone services within the agricultural sector and beyond FAW control, i.e. for activities such as crop health monitoring, yield estimation and soil analysis at farmers' fields. DAEE-UCC should partner with Acquahmayer Drone Technology Ltd to train agricultural graduates and set them up in the districts with funding from the government or other sources to make the drone services available in all districts of Ghana.

4. Prior to this study, only one out of every five farmers had seen or heard about the application of drone technology in picture taking, film making, security monitoring in the oil, gas and mineral explorations sectors, medical supply delivery, land surveying, remote sensing, and for spraying agrochemicals. Although the farmers had limited knowledge prior to the study, they were very observant and could describe the drone operation and parts of the spraying drone, such as propellers/wings, the tank/container, discharging nozzles and the remote control used by the pilot. This implies that they would respond well and retain information provided in drone use training. Drone service providers can fashion training courses in the local area to assist farmers with drone use.

5. Farmers have attested to the increased benefits of drone technology in FAW control when compared to knapsack spraying. The farmers had indicated that the drone could apply pesticides precisely to kill the FAW caterpillar easily, at speed, and with little or no chemical wastage, making drone use effective, simple and efficient. The perceived benefits are likely to lead to high technology adoption rates if the conducive conditions are put in place for drone use. The study recommends that development partners provide subsidy provisions for farmers to access drone services in each of the sub-districts.

6. Farmers felt the knapsack technology was more affordable and available, but that it required higher energy exertion when carrying and operating the equipment. They considered the knapsack to be riskier in relation to chemical spillages on the farmer, and to be more time consuming than drone use. However, the farmers had not physically experienced operating the drones themselves, and therefore did not necessarily have all the information required to make a final judgement on the most suitable technology for them. Training and demonstration sessions should be held with farmers by would-be drone service providers to convey all the necessary facts about drone technology usage, enabling the farmers to make an informed decision about which technology better suits their needs.

7. The cost-benefit comparative analysis of drone and knapsack technologies indicates the drone to be less costly in the long run. This message needs to get to farmers to enable them to make informed investment decisions. Again, training and demonstration sessions should be held with farmers to provide them with all the facts about drone technology benefits to sustain their interest for possible adoption.

8. There were wide productivity variations between the study sites over the years, attributed to FAW invasions. There is therefore the need to control FAW to reverse the downward productivity trend in the study areas. This could be done by employing modern technologies such as drone services in controlling the invasive species.

9. The returns on investments were different across the study districts for the knapsack and drone technologies. Further, the results of the benefit-cost ratio of the Nyankpala plots were significantly different from the Kukua and Salankpang plots. There was also a significant difference between the Kukua plot and the Salankpang plot. The results imply that the farmers in Nyankpala are likely to achieve a higher return on their investments than the Kukua and Salankpang farmers. The good management practices adopted at the Nyankpala experimental plots, and the close proximity of Nyankpala to Tamale city where the research team was based, could account for this.

10. When aggregated, there were no significant differences in the economic efficiency indicator data (total variable costs, total cost, total revenue, gross margin and benefit-cost ratio) between the control, drone and knapsack plots across the three districts. The implication of this result is that it is not advisable to control FAW, which contradicts the expectations of the study. This result can be accounted for by the poor plot management carried out by SARI staff.

11. The behavioural intention of farmers to use drone technology in FAW control is predicted by five variables, namely: attitude towards use of the digital technology, result demonstrability, perceived usefulness, perceived enjoyment and voluntariness. The results imply that farmers with a positive attitude towards use of the drone technology have a higher behavioural intention to use drones for FAW control, provided the drone can demonstrate results that the farmers perceive as useful and enjoyable. Attitude towards use of the drone technology was found to be the best predictor of farmer behavioural intention to use drones for FAW control. Since the farmers have optimistic attitudes and perceptions about the demonstrable outcomes of using drones for FAW control, this presents a good opportunity to capitalise on making the services available to these farmers. Again, the study recommends that the agricultural departments and potential drone service providers facilitate access to the drone technology in the study areas where the farmers have a high behavioural intention to adopt the technology. This study will need to be shared widely among drone service providers and other relevant stakeholders to create awareness about the value and efficiency of using drones for FAW pesticide spraying, and to enhance agricultural productivity. The technology also needs to be showcased across the country as the best option for controlling the invasive species to convince all Ghanaian farmers to call for such services.

