Feasibility study in the framework of SBIR: Food Security in Sub-Saharan Africa

Enhancing irrigation water productivity and yields of pineapple farmers in Ghana

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Project details

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Enhancing irrigation water productivity and yields of pineapple farmers in Ghana

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End:	31 December 2018

FutureWater appreciates the financial support received from RVO for carrying out this feasibility study. The meetings with RVO and solid cooperation between FutureWater and Farmerline contributed to the successful implementation of the study.

1 Management summary

This project evaluates the feasibility of an information service that aims at enhancing food security by increasing productivity and profitability of the most significant fruit crop in Ghana: pineapple. There is a **huge potential to boost irrigation water productivity of pineapple**, which is currently unfulfilled as farmers lack the required information to optimize their practices.

The proposed solution consists of a combination of the ThirdEye flying sensor service, successful elsewhere in Sub-Saharan Africa, extended with crop modelling for seasonal yield forecasts, and integrated with the existing Farmerline information service that provides advice to farmers in Ghana. The integration of these components requires further development and tailoring to the local needs, the production system, and local capacities. Before a development phase can start, risks and opportunities were assessed during this feasibility study.

The **objective** of the feasibility project was therefore as follows:
Determining the technical and economic feasibility of the development of an extension service for Ghanaian semi-commercial farmers based on flying sensor technology, crop models, and locally embedded data sharing and farmer advisory infrastructure.

This objective is unchanged compared to the project plan.

With regard to the **contribution to societal challenges** the activities related to stakeholder mapping and analysis, focus group discussions and expert interviews, helped significantly to map out the pineapple sector in Ghana, opportunities and challenges faced by smallholders, and the potential contribution of the proposed service. At the same time, engaging actively with local end users has constituted the initial steps of the **co-creation process** that is foreseen to be continued in the next SBIR phase.

After completion of the feasibility stage, the successful development and testing of a prototype of the proposed innovation in the following SBIR stages is assessed as **technically feasible**. To summarize, no technical bottlenecks were found to embed FutureWater's flying sensor service into the existing local information service from Farmerline, the local data availability is sufficient, technical restrictions for the farmer are limited, and the form and frequency of a new information system have been further concretised. In addition to the answering of the specific technical feasibility questions defined prior to the study, a major part of the information chain at the back-end of the proposed service was already tested during this SBIR phase 1. This included the **execution of flying sensor flights** over Gold Coast Fruits pineapple farm in Ghana, processing of the collected data, and initial runs of the crop yield / water productivity simulation model. The link with simulation models to produce yield and water productivity forecasts was already tested. An initial calibration of this model setup has highlighted substantial existing gaps regarding pineapple yields and water productivity, and thus the potential for the proposed services to **significantly enhance productivity**.

The **economic feasibility was sufficiently proven** for a subsequent research and development trajectory (SBIR phase 2/2A). This is mainly concluded by analysing the costs and benefits of the solution for semi-commercial smallholders. This analysis shows there is a positive case for the service, with a net benefit of almost GHS 20,000 (EUR 3,600) per farmer per growing season. The cost of the service is acceptable to local semi-commercial farmers, which means there is ample support for the further development of the information service. Moreover, the progress in this feasibility study, realized with a limited budget, meets the predefined expectations. After completion of a research and development trajectory (phase 2) the service will be technically mature enough for commercial expansion. After this the costs for keeping the service operational are relatively low.

With regard to phase 2, the most important **technical points** of attention are:

- The outcomes of initial mapping and modelling activities are not directly suitable for dissemination to semi-commercial smallholder farmers. In particular the modelling results, generated for different farm management strategies / scenarios to identify optimal practices, require a degree of translation to be taken up by the local end user. The research and development phase will comprise a work package dedicated to shaping the information service to user needs, in terms of content, format, and language / wording.
- The accuracy of yield simulations and water productivity projections under different farm management strategies needs to be investigated further, to ensure that sufficiently accurate information can be provided to the farmers. Key to delivery of meaningful information is timing; simulating yields and water productivity can be considered feasible from a certain point in the growing season. The timing of this point needs to be assessed in the research and development phase, as well as the accuracies (and sensitivities) associated with pineapple yield and water productivity simulations.
- Flying sensors have a sufficiently high spatial resolution to filter out weeds from the pineapple crop. However, algorithms to perform this filtering depend on weed type and crop type, and require a degree of calibration. The risk exists that weeds are incorrectly included in canopy cover and yield calculations. In the SBIR phase 2, the method for weed filtering and weed management advisory needs to be developed further for the local Ghanaian context.

Other **economic points** of attention are:

- For successful market entry, private sector organizations which offer tangible products, such as inputs and irrigation systems, should be made implementing partners for the proposed solution. Cost of these products can be bundled together with that of the advisory service as an incentive to farmers, which will be further explored in phase 2.
- Demonstration fields would significantly help farmers to appreciate the effectiveness of the intervention and will be set up in phase 2. This could be done with existing fields and/or newly cultivated fields for reference.
- As a revenue driver for both the service and business partners, we propose to develop two additional services to the irrigation information. These services (an Input Demand Forecaster and a Crop Stress Forecaster), will make use of ground data on farms/fields, combined with modules for pest and disease forecasting. They will be further explored in a research and development phase.
- A competing service for the pineapple sector in Ghana is identified. This service will be further looked into during the subsequent phase.

The **organizational** risks to achieve a fully operational, marketed version of the proposed service are low. The project partners dispose of all expertise acquired to further develop the product and have successfully collaborated in this SBIR feasibility stage, as well as in other projects. With the expertise of Farmerline regarding local stakeholders, the pineapple sector, and communication with semi-commercial farmers, and the technical skills of FutureWater regarding remote sensing and crop modelling, there is a clear division of tasks among the partners. Continuous communication between the project partners will minimize organizational risks as much as possible.

For phase 3, the **commercialization phase**, a few potential end users will already be involved in phase 2. The Gold Coast Fruit company is interested in our potential service to provide information to support pineapple production. Initial contacts were made possible thanks to the support of Farmerline and will be further extended in phase 2 and 3. Early implementation of the service in phase 2 will help increasing chances of successful market entry in phase 3. Also, partnerships with enabling environmental actors and service provision actors will be established as soon as possible.

Table of contents

2 Project execution

2.1 Objective

The objective of the feasibility project was as follows:
Determining the technical and economic feasibility of the development of an extension service for Ghanaian semi-commercial farmers based on flying sensor technology, crop models, and locally embedded data sharing and farmer advisory infrastructure.

2.2 Problem statement

The problem statement was as follows:

- Technical feasibility
    - What are the technical bottlenecks of embedding ThirdEye into the existing information services provided by the local partner?
    - For delivering the irrigation water productivity forecasts: is sufficient local data available as input for the information service, to generate sufficiently reliable outputs?
    - Are there technical limitations for the farmer that possibly inhibit successful adoption of the irrigation water productivity advice?
    - And related: what is the form and frequency with which this information should be delivered to guarantee the adoption of the service, given the local needs and capacities?
- Economic feasibility:
    - What is the foreseen cost of the solution, or different possible variants of the solution, depending on the interface with the farmer, type of information, frequency, etc.
    - What is the foreseen economic benefit for farmers using the service, given current challenges the farmers face and given the current yield gap?
    - What is the expected willingness-to-pay of end users?
    - What are the different possible service agreements with the end-user?
    - How can the initial business model (as described in 5.4) be improved to match the local context and needs?
    - Are there any possible legal, institutional or political bottlenecks that may affect the successful deployment or adoption of the solution?

The feasibility study covers both technical and economic aspects. Special emphasis is given to the match between the solution and the local context in terms of: (1) user needs, (2) solutions currently used, (3) economic potential.

2.3 Project organisation

The project organisation as proposed in the initial proposed was followed during the execution of the study, with the addition of HiView as partner. In total, three parties were involved in the execution of the project. FutureWater had the project lead and conducted the technical feasibility and cost/benefit analysis. Data analysis, literature reviews and crop modelling were also done by FutureWater. Farmerline's role was related to the local needs assessment, stakeholder identification and expert interviews. As flying sensor experts, HiView, together with Farmerline, conducted several flights in Ghana over pineapple fields and gave in-field demonstrations (Figure 1).

Figure 1. Pineapple fields in Gold Coast Fruits limited (HiView).

2.4 Phasing

The phasing of the project was divided in four work packages and was followed according to the initial project plan. Additionally, in the economic feasibility work package a study to existing information services in the Ghanaian pineapple sector was performed.

WP1: Local Needs Assessment
Objective: A local user requirement specification will be made based on expectations and needs from local potential end-users

As proposed, stakeholders and user types were identified, focus groups and user needs were assessed and expert interviews took place. This was mostly done by Farmerline and the results are described in paragraph 3.1 and Appendix 2.

WP2: Technical Feasibility

Objective: Answer the questions as listed in section 6.2 (Problem Statement) and possible additional technical issues that may pop up from WP1. The engagement of end-users from the start is vital to the study, since they represent the customer for the future service.

This part of the study was mostly done by FutureWater and followed the tasks as proposed in the project plan. An inventory of required and available data was made, risks and opportunities of the system integration were evaluated, simulated testing of irrigation water productivity advice was done using, amongst others, flying sensor data gathered by HiView in Ghana and in-field demonstrations were given by HiView to local stakeholders. The results of this study are described in paragraph 3.2, 4.1 and Appendix 1.

WP3: Economic Feasibility

Objective: Critical elements to assess the service feasibility will be analysed. These elements will cover economic factors and political and legal aspects.

For this work package a market study was performed, economical risks were identified, a cost-benefit analysis was performed and legal/political barriers were studied. This work package was done in collaboration between FutureWater and Farmerline and the results are shown in paragraph 3.3, 4.2 and Appendix 2.

WP4: Project coordination

Objective: Coordinate the project, organise all project administrative issues and streamline planning and reporting.

This was mostly done by FutureWater and all went according to plan.

Part of the research and development activities were already completed during this feasibility stage. Therefore, **SBIR phase 2/2A will already allow a focus on initial pilot implementation of the service**.

2.5 Cooperation and task division

The cooperation and task division were all executed as described in the proposal. FutureWater fulfilled its tasks as project leader (administration, coordination, planning, contact with the client and reporting). Furthermore, FutureWater conducted the technical analysis. Farmerline took care of the local needs assessment and market analysis. The Farmerline team drew from years of relevant experience to make use of the most appropriate techniques in the engagement of stakeholders. Broadly, the approach was to interview key stakeholders in Ghana's agriculture sector and major actors in the pineapple value chain. In their respective settings, stakeholders including smallholder pineapple farmers, commercial pineapple farms and experts readily offered their knowledge of existing practices and gaps, while assessing risks and opportunities with the proposed solution. HiView provided aerial images used in FutureWater's crop model analysis. The cooperation took shape because of the frequent contact between the parties and by sharing all intermediate results on a regular basis. At the beginning of the project a consortium agreement and subcontract were made.

3 Results

3.1 Contribution to societal challenges

The activities in this feasibility study related to stakeholder mapping and analysis, focus group discussions and expert interviews have helped significantly to map out the pineapple sector in Ghana, opportunities and challenges faced by smallholders, and the potential contribution of the proposed service (see also Paragraph 3.3.6). At the same time, engaging actively with local end users has constituted the initial steps of the **co-creation process** that is foreseen to be continued in the next SBIR phase. This paragraph describes how the activities in Work Package 1 of the feasibility study have gained further insights regarding existing societal challenges and the expected impact of the proposed solution

3.1.1 Stakeholder mapping and analysis

Different stakeholder groups in the pineapple value chain, as identified by Farmerline, are described below. The power/interest analysis of stakeholders identified shows the level of interaction needed to ensure that stakeholders are managed well so that their role and influence on the project positively affects implementation (Figure 2). The service will be co-created with all stakeholders that have been acknowledged to have high interest in it, shown on the right side of the matrix. They will be actively involved in further pinpointing the service to their needs in the next phase, increasing the societal and socio-economic uptake.