12. An overwhelming majority of the farmers (94.7%) are willing to pay for the drone services for FAW control in the study area. This presents very high prospects for the use of drones in this application. Putting measures in place to make the drone spraying services available and accessible to these farmers and others of similar situations will go a long way to reduce the negative FAW impacts on productivity and by extension, food security.

9. Limitations

The researchers would like to acknowledge several inherent study limitations that may have affected results and meant that the report could not be completed as expected:

1. There were issues with some of the experimental plots, due either to challenges from the weather or poor field management. Farmers observed that all the experimental plots were overgrown with weeds. Though the crops were matured and ready for harvesting, the farmers noted that the overgrown weeds impacted on the maize yield and admitted that the weeds affected their judgement on the impact of the drone and knapsack technologies, as well as that of the agrochemical applied. The lead SARI researcher had explained that the delayed rains, which set in after July, prevented them from controlling weeds since that could affect water content of maize on the plots.

2. Certain data was not made available to the researchers in time for them to carry out the necessary analyses to achieve some of the study objectives completely. For example, data on the rates of chemical application, labour and chemical savings as a result of drone application, as well as the killing capacity of the chemical used, time (labour) saving, yield per plot, farm size, labour costs, seed and seed types used, and cultural practices on the plots, were not made available.

10. References

Venkatesh, V. and Bala, H. (2008) Technology Acceptance Model 3 and a Research Agenda on Interventions. Decision Sciences, 39, No. 2. http://dx.doi.org/10.1111/j.1540-5915.2008.00192.x

11. Appendices

Appendix 1: Farmers' preferred options for the control of FAW

	1		2		3		4		5		6			
Control options	*Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Mean	SD
Synthetic control	180	59.80	84	27.90	21	7.00	7	2.30	8	2.70	1	0.30	1.61	0.95
Cultural control	87	28.90	108	35.90	40	13.30	36	12.00	22	7.30	8	2.70	2.41	1.35
Bio-pesticides	13	4.30	57	18.90	151	50.20	52	17.30	26	8.60	2	0.70	3.09	0.97
Biological control	15	5.00	21	7.00	35	11.60	167	55.50	62	20.60	1	0.30	3.81	1.01
Cocktail/mixtures	11	3.70	23	7.60	38	12.60	21	7.00	204	67.80	4	1.30	4.32	1.18
IPM	4	1.30	2	0.70	5	1.70	4	1.30	15	5.00	271	90.00	5.78	0.81

Source: DAEE-UCC, field data, 2019, n = 301, * Multiple responses. The means were estimated on a scale of 1–6, with 1 indicating the most preferred option, and 6 the least preferred.

Appendix 2: Friedman ranking test of farmers' preferred FAW control methods

Preferred control method	**Mean rank**	**χ^2**	**df**	**Asymp. sig***
Synthetic control	1.62	958.63	5	0.00
Cultural control	2.41			
Bio-pesticides	3.08			
Biological control	3.81			
Cocktail/mixtures	4.32			
IPM	5.77			

Source: DAEE-UCC, field data, 2019, n = 301, *$p < 0.05$

Appendix 3: Wilcoxon signed rank test of synthetic control and other control methods

Control methods	Z score	Asymp. sig *
Cultural control	-7.16	0.00
Bio-pesticides	-12.89	0.00
Biological control	-13.96	0.00
Cocktail/mixtures	-14.26	0.00
IPM	-15.19	0.00

Source: DAEE-UCC, field data, 2019, n = 301, *p < 0.05

Appendix 4: Farmers' perceived drone technology benefits after watching the drone video

Benefits of drone technology	Range	Min.	Max.	Mean	SD
The drone technology saves time	8	2	10	9.08	1.69
The drone technology makes pesticide application easier	9	1	10	9.03	1.63
The drone technology requires less labour	8	2	10	9.02	1.63
The drone technology enhances effectiveness of pesticide application	9	1	10	8.86	1.72
Drone technology is superior to other methods of pesticide application known to me	8	2	10	8.84	1.75
Drone technology reduces the negative impact of pesticides on the environment	9	1	10	8.81	1.75
The drone technology applies the exact quantity of pesticides	8	2	10	8.55	1.85
The drone technology fits well with the way pesticide is applied in my area	9	1	10	8.48	1.99
There is less chemical wastage in drone spraying	7	3	10	8.48	1.81
The drone technology applies pesticides to precisely kill the caterpillar stage of the FAW	10	0	10	8.32	2.19
The drone technology will not require a shift in farmers' behaviour in the application of pesticides to control FAW	10	0	10	8.19	2.36
Less pesticide is used in drone applications	10	0	10	8.08	2.27
The drone technology saves money	10	0	10	8.06	2.39
The drone technology will not require a shift in the belief of farmers in the application of pesticide for FAW control	10	0	10	7.92	2.51
The drone technology will not require a shift in the attitudes of farmers in the application of pesticide for FAW control	10	0	10	7.57	2.86
Composite mean	10	0	10	7.57	1.86

Source: DAEE-UCC, field data, 2019. n = 145

Appendix 5: Farmers' perception on the cost and benefits of drone technology after watching the drone video

Indicators	Range	Min.	Max.	Mean	SD
Efficiency of the equipment	10	0	10	8.50	2.23
Performance of the equipment	10	0	10	8.40	2.30
Ease of use of the equipment	10	0	10	8.32	2.64
Amount of capital for acquisition of equipment	10	0	10	8.14	2.44
Consistency with FAW control practice	10	0	10	8.01	2.49
Flexibility in the manipulation of the equipment	10	0	10	7.80	2.69
Consistency with the needs of farmers to control FAW	10	0	10	7.73	2.70
Reliability of the equipment	10	0	10	7.12	2.97
Cost of pesticide application services	10	0	10	6.85	2.91
Cost of maintenance	10	0	10	6.54	2.79
Skills needed to use the technology	10	0	10	6.25	3.34
Knowledge operating the equipment	10	0	10	5.84	3.26
Effect of weather on the use of the equipment (wind and rain)	10	0	10	4.95	3.20
Landscape/terrain of the fields	10	0	10	4.81	2.91
Bulkiness of the equipment	10	0	10	4.77	3.08
Affordability of the technology	10	0	10	4.38	2.99
Time duration of pesticide application per plot	9	1	10	4.35	3.14
Quantity of pesticide used	10	0	10	4.05	2.85
Drift (missing of targeted plants) during application	10	0	10	3.90	3.09
Availability of labour to use the technology	10	0	10	3.52	2.74
Availability of support systems to use the technology	10	0	10	3.47	2.52
Riskiness (safety) to the health of the sprayer	10	0	10	3.31	2.82
Spillage of pesticide during spraying	10	0	10	3.22	2.67
Exertion of energy in the process of application	10	0	10	3.07	2.35
Effect of weight of the equipment on the sprayer	10	0	10	2.95	2.39
Availability of the equipment	10	0	10	2.66	2.32
Composite mean	7.58	1.27	8.87	5.51	1.18

Source: DAEE-UCC, field data, 2019. n = 145

Appendix 6: Farmers' perception on the cost and benefits of the knapsack sprayer after watching the knapsack sprayer video

Indicators	Range	Min.	Max.	Mean	SD
Energy exertion in the process of application	9	1	10	8.64	1.88
Availability of the equipment	9	1	10	8.58	2.17
Effect of weight of the equipment on the sprayer	9	1	10	8.31	1.86
Riskiness (safety) to the health of the sprayer	9	1	10	8.10	2.24
Time duration pesticide application per plot	10	0	10	7.65	2.77
Spillage of pesticide during spraying	9	1	10	7.62	2.17
Availability of labour to use the technology	9	1	10	7.17	2.84
Affordability of the technology	10	0	10	7.06	3.02
Availability of support systems to use the technology	10	0	10	7.02	3.03
Quantity of pesticide used	10	0	10	6.68	2.55
Drift (missing of targeted plants) during application	9	1	10	6.55	2.68
Bulkiness of the equipment	10	0	10	6.51	3.07
Effect of weather on the use of the equipment (wind and rain)	10	0	10	5.84	2.75
Landscape/terrain of the fields	10	0	10	5.74	2.82
Consistency with the FAW control needs of farmers	10	0	10	5.36	2.95
Consistency with FAW control practice	10	0	10	5.18	3.03
Knowledge operating the equipment	10	0	10	5.12	3.04
Cost of pesticide application service	10	0	10	4.97	2.87
Reliability of the equipment	10	0	10	4.87	2.66
Cost of maintenance	10	0	10	4.82	2.61
Skills needed to use the technology	10	0	10	4.69	2.92
Flexibility in the manipulation of the equipment	10	0	10	4.41	2.47
Performance of the equipment	10	0	10	4.29	2.34
Efficiency of the equipment	9	1	10	4.26	2.31
Ease of use of the equipment	10	0	10	3.90	2.28
Amount of capital for acquisition of equipment	10	0	10	3.62	2.62
Composite mean	5.35	3.42	8.77	6.04	1.03