<u>Enabling Environment Actors</u>

The study noted that a number of government ministries, departments and agencies are very active in the irrigation sector to ensure a conducive policy environment and regulatory framework for proper use of land and water resources in Ghana for crop production. These include the Ministry of Food and Agriculture (MoFA), Ghana Irrigation Development Authority, Lands Commission, Hydrological Services, Local Government, and Ghana Meteorological Agency. In addition to the ministries, departments and agencies, consist of bilateral and multilateral donor-funded projects and programs (such as GIZ, IFDC). These institutions enhance the sector by focusing on infrastructure, capacity building, research, farm/farmer productivity and income interventions.

<u>Production Actors</u>

These actors within the value chain are considered as a central focus, as they use the allocated water and land resources to produce pineapple, the focus of this feasibility study. The actors here include smallholder, semi-commercial and commercial pineapple farmers. Commercial pineapple farms such as Jei River Farms, Gold Coast Fruits and Bomarts Farms are among the largest producers and exporters of pineapple in Ghana and are relevant in offering useful insight.

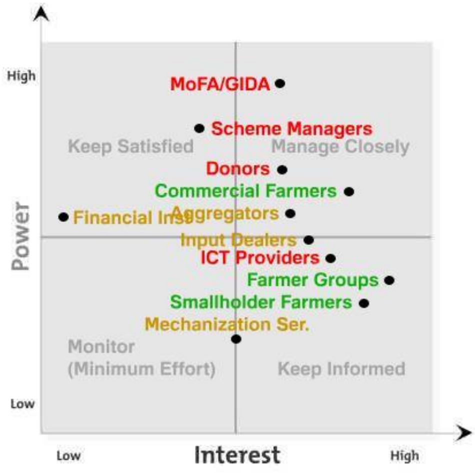

Figure 2. Stakeholder power/interest matrix.

<u>Service Provision Actors</u>

These actors are either public, private or non-governmental organizations. Their aim is to deliver support services to farmers to ultimately increase productivity and incomes. Several of these service provision actors have business arrangements with farmers to deliver services for which there is compensation. Examples of these actors are Callighana, Ministry of Food and Agriculture extension officers, financial and lending institutions and farmer education or information providers.

Market Access Actors

The role of these actors in the value chain is to offer farmers market for their produce either at guaranteed or negotiated prices. Here, the activities of off-takers / market aggregators are most active. Examples of actors include Blue Skies and HPW Fresh and Dry Limited.

3.1.2 Challenges faced by the pineapple sector

From each of the above categories, a representative number of stakeholders were selected to engage in interviews, in order to enhance the comprehensiveness of insights. Interviews were structured around the interview guides provided in Appendix 5, expanded with additional questions or topics on-the-fly according to expert knowledge. This has yielded **lively discussions with key stakeholders** with regards to their needs and views on design of an information system supporting pineapple production (e.g. form, frequency, service agreements, etc.). This section summarizes key findings of expert interviews with regards to semi-commercial smallholders and larger commercial farms producing pineapple in Ghana.

Semi-commercial smallholders

In Ghana, pineapple production is key to food security and macro-economy as well as livelihoods of individual farmers. Traditionally, the largest share of the Ghanaian national pineapple production is generated by semi-commercial smallholders. As concluded from the feasibility study, they are mostly producing Smooth Cayenne and Sugar Loaf varieties which are sold in the local market, while also producing other crops to sustain profits. During the interviews, smallholders in Bawjiase region indicated that Sugar Loaf is more resistant to various conditions and has much lower production costs than MD2. However, there is a tremendous pressure to change the production to MD2 pineapple variety to be able to compete in international markets.

Pineapple yields are currently very much below their potential level, as farmers do not have access to information to improve their practices. Most smallholder farmers do not apply irrigation (Figure 3), indicating costs of equipment and challenges with water sources as reasons for producing without irrigation. However, they have other ways to influence crop exposure to stresses, such as weed control, timing of sowing and harvesting, application of fertilizers and pesticides, and other farm management practices.

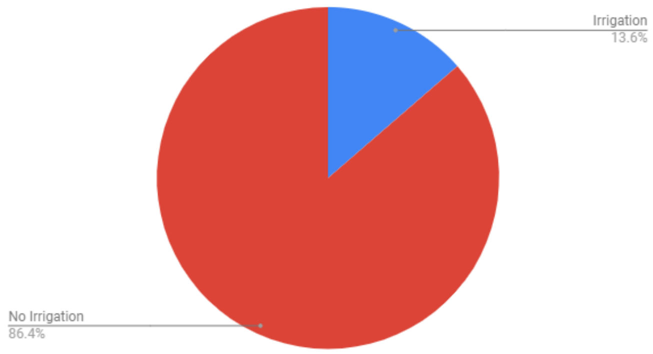

Figure 3. Result from the field survey: Irrigation among semi-commercial smallholders, which shows most do not irrigate their pineapple crops.

Commercial farms

Based on the various stakeholder interviews, commercial pineapple farmers in Ghana switched from production of Smooth Cayenne to MD2 variety in 2007. The feasibility study indicated that only large commercial farms have the economic and technical capacity to grow MD2 for exports. Commercial farms and processors, like HPW Fresh and Dry Ltd, confirmed the international demand for MD2 and unanimously attested to the seemingly unbeatable competition with Costa Rica in the international market. Competition with Costa Rica has driven some commercial farms including Jei River Farms and Gold Coast Fruits to truncate their outgrower schemes. In the words of the Farm Manager of Jei River Farms: *"We are unable to compete with them because their cost of production is very low".* This caused them to shift part of their resources to passion fruit production. The MD2 variety requires higher pest control, fertilization, and irrigation requirements compared to Smooth Cayenne and Sugar Loaf. In Ghana, information about the adequate implementation of MD2 is lacking. Yield losses occur due to water deficit, fertility stress and pests during crop development.

Representatives of commercial farms generally agreed on the relevance of irrigation to productivity, although their practices differ. Commercial farms often practice "supplementary irrigation", relying principally on rains for plant water needs (Figure 4). In the dry seasons (4-5 months), some minimal irrigation is carried out. On the type of irrigation system used, Jei River Farms strongly asserted that the sprinkler is the most prudent and efficient irrigation system for pineapple production. They remarked that pineapple production which is done in cycles of blocks makes the drip alternative inefficient. The cycle would mean leaving the drip lines idle during the period when pineapple stalks are left to shoot suckers. This, they believe, is not as cost-effective as the sprinklers which are moveable. Bomarts Farms currently have 70% of their 400 acres of pineapple fields under drip irrigation. Although both Albe Farms and Gold Coast Fruits agree with the others on the need for irrigation, they do not practise accordingly. Albe Farms does not carry out any irrigation at all. They reckon that water used in fertilizer application (fertigation) which is done bi-monthly is enough to meet the needs of pineapples. Gold Coast Fruits, one of the largest pineapple producers in Ghana, says they are unable to afford an irrigation system.

Figure 4. Result from the field survey: Irrigation among commercial farms, which shows most do not irrigate their pineapple crops.

3.1.3 Gender

Most of the land owners, commercial farmers and decision makers who are potential clients to buy the service are men, making it difficult for us to sell our service to women. However, **most of the farmers working in the field are women**. In terms of agricultural production, women – especially those in rural areas – play a major role in all aspects of farming, including planting, weeding, fertilizer application, harvesting and storage (FAO, 2018). As a result, women are mainly engaged in producing about 70% of food crops, such as rice, maize, cassava, cocoyam, groundnuts, soybean and vegetables (Duncan and Brunt, 2004). Due to the large presence of women in the field, women play a key role in the farming business and are therefore a very important contact point for our service. Thus, most of our contact (for example in the form of advisory on farming practices) will be with women.

According to FAO's 'National Gender Profile of Agriculture and Rural Livelihoods – Ghana: Country Gender Assessment Series' report (2018), women have unsatisfactory access to technical knowledge on agriculture due to numerous barriers to accessing information and benefiting from extension services and training. Given the lack of appropriate technologies for most farming activities across rural Ghana, women perform labour intensive tasks with the use of simple and traditional farming technologies. By comparison, men are generally responsible for those parts of agricultural production that are mechanized, such as use of the tractor or bullock ploughs for land preparation. **Our innovation will especially empower women**, since they will be the ones who receive the advice in the field. Furthermore, operators providing the advice will provide training on improving their agricultural practices. Therefore, the final beneficiaries of our service will be women.

Phase 2 will start with training a team of operators who will be taught on how to use the innovation. They will conduct flying sensor flights, process the images, make yield forecasts and give advice to farmers. Our team will pay utmost attention to **having an equal gender balance in the operating team**.

3.1.4 Expected contribution of proposed solution

Overall, interviewed local experts and stakeholders indicated that improved information on **crop management procedures** and **irrigation scheduling** would allow better planning and investments, increase pineapple production and enhance livelihoods and food security. Providing an integrated information service to the Ghanaian pineapple sector would be crucial to enhance decision making and compete in national and international markets, which have a huge demand for pineapple. Semi-commercial smallholders in particular, who have seen a decline in their pineapple production and marketing over the past years[1], could benefit from enhanced access to information to lower their production costs and increase their productivity.

The proposed innovation addresses the problem statement in the SBIR tender related to current **insufficient productivity at primary production level in Sub-Saharan Africa, focusing on** the pineapple production sector in Ghana. More specifically, it is expected to contribute directly and significantly to:

- Ensuring a good start of the growing season
- Ensuring good growth of the crop
- Making irrigation more efficient
- Expanding climate-smart cropping systems

The individual components of the proposed solution were previously successfully tested in operational environments and are currently implemented and serving a large number of small-holders in Sub-Saharan Africa. The ThirdEye technology is currently implemented in Mozambique and Kenya, supporting proven water productivity improvements of over 25%. The Farmerline information service is already serving over 7000 smallholder farmers in Ghana. By combining these components, near real-time information about the condition of the pineapple crop at each growth stage can be provided to the farmer, allowing **timely detection** of nutrient deficiencies, pests or water stress. The integration with a crop growth model[2] allows for scenario analyses of different farm management options and subsequent **actionable information** provision to farmers with regards to farm practices to optimize yields. As the service directly addresses the challenges mentioned by local stakeholders, and can be delivered at low cost, its expected impact on pineapple productivity is expected to be very high.

Figure 5. Pineapple field close to Accra, in Ghana (HiView)

3.1.5 Regulation or property protection bottlenecks

No bottlenecks were found with regards to regulation or property protection.

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[1] T. Zottorgloh (2014), Characterization of smallholder pineapple production systems in Ghana and expert-based perspective on value chain developments, Wageningen University (http://edepot.wur.nl/315145)

[2] For a comprehensive description of the technology behind the proposed solution, see Appendix 1.

3.2 Technical feasibility

A full report of the technical feasibility study is added as Appendix 1 to this report.

In this feasibility study the **technical feasibility was sufficiently proven** for a subsequent research and development trajectory (phase 2). The questions, as posed in the project plan, were answered during the study. To summarize, no technical bottlenecks were found to embed FutureWater's flying sensor service into the existing local information service from Farmerline, the local data availability is sufficient, technical restrictions for the farmer are limited, and the form and frequency of a new information system have been further concretised.

In addition to the answering of the specific technical feasibility questions defined prior to the study, a major part of the information chain at the back-end of the proposed service was already tested during this SBIR phase 1, as described in Appendix 1. This included the **execution of flying sensor flights** over Gold Coast Fruits pineapple farm in Ghana (Figure 6), processing of the collected data, and initial runs of the crop yield / water productivity simulation model. The link with simulation models to produce yield and water productivity forecasts was already tested. An initial calibration of this model setup has highlighted substantial existing gaps regarding pineapple yields and water productivity, and thus the potential for the proposed services to **significantly enhance productivity**.

Figure 6. Flying sensor flights at the pineapple fields in Gold Coast Fruits limited (1 December 2018).

3.2.1 Bottlenecks in incorporating the proposed information service into the existing system

In the past years, mobile phone network as well as ownership of these communication assets have been improved at a high rate in Sub-Sahara Africa (Tall et al., 2018). In 2008, 60% of the population had access to a mobile phone network compared to a rate of less than 10% in 1999 (Aker & Mbiti, 2010). In our field survey all respondents had mobile phones. Thanks to the accessibility of mobile phones, diverse information services are currently available. In Ghana, Farmerline is providing information services to registered farmers about weather conditions, crop prices and market trends for their specific needs. Farmerline has been successful in reaching out to semi-commercial smallholder farmers and providing them with information for better decision making. Information is sent to the farmers via mobile phone. Our in-field survey results show that all farmers interviewed own a mobile phone.

A limitation of the Farmerline service is that information is delivered through SMS messages. This means that only text messages can be sent, which can include values for specific indicators, but no images or maps. However, the spatial data collected with flying sensors show the spatial distribution in a farm and provide visual information about the spatial variability of the variable of interest (e.g. canopy cover, predicted yield), see Figure 7. To account for this limitation, an approach was designed in which the variable of interest (value) will be provided per plot. The plots in the pilot area of Gold Coast Fruits follow a number classification, thus the user will understand easily to which plot the value is assigned. Companies such as Gold Coast Fruits will be responsible in conveying the crop information to local decision makers to improve field practices. Semi-commercial smallholders will be advised through will be trained in the next SBIR phase. These operators will conduct flying sensor flights, process the images, make yield forecasts and give advice to farmers.

FutureWater processes the information measured with flying sensors and provides data for the variables of interest. For example, the percentage of canopy cover and the crop yield in tons per hectare can be delivered. Different values can be provided over agreed time steps (e.g. hourly, daily, monthly) for a given growth period in a defined agricultural plot. During the continuation of the co-creation process in the next SBIR phase, time steps should be agreed depending on the type of crop and field management procedures, and based on preferences of the farmers. Decision makers such as Gold Coast Fruits company should be trained to understand what the specific values mean for translating it into useful information.

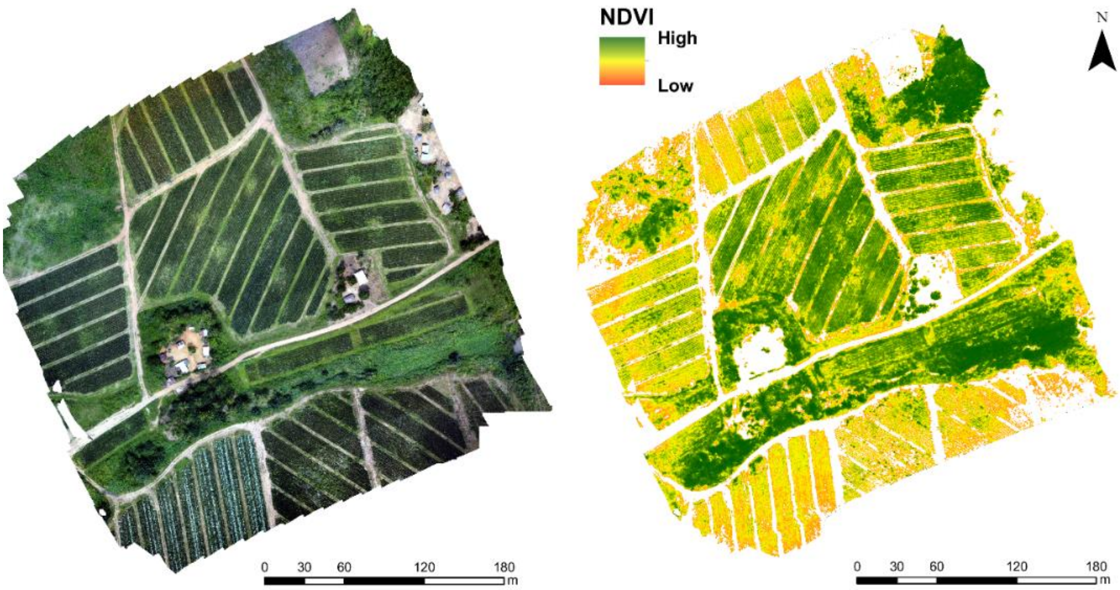

Figure 7. Field 1 of Gold Coast Fruits, as captured during Flying Sensor flights on 1 December 2018, two weeks before harvest. The left image shows a visual overview. The right image shows the distribution of crop vigor/health (as indicated with the NDVI vegetation index) across the individual plots.

3.2.2 Local data availability

For the pilot farm, as well as in Ghana in general, sufficient local data is available for the information service to generate sufficiently reliable AquaCrop model outputs. Meteorological information is available thanks to several stations accessible in the online National Oceanic and Atmospheric Administration (NOAA) meteorological system and in the online Trans-African HydroMeteorological Observatory (TAHMO) weather data system. In addition, for potential upscaling purposes in the Ghana's pineapple belt, remote sensing precipitation datasets such as CHIRPS (Funk et al., 2015) and MSWEP (H. E. Beck et al., 2017; H. Beck, Yang, Pan, Wood, & William, 2017) are available worldwide and have shown to be useful for irrigated agriculture purposes at local application (Kaune et al., 2018). Also, WaPOR online services supported by FAO, provide remotely sensed derived datasets for the African continent such as evapotranspiration and biomass information.

Available platforms such as Google Earth Engine provide datasets from remote sensing missions such as Sentinel and Landsat. Information about NDVI can be retrieved, which may be used as an indicator for the canopy cover of crops. Retrieving information from remote sensing requires certain technical capacity. FutureWater provides this service, including the adequate processing of the datasets to convert it into useful information.

With basic data needs already fulfilled by available remote sensing datasets, further improvements by incorporation of local data will be explored by pursuing partnerships with local stakeholders, e.g. enabling environment actors and service provisions actors mentioned in paragraph 3.1.1.

3.2.3 Technical limitations for the farmer

The technical limitations for the farmer will depend on their educational background and experience. Current semi-commercial farmers which receive the service from Farmerline are technically able to understand the information that is provided through their phones. This information is related to crop prices, market variations and weather. In the same way, it is expected that they will be able to understand new information about crop health status, yield predictions and recommended field management provided by the proposed service. Target values (e.g. yields) can be pre-established with the farmers. From the survey, it was identified that farmers feel most comfortable in using yield values in tonnes per hectare, and do not feel comfortable in using mm units to identify water loss. The results of this feasibility study show that it is possible to account for these preferences in the information service.

3.2.4 Form and frequency of new information system

The proposed back-end information service consists of monitoring canopy cover through flying sensors and simulating crop yield and water productivity with a crop model. A key outcome from previous FutureWater experience entails the importance of **timely planning** of flying sensor monitoring with the local partner and farmers. Monitoring crops with flying sensors during the growing season is to be planned cost-effectively and according to crop characteristics. Depending on the sensitivity to water deficit, water excess and soil fertility during different growth stages, flight schedules can be optimized to maximize benefits and minimize costs.

In Ghana, the total growth period of pineapple is 18 months. During this period, key measurements of the canopy cover with flying sensors are recommended in each growth stage. Pineapple is sensitive to water deficit especially during the vegetative growth stage. The vegetative stage is 9 months between December and August. Flying sensor flights should be prioritized in these months, with a recommended interval of 20 days. After August measurements can be done every 40 days, with special attention at the beginning and end of the flowering stage, to monitor excess water supply. In total, between December and August the pineapple farm will receive 14 SMS messages, and between September and May it will be 7 (Table 1).

Table 1. Interval and amount of SMS messages for pineapple monitoring

December – August (9 months) Pineapple vegetative stage		September – May (9 months) Pineapple flowering and yield formation stage	
Interval of SMS messages (days)	**Amount of SMS messages per pineapple plot**	**Interval of SMS messages (days)**	**Amount of SMS messages per pineapple plot**
20	14	40	7

In addition, predicting dry periods and water scarcity conditions provides further information for prioritizing flying sensor flights. Dry periods can be predicted by evaluating historical data on precipitation. Also, for irrigated pineapple, the periods with the highest probability of water scarcity can be determined by evaluating historical data on available water (e.g. river discharge) and irrigation demand. Local data can be provided, but the period of record may not be fully available.

In that case, a solution is using earth observation datasets to complete the necessary information for these periods and prioritize flying sensor flights.

3.2.5 Regulation or property protection bottlenecks

No bottlenecks were found in the area of regulation or property protection.

3.3 Economic feasibility

A full report of the economic feasibility study is added as Appendix 2 to this report.

In this feasibility study the **economic feasibility was sufficiently proven** for a subsequent research and development trajectory (SBIR phase 2/2A). This is mainly concluded by analysing the costs and benefits of the solution for semi-commercial smallholders. This analysis shows there is a positive case for the service, with a net benefit of almost GHS 20,000 (EUR 3,600) per farmer per growing season. The cost of the service is acceptable to local semi-commercial farmers, which means there is ample support for the further development of the information service. Moreover, the progress in this feasibility study, realized with a limited budget, meets the predefined expectations. After completion of a research and development trajectory (phase 2) the service will be technically mature enough for commercial expansion. After this the costs for keeping the service operational are relatively low. Below, the questions, as posed in the project plan, are answered. An extra question was added to the original plan to study existing information services in the Ghanaian pineapple sector.

3.3.1 Pineapple market

The survey team made significant observations regarding the market and marketing of pineapples by farmers in Ghana. The divide between smallholder and commercial farmers is such that no overlap exists in their respective market spaces.

All the commercial farms including Bomarts Farms and Albe Farms primarily produce for exports. With Costa Rica being the market leaders of the international pineapple market, small market players like Ghana are subjected to price fluctuations among other unfavourable market conditions. These challenges have compelled farmers to cap their production capacity. The secondary market for these farms is the major processing factory in Ghana, Blue Skies.

Figure 8. Pineapples sold on the local market.

Smallholder farmers, on the other hand, mainly have the local market to actively compete in (Figure 8). With more producers than buyers, smallholders are seemingly powerless in the pricing of their produce. During the focus group discussions, farmers indicated that though local buyers quoted very low prices, they have no other option than to sell at those prices; otherwise, bear the risk of their produce perishing. They lamented that local buyers paid as low as GHS 0.50 per pineapple while processing factories bought similarly sized pineapples from suppliers at a unit price of GHS 2.00. This phenomenon has compelled smallholder farmers to prioritize selling on local markets over working with local buyers or processing factories. The market need of the farmers is interestingly expressed in some respondents coming along with some pineapples to the focus group discussion, after clear communications of the purpose of the interview. They hoped their samples would move us to buy or recommend some buyers.