Source: DAEE-UCC, field data, 2019. n = 145

Appendix 7: Farmers' willingness to pay for drone technology for FAW control

Willingness to pay for drone	Males		Females			
	Freq.	%	Freq.	%	Total freq.	%
Yes	87	95.6	57	93.4	144	94.70
No	4	4.4	4	6.6	8	5.30
Total	91	100.0	61	100.0	152	100.00

Source: DAEE-UCC, field data, 2019

Appendix 8: The composite means of the TAM 3 constructs

TAM 3 constructs	Min.	Max.	Mean	SD
Perceived enjoyment (ENJ)	2.00	10.00	7.60	1.65
Perceived ease of use (PEOU)	3.40	10.00	7.51	1.51
Computer (drone) self-efficacy (CSE)	0.33	10.00	7.50	1.83
Perceived usefulness (PU)	1.40	10.00	7.48	1.61
Subjective norms (SN)	1.25	10.00	7.42	1.57
Image (IMG)	1.00	10.00	7.38	1.74
Voluntariness (VOL)	0.00	10.00	7.33	1.92
Output quality (OUT)	0.67	10.00	7.28	1.80
Result demonstrability (RES)	1.00	10.00	7.28	1.73
Job relevance (REL)	0.33	10.00	7.25	2.11
Behavioural intension (BI)	1.00	10.00	7.20	1.79
Attitude towards use (ATT)	1.67	10.00	7.27	1.75
Perception of external control (PEC)	2.00	10.00	7.17	1.55
Computer (drone) playfulness (CPLAY)	0.50	10.00	7.17	1.91
Computer (drone) anxiety (CANX)	1.25	10.00	6.69	2.16

Source: Source: DAEE-UCC, field data, 2019, n = 152

Appendix 9: Associations of behavioural intention of farmers to use drone technology for FAW control in the study area

	Mean	SD	BI	PEOU	PU	CSE	PEC	CPLAY	CANX	ENJ	SN	VOL	IMG	REL	OUT	RES	ATT
BI	7.20	1.79															
PEOU	7.51	1.51	.653**														
PU	7.48	1.61	.717**	.700**													
CSE	7.50	1.83	.647**	.663**	.763**												
PEC	7.17	1.55	.565**	.707**	.590**	.540**											
CPLAY	7.17	1.91	.572**	.644**	.485**	.409**	.713**										
CANX	6.69	2.16	.688**	.642**	.587**	.525**	.685**	.602**									
ENJ	7.60	1.65	.598**	.664**	.722**	.689**	.574**	.501**	.502**								
SN	7.42	1.61	.590**	.580**	.592**	.540**	.648**	.620**	.580**	.644**							
VOL	7.33	1.92	.480**	.561**	.425**	.416**	.571**	.687**	.545**	.532**	.747**						
IMG	7.38	1.74	.579**	.644**	.519**	.508**	.635**	.596**	.689**	.630**	.609**	.608**					
REL	7.25	2.11	.546**	.716**	.499**	.518**	.669**	.562**	.663**	.560**	.533**	.517**	.743**				
OUT	7.28	1.80	.588**	.649**	.482**	.466**	.678**	.476**	.589**	.559**	.539**	.471**	.501**	.642**			
RES	7.28	1.73	.661**	.559**	.489**	.478**	.517**	.597**	.503**	.497**	.621**	.592**	.549**	.369**	.488**		
ATT	7.27	1.75	.762*	.711**	.617**	.653**	.675**	.559**	.740**	.692**	.622**	.593**	.743**	.713**	.634**	.513**	