3.3.2 Cost-benefit analysis

The achieved fresh pineapple yield is between 45 and 55 tonnes per hectare in Ghana (WorldBank, Gold Coast Fruits). However, the full production potential has not been achieved yet. According to FAO, pineapple fresh yield can reach up to 90 tonnes per hectares. Using timely flying sensor images can help in monitoring pineapple growth and support field management decisions. In addition, combining this information with yield predictions can potentially fill in the yield gap. From previous pilot studies in Kenya and Mozambique, it is assumed that a yield increase of 20 percent can easily be realized. The cost of the service will be around 60 GHS/ha, which is around 10 euro/ha.

Figure 9 shows the total costs, total benefit and net benefit per farmer in time. Given the amount of services per growing season that are proposed (see paragraph 3.2.4), the total costs per farmer were calculated (grey line). The total benefit per farmer increase after 18 months, when 20 percent extra yield is harvested and sold at a price of 1 GHS/kg (blue line). After this a new cycle starts. The net benefit per farmer is given with the yellow line and shows that **there is a positive case for the service**.

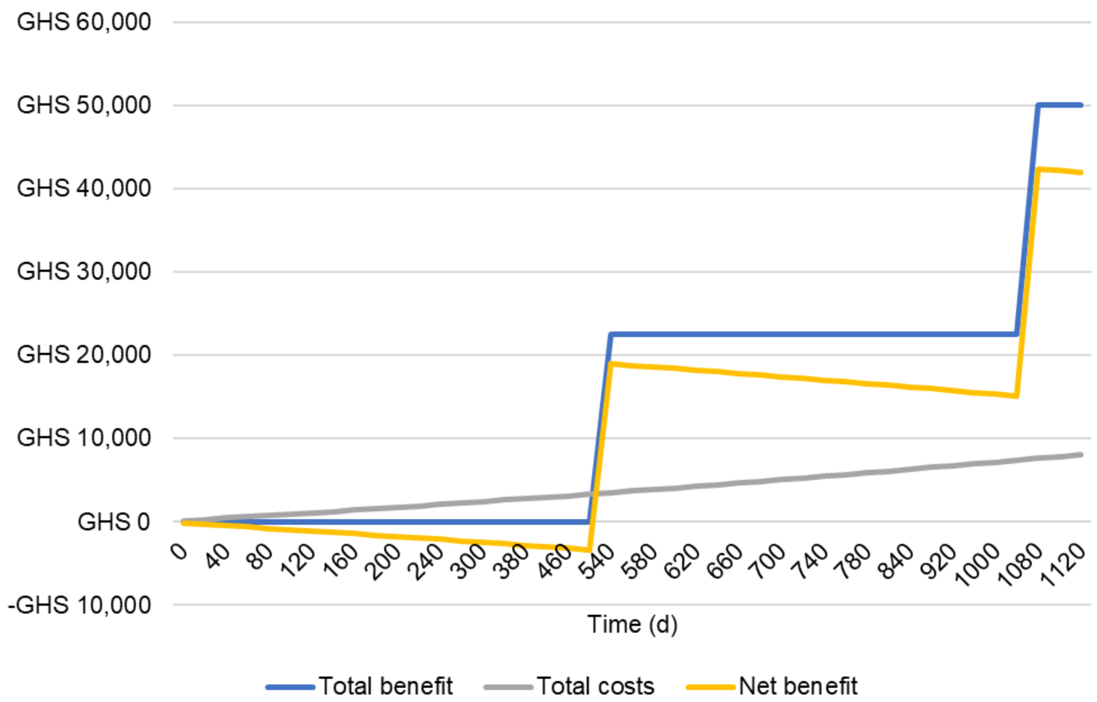

Figure 9. Total costs, total benefit and net benefit per semi-commercial farmer through time.

Given the total amount of semi-commercial smallholders in Ghana being 170,000, the total potential benefit of the service is more than 450 million euros per year. A decrease in the use of fertilizers and other agro-chemicals and a subsequent decrease in expenses for farmers, which has been observed in previous cases in Kenya and Mozambique, has not been taken into account in the above calculations. A full overview of the calculations can be found in Appendix 3.

3.3.3 Acceptance and willingness to pay of end users

Mostly, the respondents expressed appreciation of the proposed intervention and agree to the relevance thereof. Although existing IFDC[1] training services are not paid for by farmers, they view the concept of farmers paying for the proposed service as a "sound sustainability" element. Key

[1] International Fertilizer Development Center

stakeholders however predicted that, willingness to pay will be contingent on some conditions. These are identified as follows:

- ***The intervention should be initiated with intensive sensitization:*** Stakeholders believe farmers should first receive some intensive education on the relevance of irrigation, and the role of timely accurate information in maximizing irrigation. Seeing that irrigation is hardly practised among pineapple farmers, introduction of the technology without adequate education would not be advised.
- ***Advisory service accompanied by equipment and water source support:*** Key stakeholders including the Ministry of Food and Agriculture recommended that, the proposed information service be supplemented with some support services. Realising that many smallholder farmers do not have water sources nor capital for irrigation systems, information on irrigation would not be useful. A partnership is suggested to make this possible.
- ***Proven effectiveness:*** Farmers interviewed indicated a willingness to pay for proven results. Key stakeholders accordingly recommended the setup of demonstration fields to prototype the solution. It is expected that the outcomes of implementation on these farms should enhance uptake among farmers. In the words a GIZ respondent, *"...let them see how efficient it is."* A gradual approach in coverage is also proposed. Farmer cooperatives could be the first point of call as they are more likely not to be deterred by the capital needed to adopt irrigation systems as capital can easily be pooled among members.
- ***Conveniently paced payment schedule:*** Smallholder farmers foresee challenges with paying upfront. They recommend that payments be made after harvest, by which time they can attest to effectiveness with results. Another option is to have payments made in instalments or per information type.

3.3.4 Business model and service agreements

<u>Franchise structure</u>

An initial business model for the service has been made (Figure 10). FutureWater and Farmerline are seeking to set up its operations in Ghana in accordance with a "light" business model, which can be easily implemented without heavy supporting structures and costs (FutureWater chooses not to heavily invest in assets in the country), is seeking some equal risk taking from local partners, and is easily expandable into other geographical areas.

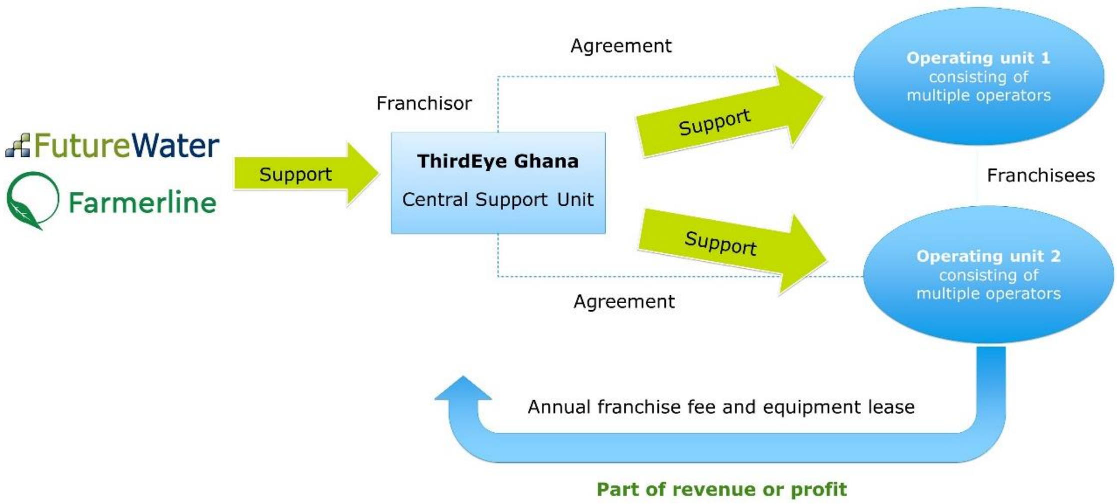

Figure 10. Initial ThirdEye business model.

The idea to set up a central “Support Unit” which on a flexible basis provides the necessary support to the operators (or local managers, who may act as technical operator or outsource technical operations) in different locations, is best served by setting up a single unit franchise structure. It allows FutureWater and Farmerline to be able to expand a network of interdependent business operators effectively and efficiently. The investment requirement is low, however proper emphasis should be given on providing the right support to local operators (i.e. the franchisees). For the franchisee, the advantages include a low threshold in stepping into the business: the operator does not need to acquire assets, rather it invests in an operating system through which it can present the extension service, effectively make sales, and collect revenues. To that end, “ThirdEye Ghana” would act as local franchise holder supporting the operations in any geographical location where local operations will be set up.

In a single unit franchise relationship, the franchisor grants to the franchisee the right to operate one location using the franchisor’s trade name, service marks, and operating system. This means that the franchisor should enter into a franchise agreement with every franchisee. From a managerial and operational point of view it is more beneficial to have each location covered by a separate franchisee, moreover as both locations are characterized by different market dynamics and hence require different operational business models. The proposed single-unit franchise system will allow the franchisor to test the commercial relationship with the operator before eventually allowing the franchisee to open up new facilities in the area, if so applicable. The business model will tested and, if needed, further refined in the next SBIR phase.

<u>Identified revenue streams</u>

FutureWater and Farmerline opt to provide the service on a subscription basis: a farmer(s) can request the service, after which the flying sensor operator conducts the flight, processes the images, makes yield forecasts and provides advice to the farmer(s). Payment is best conducted through a mobile phone-based money transfer system, like MTN Mobile Money.

The three different revenue streams that have been identified so far are shown in Figure 11. The operating unit, in a certain area, supported by the central support unit, can sell the service directly to commercial farms, semi-commercial smallholders (who can pay directly or through their irrigation district or farmers’ association), the sub-county itself and processors who work with smallholder farmers. In case of the latter, the service is delivered to smallholder farmers, who sell their harvest to processors (i.e. contract farming). These processors benefit from buying the service for their smallholder producers by getting more and higher quality inputs for their production process.

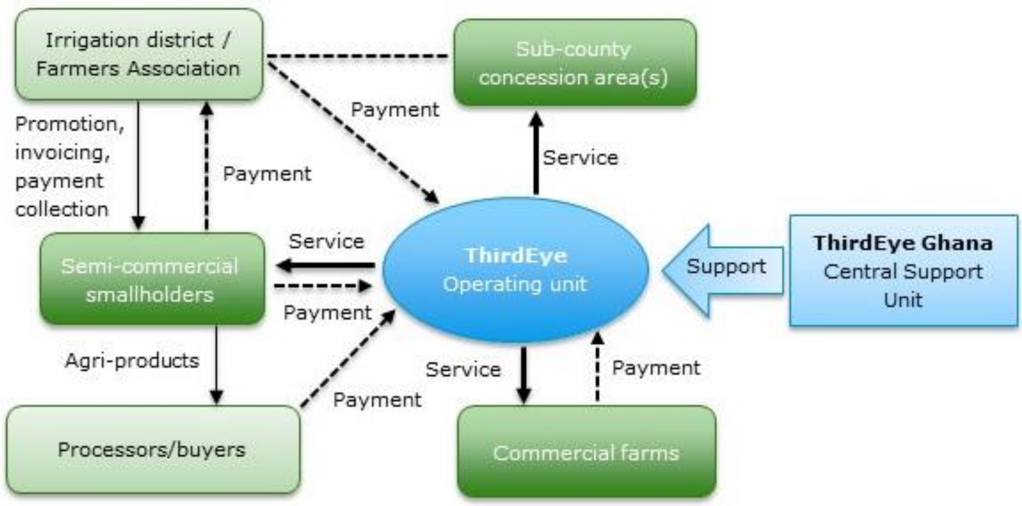

Figure 11. Overview of identified revenue streams.

3.3.5 Existing information services

The feasibility study has uncovered huge gaps in existing information services, especially among smallholder pineapple farmers. The commercial farms make up for the dearth of advisory services with periodic training. Gold Coast Fruits, for instance, mentioned during the interview that they have not subscribed to any information service, but they are beneficiaries of skills development training funded by Sustaining Competitive and Responsible Enterprises (SCORE). HPW Fresh and Dry Ltd which supports 300 outgrowers to produce for their processing factory, organises training for their farmers periodically. This was confirmed by some outgrowers interviewed. Apart from the periodic training received by outgrowers, smallholder pineapple farmers do not receive any advisory services at all. The Ministry of Food and Agriculture (MoFA) extension officers are expected to offer some guidance and training to farmers in the areas assigned. Some pineapple farmers interviewed at Bawjiase confirmed receiving some information and training from the erstwhile MoFA Extension Officer in the area, but none from the current.

In Ghana, a few start-up companies are developing information services for farmers. Farmerline is a successful local start-up company providing information about market prices, quality of farm inputs (e.g. fertilizers), and weather forecast using Mobile Phone-Enabled Services. This has shown to be beneficial to farmers. The benefit consists in improving production planning and management of weather related risks (Baumüller, 2018).

Both Bomarts Farms and Gold Coast Farms made mention of a drone irrigation project that has been proposed to them “recently”. The proposed service used drones in pesticide application. Also, field demonstrations have been carried out much to the satisfaction of the respective farm managers. The company providing the service is identified as AquaMeyer. Bomarts observed that their service is “faster and cost effective” as their proposed charge is GHS 50 per acre. They specified that, this purely is pesticide application with drones, and does not come with any advisory services. Similarly, GIZ is partnering with a drone service provider, to introduce the use of drones in spraying crops with pesticides.

On the existence of any similar technology to accurately measure crop stress and water need, the study revealed none. **Generally, all respondents acknowledged that the proposed solution would fill a major gap in their production.**

3.3.6 Regulation or property protection bottlenecks

No bottlenecks were found in the area of regulation or property protection. A **national drone permit was successfully issued** at the Ghana Civil Aviation Authority (GCAA) and regulation regarding the use of drones would not form a risk in the next phases of the project.

4 Conclusion and outlook

4.1 Technical risks

After completion of the feasibility stage, the successful development and testing of a prototype of the proposed innovation in the following SBIR stages is assessed as **technically feasible**. Each of the pre-defined technical feasibility questions was answered positively, as described in this report. At this stage, no technical bottlenecks have been found which prevent embedding of a flying sensor service into the local Farmerline information service, local input data availability is sufficient, technical restrictions for the farmer are expected to be limited, and the form and frequency of a new information system have been further concretised.

In addition to the answering of the specific technical feasibility questions defined prior to the study, a major part of the information chain at the back-end of the proposed service was already tested during this SBIR phase 1, as described in Appendix 1. This included the **execution of flying sensor flights** over Gold Coast Fruits pineapple farm in Ghana, processing of the collected data, and initial runs of the crop yield / water productivity simulation model. The link with simulation models to produce yield and water productivity forecasts was already tested. An initial calibration of this model setup has highlighted substantial existing gaps regarding pineapple yields and water productivity, and thus the potential for the proposed services to **significantly enhance pineapple productivity**.

Since part of the research and development activities were already completed during the feasibility stage, SBIR phase 2/2A will already allow a focus on initial pilot implementation of the service. However, still some technical risks were identified which require further attention in the SBIR research and development stage:

- In the feasibility study, initial mapping and modelling activities were tested. However, the outcomes of such models and maps are not directly suitable for dissemination to semi-commercial smallholder farmers. In particular the modelling results, generated for different farm management strategies / scenarios to identify optimal practices, require a degree of translation to be taken up by the local end user. The research and development phase will comprise a work package dedicated to shaping the information service to user needs, in terms of content, format, and language / wording. The risk that the translation of flying sensor images and model outputs into actionable information is unsuccessful, is considered **low**. An intensive, co-creative approach with farmers and other stakeholders will be applied, and Farmerline has a long track record in disseminating agricultural information to semi-commercial smallholders.
- Preliminary yield and water productivity simulations were produced for a single pilot site, to assess the technical feasibility of integrating flying sensor images and crop modelling. However, the accuracy of yield simulations and water productivity projections under different farm management strategies needs to be investigated further, to ensure that sufficiently accurate information can be provided to the farmers. Key to delivery of meaningful information is timing; simulating yields and water productivity can be considered feasible from a certain point in the growing season. The timing of this point needs to be assessed in the research and development phase, as well as the accuracies (and sensitivities) associated with pineapple yield and water productivity simulations. Due to the use of proven technology such as the FAO AquaCrop model and ThirdEye flying sensors, the risk of unsatisfactory accuracies of yield and WP simulations is considered **low**.
- Weeds have a negative impact on pineapple yields and weed control is one of the main actions semi-commercial can take to mitigate suboptimal crop production. Flying sensors have a sufficiently high spatial resolution to filter out weeds from the pineapple crop. However, algorithms to perform this filtering depend on weed type and crop type, and

require a degree of calibration. The risk exists that weeds are incorrectly included in canopy cover and yield calculations. In the SBIR phase 2, the method for weed filtering and weed management advisory needs to be developed further for the local Ghanaian context. Associated risks are estimated as **very low** due to the consortium's previous experience with the same issue in a Sub-Saharan African setting.

4.2 Economic risks

In this feasibility study the **economic feasibility was sufficiently proven** for a subsequent research and development trajectory (SBIR phase 2/2A). This is mainly concluded by analysing the costs and benefits of the solution for semi-commercial smallholders. This analysis shows there is a positive case for the service, with a net benefit of almost GHS 20,000 (EUR 3,600) per farmer per growing season. The cost of the service is acceptable to local semi-commercial farmers, which means there is ample support for the further development of the information service. Moreover, the progress in this feasibility study, realized with a limited budget, meets the predefined expectations. After completion of a research and development trajectory (phase 2) the service will be technically mature enough for commercial expansion. After this the costs for keeping the service operational are relatively low.

Uptake of the innovation is expected to be very successful since it has been specifically designed for semi-commercial smallholders in Ghana. The innovation lies in the fact that we have managed to incorporate very advanced technology with relatively inexpensive hard- and software - we make use of high-quality drones and cameras that have been simplified and adapted to local circumstances. This frugal innovation costs around 2,000 euros per flying sensor kit, compared to 15,000 euros for more complex systems used in the developed world. Furthermore, we make use of open source software for image processing and do all of this processing locally, meaning no heavy internet connections are needed. This makes the concept extremely suitable for the 'Bottom of the pyramid (BoP)' and the new middle-class in emerging economies.

From the study, it was observed that farmers' willingness to pay for advisory services is highly dependent on how efficient the scheme operates and supports their farming activities. The study also noted that a partnership with related product/service providers in the value chain offers potentially stronger commitment to adoption of the use of advisory services to benefit farmers. Again, the market for irrigation advisory services is largely untapped given that not much is being done in Ghana.

Based on the findings of the study, some economic risks were identified which require further attention in the SBIR research and development stage:

- Successful market entry could be hampered if local partners are not willing to cooperate. For successful market entry, private sector organizations which offer tangible products, such as inputs and irrigation systems, should be made implementing partners for the proposed solution. Cost of these products can be bundled together with that of the advisory service as an incentive to farmers, which will be further explored in phase 2. Given the excellent local connections of Farmerline, the risk of not finding helpful collaborations is considered **low**. IFDC has already indicated willingness to collaborate in the implementation of the project.
- Farmers can be very conservative and could be reluctant to buy the service. Demonstration fields would significantly help farmers to appreciate the effectiveness of the intervention and will be set up in phase 2. This could be done with existing fields and/or newly cultivated fields for reference. Since, locations for such fields have already been devised, the risk of not finding such locations is considered **low**.
- Developing only one service makes the enterprise fragile. As a revenue driver for both the service and business partners, we propose to develop two additional services to the irrigation information. These services (an Input Demand Forecaster and a Crop Stress

Forecaster), will make use of ground data on farms/fields, combined with modules for pest and disease forecasting. They will be further explored in a research and development phase. Data from these forecasters can be licensed to relevant businesses looking to access such insights. Initial contacts with such businesses are ongoing. Since these services are relatively new, the development risk is considered to be **moderate**.

- A competing service for the pineapple sector in Ghana is identified. This service will be further looked into during the subsequent phase. Given the elaborate nature of the sector and analysis executed in this feasibility study, this risk is considered **very low.**
- Even though costs to keep the service operational are relatively low, initial investment costs could be considered as high. The SBIR funding will be used to cover these costs and given the experience of the consortium in setting up similar services in developing countries the risk of failure is considered **very low**.

4.3 Organizational risks

The organizational risks to achieve a fully operational, marketed version of the proposed service are **low**. The project partners dispose of all expertise acquired to further develop the product and have successfully collaborated in this SBIR feasibility stage, as well as in other projects. With the expertise of Farmerline regarding local stakeholders, the pineapple sector, and communication with semi-commercial farmers, and the technical skills of FutureWater regarding remote sensing and crop modelling, there is a clear division of tasks among the partners. Continuous communication between the project partners will minimize organizational risks as much as possible.

4.4 Outlook to phase 3

For phase 3, the commercialization phase, a few potential end users will already be involved in phase 2. The Gold Coast Fruit company is interested in our potential service to provide information to support pineapple production. Initial contacts were made possible thanks to the support of Farmerline and will be further extended in phase 2 and 3. Early implementation of the service in phase 2 will help increasing chances of successful market entry in phase 3.

Partnerships with enabling environmental actors and service provision actors will be established as soon as possible. These include the Ministry of Food and Agriculture (MoFA), Ghana Irrigation Development Authority, Lands Commission, Hydrological Services, Local Government, and Ghana Meteorological Agency. In addition to the ministries, departments and agencies, consist of bilateral and multilateral donor-funded projects and programs (such as GIZ, IFDC). These institutions enhance the sector by focusing on infrastructure, capacity building, research, farm/farmer productivity and income interventions.

Service provision actors are either public, private or non-governmental organizations. Their aim is to deliver support services to farmers to ultimately increase productivity and incomes. Several of these service provision actors have business arrangements with farmers to deliver services for which there is compensation. Examples of these actors are Callighana, Ministry of Food and Agriculture extension officers, financial and lending institutions and farmer education or information providers.

Figure 12 shows a schematic overview of the workflow and different collaborations proposed for phase 3.