Source: DAEE-UCC, field data, 2019, n = 152

** Correlation is significant at the 0.01 level (2-tailed)

Appendix 10: Best predictors of behavioural intention of farmers to use drone technology for FAW control

Steps of entry	R	R^2	Adjusted R^2	R^2 change	Beta stand.	SEE	F change	df	Sig. *
ATT (X1)	0.762	0.581	0.578	0.581	0.52	1.16	207.73	150	0.00
RES (X2)	0.824	0.679	0.675	0.099	0.35	1.02	45.91	149	0.00
PU (X3)	0.859	0.738	0.733	0.059	0.38	0.92	33.10	148	0.00
ENJ (X4)	0.866	0.749	0.742	0.011	-0.15	0.91	6.49	147	0.01
VOL (X5)	0.870	0.757	0.748	0.008	-0.12	0.89	4.54	146	0.03

Source: DAEE-UCC, field data, 2019. n = 152, *$p < 0.05$

Appendix 11: A test of significance between willingness of farmers to pay and mean maximum amount the farmers are willing to pay for the drone spraying service

	N	Mean	SD	SEM	Test value = 45.58			
					t	df	Sig.	Mean difference
Willingness to pay for drone	144	20.50	11.69	0.97	25.72	143	.000	25.07
Maximum amount willing to pay for drone	144	26.89	14.23	1.19	15.75	143	.000	18.68

Source: DAEE-UCC, field data, 2019

Appendix 12: Benefit-cost ratio analysis

The expression for the return on investment was calculated using benefit-cost ratio.

Mathematically, this has been specified as:

$$BCR = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}$$

The 'r' is the discounted rate of the project. The discounted rate of the project was zero (the price of the project was at a spot rate). This was because the project was self-financed by CTA, hence the discount rate associated with the project will have no effect on the project.

t = 1 because the project life span stretched over 1 year, despite the main field activities taking place over six months. The formula was therefore reduced to:

$$BCR = \frac{B}{C}$$

The benefit-cost analysis was used to help parties in the project make informed choices on which project options were more viable to invest in, considering the cost involved against the benefit to be reaped from engaging in a venture. The various plots (knapsack, drone and control plots) were considered as individual investment options for the farmers. Per the principles of benefit-cost analysis, the farmer is expected to select the option that will give him the highest benefit at a minimum cost. Ideally, the evaluation of the benefit-cost analysis is calculated over the life span of the project allowing for the cost to be discounted over the project period. Since this project was performed at a fixed period of time, the spot rate was used in the discounting process, where no interest will be accumulated over the life span of the project.

Appendix 13: Operational definition of TAM 3 variables

Perceived usefulness – The extent to which a farmer believes that using the drone spraying application services will enhance his or her farming performance.

Perceived ease of use – The degree to which a farmer believes that using drone spraying for the control of FAW will be free of effort.

Subjective norm – The degree to which a farmer perceives that most people who are important to him/her in the community think he/she should or should not use the drone spraying application for the control of FAW.

Image – The degree to which a farmer perceives that use of the drone spraying application will enhance his or her status in the community.

Job relevance – The degree to which a farmer believes that the drone spraying application is applicable to his or her farming operations.

Output quality – The degree to which a farmer believes that the drone spraying system performs well in the chemical application of pesticide to control FAW.

Result demonstrability – The degree to which a farmer believes that the results of using drone spraying technology for the control of FAW are tangible, observable, and communicable.

Computer self-efficacy – The degree to which a farmer believes that the drone spraying service operator has the ability to perform the spraying task.

Perception of external control – The degree to which a farmer believes that organisational and technical resources exist to support the use of drone pesticide spraying to control FAW.

Computer anxiety – The degree of a farmer's apprehension, or even fear, when she/he is faced with the possibility of using drone technology to apply pesticide to control FAW.

Computer playfulness – The degree of a farmer's cognitive spontaneity in using the drone sprayer to control FAW.

Perceived enjoyment – The extent to which the activity of using the drone for spraying chemicals for FAW control is perceived to be enjoyable in its own right, aside from any agricultural performance consequences resulting from drone use.

Behavioural intention – The intention of the farmer to use the drone technology to apply pesticide for FAW control.

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