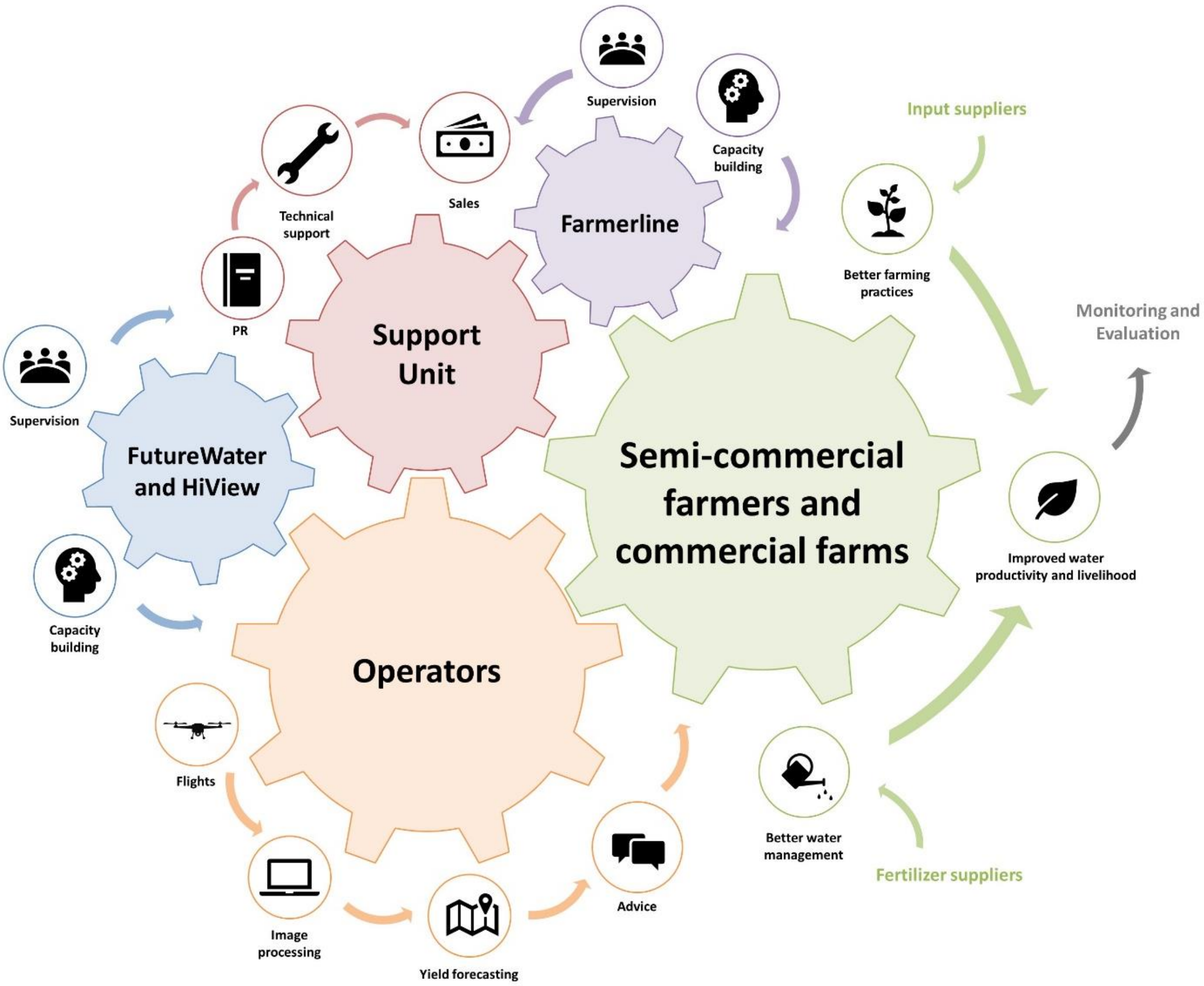

Figure 12. Proposed workflow and collaboration for phase 3.

5 Finances

Below are two tables with the planned and realized amount of days and costs.

Table 2. Planned vs. realized days.

		Planned (d)	Realized (d)
Description		**Total**	**Total**
WP 1	**Local needs assessment**		
	Identification stakeholder and user types	10	14
	Focus groups and user needs	45	40
	Expert interviews	10	16
WP 2	**Technical feasibility**		
	Inventory of required and available data	11	11
	System integration: risks and opportunities	14	11
	Simulated testing of irrigation water productivity advice	11	13
	In-field demonstrations	13	14
WP 3	**Economic feasibility**		
	Market study and SWOT analysis	9	10
	Cost/benefit analysis	9	8
	Legal/political barriers	7	4
WP 4	**Project coordination**	6	6
Total		**145**	**146**

Table 3. Planned vs. realized costs.

		Planned (d)	Realized (d)
Description		**Total**	**Total**
WP 1	**Local needs assessment**		
	Identification stakeholder and user types	€ 1,700	€ 2,380
	Focus groups and user needs	€ 7,650	€ 6,800
	Expert interviews	€ 1,700	€ 2,720
WP 2	**Technical feasibility**		
	Inventory of required and available data	€ 5,650	€ 5,650
	System integration: risks and opportunities	€ 8,050	€ 6,910
	Simulated testing of irrigation water productivity advice	€ 5,650	€ 7,250
	In-field demonstrations	€ 7,250	€ 6,800
WP 3	**Economic feasibility**		
	Market study and SWOT analysis	€ 4,050	€ 2,330
	Cost/benefit analysis	€ 4,050	€ 5,770
	Legal/political barriers	€ 2,450	€ 1,940
WP 4	**Project coordination**	€ 4,800	€ 4,800
Sub-total labour		€ 53,000	€ 53,350
Direct expenses		€ 5,500	€ 3,090
TOTAL		**€ 58,500**	**€ 56,440**
Own-contribution		€ 8,500	€ 6,440

The amount of days and labour costs spent was slightly higher than proposed. This has to do with the fact that more attention was paid to the technical testing and in-field activities. The direct expenses were lower because no hardware was bought for the project. All hardware used was provided by HiView free of charge.

Appendix 1: Technical Feasibility report

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Table of contents

Tables

Figures

1 Introduction

Agricultural losses are abundant and pose a threat to food security. Water stress, pests, and weeds hamper the growth of crops worldwide. In Ghana, pineapple production is key for local and country economy and livelihood. Pineapple production sustains several semi-commercial farms and smallholder farmers. Three main varieties are grown i) Smooth Cayenne and ii) Sugar Loaf and iii) MD-2. The MD-2 variety was recently introduced into the market due to higher international demand. MD-2 is known for its sweet taste and improved physical properties (e.g. cylindrical shape, long shelf life). However, MD-2 requires higher pest control, fertilization, and irrigation requirements compared to Smooth Cayenne and Sugar Loaf. In Ghana, only semi-commercial farms have the economic and technical capacity to grow MD-2. The Gold Coast Fruits company has successfully invested in the MD-2 variety including an irrigation system and soil fertility procedures. Their pineapple fields are located 50 km from the capital city Accra, enclosing approximately 400 hectares of farmland. The achieved fresh pineapple yield is between 45 and 55 tonnes per hectare. The pineapple MD-2 production from Gold Coast Fruits is known for its high export quality.

Smallholder farmers and other semi-commercial farms are producing Cayenne and Sugar Loaf varieties which are sold in the local market and are producing other crops to sustain profits. There is a tremendous pressure to change the production to MD-2 variety to be able to compete in international markets. However, the economic means and information about the adequate implementation of the variety are lacking. Improving information about crop management procedures and irrigation scheduling would allow better planning and investments in MD-2 pineapple variety. Providing an integrated information service for these semi-commercial farms is crucial to enhance decision making and compete in national and international markets.

In Ghana, already startup companies are developing information services for farmers. Farmerline is a successful local startup company providing information about market prices, quality of farm inputs (e.g. fertilizers), and weather forecast using Mobile Phone-Enabled Services. This has shown to be beneficial to farmers. The benefit consists in improving production planning and management of weather related risks (Baumüller, 2018). However, pineapple yields remain low. Yield losses occur due to water deficit, fertility stress and pests during the crop development. Providing near-real time information about the condition of the plant at each growth stage can prevent pineapple yield losses. This information can be provided using flying sensors (drones) designed to monitor large crop fields.

Using flying sensors to monitor the crop growth has shown to be technically feasible. FutureWater has developed successful tests in Mozambique and Kenia providing valuable information for farmers about crop development and predicting crop yields. In this project, the aim is to co-create a service between Farmeline and FutureWater which can integrate flying sensors monitoring information and pineapple yield predictions into the existing Mobile Phone-Enabled Service.

2 Overview

In order to meet the future needs of food and fibre production, developing and developed countries need to focus more on efficient and sustainable use of land and water (Bastiaanssen & Steduto, 2017). Farmers have been able to gain profit by increasing agricultural production per unit of land. However, it is key to include the water consumption component in agricultural production. This would allow to improve agricultural production per unit of water consumed.

Water productivity consists of two components: crop yield and water consumed. Water consumption occurs through evapotranspiration which is the sum of plant transpiration through the stomata in the leaves, and evaporation that occurs from the soil surface and intercepted water by the leaves (Squire, 2004). As such, water productivity can be expressed as:

$$WP = \frac{Y}{ET} \tag{1}$$

where WP = water productivity (kg/m^3), Y = crop yield (kg/ha) and ET = actual evapotranspiration (m^3/ha)

Higher water productivity can be obtained in two ways: maintaining the same production while consuming less water resources, and/or achieving a higher production while consuming an equal amount of water. Thus, to assess WP and evaluate the impact of interventions in the field, yield should be documented, but also ET.

Yield can be recorded and measured in several ways. Online databases exist on predominantly national or provincial level but these are not site-specific. Field surveys can be conducted to inquire farmers on their yield of last year or last years. However, this is generally costly and time-consuming. Therefore, yield is often predicted using crop water simulation models, or agro-hydrological models (see section 3.3). An additional advantage to use these models is that they actually allow assessing the potential for improvements and performing scenario analysis. The models also require field data (soil, planting density, etc) but generally easier to obtain by either field visits or remote sensing.

ET_{act} is hard to measure in the field, and therefore commonly studies use potential evaporation resulting from a reference crop and crop coefficients. These crop coefficients need to be adjusted to the actual soil moisture and soil salinity situation, to calculate the correct actual evaporation. Remote sensing can also be used to measure the actual evaporation, as with thermal infra-red observations and surface energy models it is possible to quantify water consumption (Bastiaanssen & Steduto, 2017). However, these methodologies have certain limitations in terms of applicability in agriculture. Often the satellite data is of low temporal and spatial resolution, or data is unavailable due to cloud formation (Xiang & Tian, 2011). Therefore, we argue that, on field scale, highest quality results can be obtained by using an agro-hydrological model, combined with FS remotely sensed data, and meteorological data. This way, WP can be assessed at the farm-level and options to improve WP can be compared.

3 Literature review

3.1 Flying sensors

The high-resolution data from flying sensors can play a crucial role in closing the gap between satellite-based imagery and ground observations (Xiang & Tian, 2011). Although most academic research focusses on FS applications for agricultural management (Caruso et al., 2017) and (Katsigiannis et al., 2016)**,** amongst others, there has been some academic attention for crop yield prediction methodologies using FS-derived data. Most of these crop prediction methodologies compute DEMs or height of the plants as an input for regression models.

Especially vineries have experimented with FS use in their agricultural practices (Caruso et al., 2017; Fiorillo et al., 2012; Rey-Caramés, Diago, Pilar Martín, Lobo, & Tardaguila, 2015) Flying sensor data has been used to estimate grape quality parameters and wine productivity. For example, by creating a digital Crop Surface Model (CSM) and NDVIs of the vinery it is possible to get biophysical and geometrical characteristics of grapevines, such as pruning weight, canopy volume and Leaf Area Index (LAI). These variables are important indicators for the farmer to manage their farm; e.g. where to irrigate and apply fertilizers.

Furthermore, biomass estimation has been proven useful in yield prediction. Biomass can be estimated from Vegetation Indices (VIs) incorporating NIR reflectance (Juliane Bendig et al., 2015). Additionally, it is also possible to estimate biomass through crop surface models, or in combination with vegetation indices (Possoch et al., 2016). CSMs are DEMs that require a baseline to measure the relative crop height, consequently calculating the volume of the crop. Based on CSMs constructed with low cost FS, (Juliane Bendig et al., 2015)) proposed an FS-based methodology with VIs and Plant Height (PH). They applied several regression models to estimate the biomass with a combination of VI and/or PH as the variables. The results show a normalised ratio index, named GnyLi, and PH show the highest correlation with dry biomass.

The GnyLi index put forward by (Gnyp et al., 2014) was computed in a study on winter barley. The basis of this index lies in the NRI, Normalized Ratio Index, calculated from NIR and SWIR bands. Like NRI, GnyLi focusses on two absorption and reflection features that range between 800 and 1300 nm. The high reflection in these bandwidths is due to the intercellular structure of plants. The absorption signature in this bandwidth is dependent on presence of water in the plant, for example. To capture these signatures and relate them to biomass, an optimization approach is followed to identify the four spectra visible in reflectance and absorbance of the crop. This methodology can only be applied with a multi-spectral camera (“Imagery from multispectral sensors vs . imagery from cameras,” 2004)

$$\frac{R_{900} \times R_{1050} - R_{955} \times R_{1220}}{R_{900} \times R_{1050} + R_{955} \times R_{1220}}$$ (Gnyp et al., 2014).

Another example of combining VIs with CSMs is provided by (Geipel, Link, & Claupein, 2014). In their research they assessed the potential to use CSM to calculate potential yield with the help of linear regression models. The researchers focussed on corn grain yield at early- to mid-season growth stages. In their methodology they computed a CSM, and with the help of ExG (Excess Green Index) the area covered with crop was extracted from the uncovered area. The latter was done to produce an average crop height, with different ExG thresholds. The mean crop height was then used as an input for three standard linear regression models to predict corn yield. Results showed that the resolution of the CSM is of importance at the beginning of the growing stage, later the regression models show fairly equal outcomes in terms of correlation. Yield prediction can benefit from including CSMs and VI in the methodology. (Geipel et al., 2014)

More research on the application of CSMs in agriculture has been performed, already formulating and testing opportunities of the FS-retrieved data (J Bendig et al., 2013), with (Eisenbeiss, 2004)) one of the first to showcase the potential added value of CSMs to crop monitoring (Aasen & Gnyp, 2014). (Juliane Bendig et al., 2014)) deployed a simple low-cost drone with an RGB camera to research applicability for crop yield prediction. In their approach they abstracted a mean Plant Height as an input for five linear models estimating biomass (fresh and dry) and tested through cross-validation.

As one can conclude from this overview of academic work on usage of FS- retrieved data in the domain of precision agriculture, no literature links FS-derived VIs directly to crop growth models. Neither there is literature on the effect of the farmer’s yield after incorporating FS-based information.

There are, however, existing yield forecasting methodologies based on satellite remote sensing and crop growth models (Johnson, 2014). An example is the study by (Bolton & Friedl, 2013)), who deployed MODIS imagery to predict maize and soybean yields with linear models. Various studies have shown the correlation between VIs and yield varies in different stages. (Bolton & Friedl, 2013)) found yield prediction after 65-75 days after green-up of maize most successful. In their research they also point out that the spatial resolution of the product used (500m) will hamper the applicability to regions with less intensive agriculture. Other approaches focus on estimating photosynthetically active radiation (PAR), or link imagery to crop simulation models for calibration (Sibley, Grassini, Thomas, Cassman, & Lobell, 2014).

The development of FS-based yield forecasting can be inspired by existing methodologies within the field of satellite remote sensing. That said, it is important that databases with small-scale resolution imagery are created to improve research and refine methodologies. Because there is little to no literature on existing methodologies linking FS imagery to agro-hydrological models, the next sections will be dedicated to outlay the possible information that can be retrieved with simple, low-cost UAVs (NIR-G-B or RGB cameras). Additionally, we explore the different parameters that can be linked to existing crop models, to evaluate the possibilities to link FS information directly to modelling outcomes.

3.1.1 Sensor techniques

When light falls on a leaf, reflection occurs. The amount of reflection of green light (540 nm) is very high, therefore the plant is observed green by humans. Healthy vegetation does not reflect much red light (700 nm), since it is absorbed by chlorophyll abundant in leaves. In the near-infrared spectrum (800 nm) the amount of reflection increases rapidly to 80% of the incoming light (see Figure 1). This increase is caused by the transition of air between cell kernels. This is characteristic for healthy vegetation.

Damaged plant material does not show this increase in reflected near-infrared light. Moreover, the reflection of red light is much higher than in healthy plant material. By measuring the reflection in these spectra, damaged plant material can be distinguished from healthy plant material (van der Schans, van Evert, Malda, & Dorka-Vona, 2012).

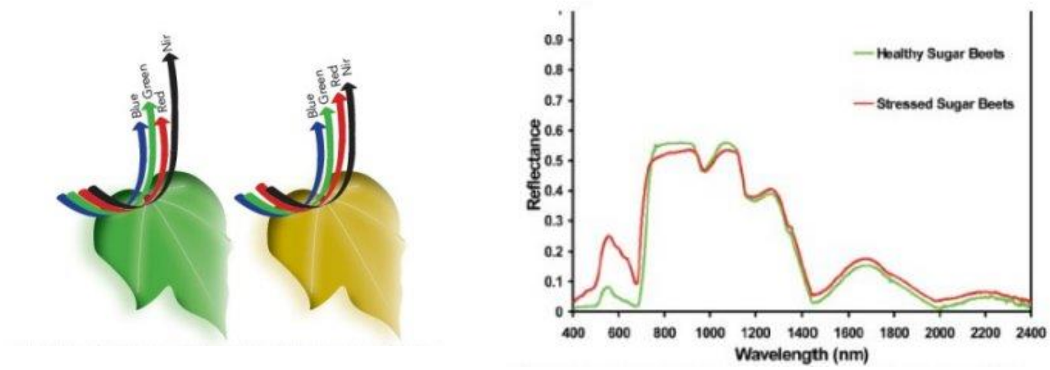


Figure 1. An illustration of the spectral reflectance of a healthy sugar beet plant and a sugar beet plant that faces stress (Source: http://www.aces.edu/pubs/docs/A/ANR-1398/index2.tmpl).

3.1.2 Possible vegetation indices

In this section we present the possible vegetation indices that can be computed with low-cost FS and in what way the data coming from the FS can be used to obtain relevant crop information. Low-cost FS (e.g. Mavic, Phantom) contain, or can be customized to facilitate, two types of sensor technologies. The first type is a sensor with RGB bands, capturing the reflectance of the red, green and blue wavelengths/bandwidths. The other possibility is a camera capturing NIR-G-B spectra. Table 1 lists the possible Vegetation Indices (relevant to yield forecasting) available for the type of spectra available (NIR, R, G, B).

Table 1. A list of possible Vegetation Indices that can be sensed with the available low-cost UAVs, an explanation and relevant crop information is also given.

Vegetation indices ↓	**Explanation**	**Relevant crop information**
NDVI[1]	$\frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}}$ The Normalized Vegetation Index quantifies the difference between near infra-red and red light. NIR is reflected by vegetation, while red light is absorbed. This pattern changes as the plant faces stress.	Canopy cover, LAI, Biomass, Crop stress
NDVI-B	$\frac{R_{NIR} - R_{Blue}}{R_{NIR} + R_{Blue}}$ When the NDVI is replaced by blue light the index becomes less sensitive to crop stress. Compared to red NDVI, the blue NDVI shows less contrast between stressed and unstressed crops. When a plant is facing stress the changes in reflectance in the blue spectrum is not directly linked to crop stress, but leaf pigment.[2]	Canopy cover, LAI, Biomass, Crop stress
GNDVI	$\frac{R_{NIR} - R_{Green}}{R_{NIR} + R_{Green}}$ In the green NDVI the red band is replaced by the green band. GNDVI is more sensitive to chlorophyll content, which indicates the nitrogen and water uptake. (Hunt et al., 2011)	Canopy cover, LAI, Biomass, Crop stress

[1] Only possible if two flights will be performed with the available drones
[2] http://www.senteksystems.com/2015/11/23/ndvi-definitions-red-blue-enhanced/

Vegetation indices ↓	**Explanation**	**Relevant crop information**
SAVI	$\frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red} + L}(1 + L)$ NDVI has been found unstable, varying with soil type amongst other factors. Soil Adjusted Vegetation Index attempts to correct for soil brightness with an adjustment factor, L. Areas with little vegetation will give low values.	Canopy cover, LAI, Biomass, Crop stress
GRVI	$\frac{R_{Green} - R_{Red}}{R_{Green} + R_{Red}}$ Green-Red Vegetation Index can be used to distinguish between green vegetation and other types of ground cover. In comparison to NDVI, GRVI can detect the phenology better during saturation, thus can detect subtle disturbances in the growing period better. (Motohka, Nasahara, Oguma, & Tsuchida, 2010)	Canopy cover, detecting subtle disturbances
RVI	$\frac{R_{NIR}}{R_{Red}}$ Th Ratio Vegetation Index is the predecessor of the NDVI. Dense green vegetation will produce a high ratio, while soil reflectance will turn out low. This creates a contrast between the different land cover types.	Canopy cover, LAI, Biomass, Crop stress
ExG	$2 \times R_{Green} - R_{Red} - R_{Blue}$ Excess Green Index is an index used for greenness identification. With this index it is possible to detect (healthy) crops from bare ground.	Canopy cover, LAI, Biomass,
CSM	$\text{Plant Height} = DEM_{crops} - DEM_{base}$ Crop Surface models can be constructed with the help of Digital Elevation Models (DEM). With CSMs it is possible to derive plant height distribution and determine biomass.	Biomass, yield

In this study, we will focus in obtaining the canopy cover (CC) information with low-cost flying sensors. The canopy cover is the fraction of the soil surface covered by the canopy:

$$CC = \frac{Soil\ surface\ covered\ by\ the\ green\ canopy}{Unit\ ground\ surface\ area} \quad (2)$$

CC ranges from zero at sowing (0 % of the soil surface covered by the canopy) to a maximum value at mid-season which can be 1 when a full canopy cover is reached and 100 % of the soil surface is covered by the canopy. The shadow on the soil surface of the canopy cover when the sun is right overhead is the canopy cover.

4 The AquaCrop model

AquaCrop is the FAO crop-model to simulate yield response to water. It is designed to balance simplicity, accuracy and robustness. AquaCrop is a companion tool for a wide range of users and applications including yield prediction under climate change scenarios. AquaCrop is a completely revised version of the successful CropWat model previously designed by FAO. The main difference between CropWat and AquaCrop is that the latter includes more advanced crop growth routines. Aquacrop is water driven.

AquaCrop includes the following sub-model components: the soil, with its water balance; the crop, with its development, growth and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand and CO2 concentration; and the management, with its major agronomic practice such as irrigation and fertilization. AquaCrop flowchart is shown in Figure 2.

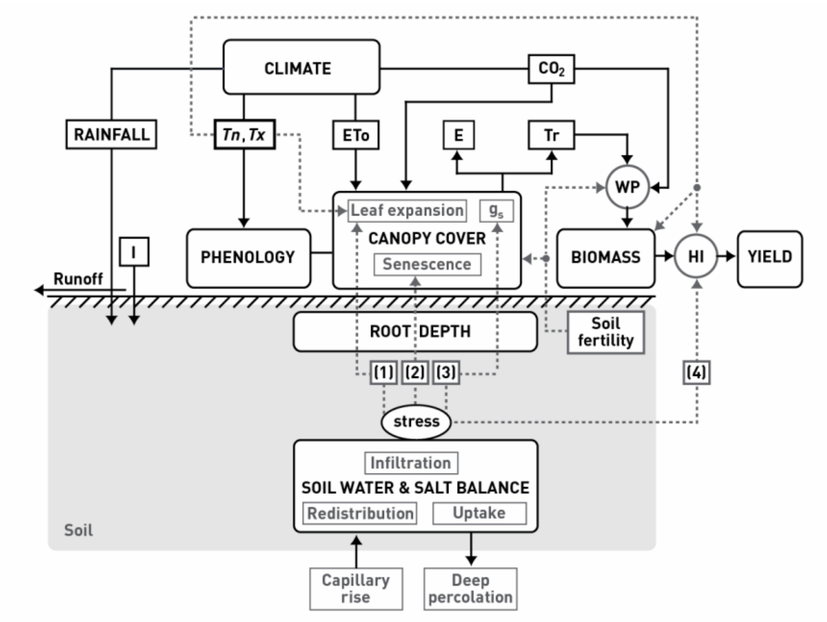


Figure 2. Main processes included in AquaCrop.

The features that distinguish AquaCrop from other crop models is its focus on water, the use of ground canopy cover instead of leaf area index, and the use of water productivity values normalized for atmospheric evaporative demand and of carbon dioxide concentration. This enables the model with the extrapolation capacity to diverse locations and seasons, including future climate scenarios.

The input files needed for Aquacrop are relatively few. To simulate Aquacrop effectively a climate file is needed – containing temperature, ET_{ref}, rain, perhaps CO_2 – other environmental information is also required: crop type, management specification, soil profile, groundwater file. Furthermore, the start of the growing season is needed, some information about the initial condition, and the simulation period. (Raes, Steduto, Hsiao, & Fereres, 2012). However, Aquacrop has still around 100 parameters relating to crop, soil, management and input factors (Silvestro et al., 2017).

Vegetation indices can be linked to Aquacrop by calibrating canopy cover to obtain better results. The dimensionless crop growth indicator, canopy cover, can be retrieved from high-resolution satellite data, FS imagery or field-based images. Satellite imagery has the issue of clouds and are often too expensive for high-resolution images. Field-based cameras are only useful for small plots and are not feasible for the monitoring of several plots at the same time.

AquaCrop is a widely used crop model, which simulates the yield response to water using physically-based parameters. It has been used in climate change impact studies in various parts of the world (J E Hunink & Droogers, 2010, 2011; Johannes E Hunink, Droogers, & Tran-mai, 2014). In addition, AquaCrop has been applied to predict water productivity and crop yield based on flying sensor information (den Besten, Simons, & Hunink, 2017) and to assess irrigation scheduling scenarios (Goosheh, Pazira, Gholami, Andarzian, & Panahpour, 2018). It is specially recommended for small scale farm level application. Hence, the appropriate model for our purposes.

A general description of the Aquacrop model is provided in section 3.3.1. This section further specifies the model properties relevant to this application.

4.1 Theoretical assumptions

The complexity of crop responses to water deficits led to the use of empirical production functions as the most practical option to assess crop yield response to water. Among the empirical function approaches, FAO Irrigation & Drainage Paper 33 (Doorenbos and Kassam, 1979) represented an important source to determine the yield response to water of field, vegetable and tree crops, through the following equation:

$$\left(\frac{Y_x - Y_a}{Y_x}\right) = k_y \left(\frac{ET_x - ET_a}{ET_x}\right) \quad (3)$$

where Y_x and Ya are the maximum and actual yield, ET_x and ETa are the maximum and actual evapotranspiration, and k_y is the proportionality factor between relative yield loss and relative reduction in evapotranspiration.

AquaCrop evolves from the previous Doorenbos and Kassam (1979) approach by separating (i) the ET into soil evaporation (E) and crop transpiration (Tr) and (ii) the final yield (Y) into biomass (B) and harvest index (HI). The separation of ET into E and Tr avoids the confounding effect of the non-productive consumptive use of water (E). This is important especially during incomplete ground cover. The separation of Y into B and HI allows the distinction of the basic functional relations between environment and B from those between environment and HI. These relations are in fact fundamentally different and their use avoids the confounding effects of water stress on B and on HI. The changes described led to the following equation at the core of the AquaCrop growth engine:

$$B = WP \cdot \Sigma Tr \quad (4)$$

where Tr is the crop transpiration (in mm) and WP is the water productivity parameter (kg of biomass per m^2 and per mm of cumulated water transpired over the time period in which the biomass is produced). This step from Eq. 1.1 to Eq. 1.2 has a fundamental implication for the robustness of the model due to the conservative behavior of WP (Steduto et al., 2007). It is worth noticing, though, that both equations are different expressions of a water-driven growth-engine in terms of crop modeling design (Steduto, 2003). The other main change from Eq. 1 to AquaCrop is in the time scale used for each one. In the case of Eq. 1.1, the relationship is used seasonally or for long periods (of the order of months), while in the case of Eq. 2 the relationship is used for daily time steps, a period that is closer to the time scale of crop responses to water deficits.

4.2 Software and scripts

For this analysis, the AquaCrop version 6.1 was used with the accompanying plugin. The main components included in AquaCrop to calculate crop growth are in Figure 3:

- Atmosphere
- Crop
- Soil
- Field management
- Irrigation management

More details on each of these components can be found in the AquaCrop documentation (Raes et al., 2009)

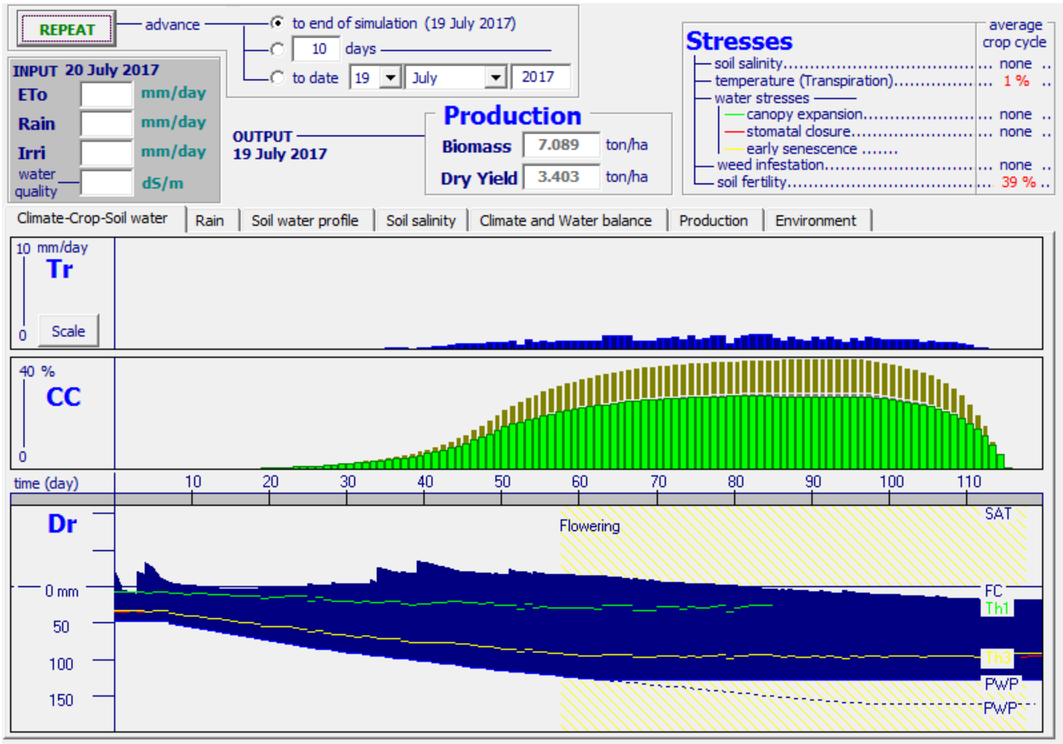


Figure 3. Example of a simulation in AquaCrop of a plot in the study area (Tr = transpiration, CC = canopy cover, Dr = soil moisture)

The plugin was used to automate the simulations, reading a large number of parameter combinations from an Excel file. The automation procedure scripted in Python was further enhanced compared to an earlier version.

This shell around Aquacrop developed by FutureWater allows a large number of crop simulations to be carried out in a small amount of time, easily adjustable and analysable. Sensitivity analysis can be carried out, calibration and validation, and the existing variability within an area can be simulated by running all combinations at once.

5 Concept

To assess and monitor water productivity on the plot-level, a technology is being developed that combines low-cost Flying Sensor imagery providing high-resolution information on the crop growth status, and a crop growth model that uses these data and other easily available ground data to estimate a number of output variables, including crop water consumption, yield, water productivity (Figure 4). Also yield gaps (difference between the actual yield and the feasible yield given the local biophysical constraints of a location) can be assessed and mapped for the different plots analysed. With a calibrated model, also future scenarios can be studied to improve water productivity.

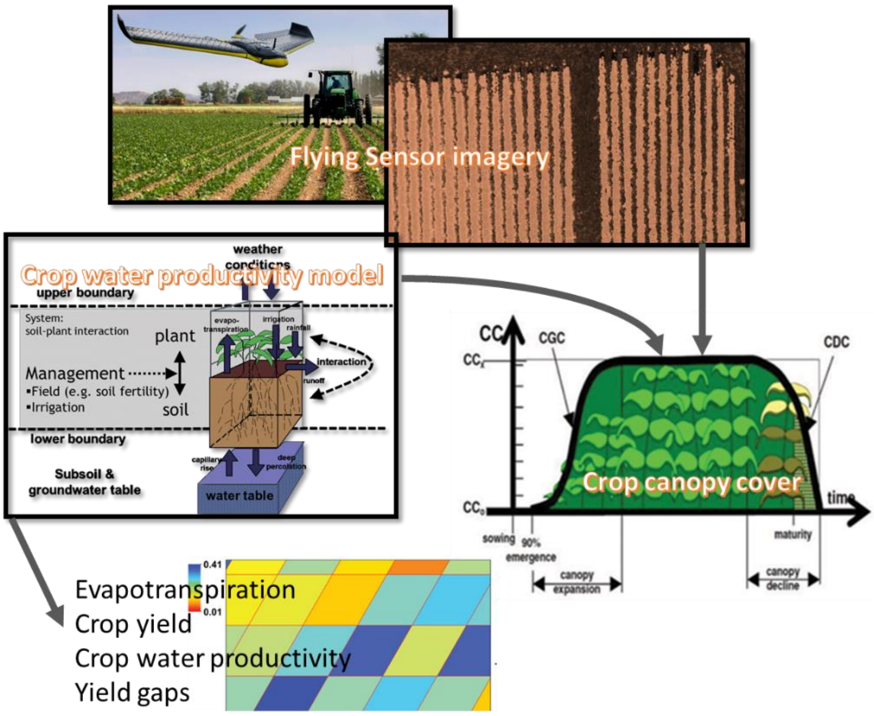


Figure 4. The overall concept of the technology to assess and monitor water productivity for agricultural fields

The main steps in the analysis procedure are:

- Flying sensors (FS) imagery collection to capture the growth curve
- Crop model setup simulating the existing variability in the agricultural district
- Based on the FS-based CC curves, identify the best fit with the model simulations

In this study, it is crucial to work with a current operational front-end system that provides information to the farmers. The concept is that the local partner in Ghana (Farmeline) which is already providing mobile SMS information to farmers, will add information from FutureWater back-end service. The back-end service consists of the flying sensor technology (Third Eye) and satellites to add information about canopy cover and predict water productivity and crop yield (Figure).

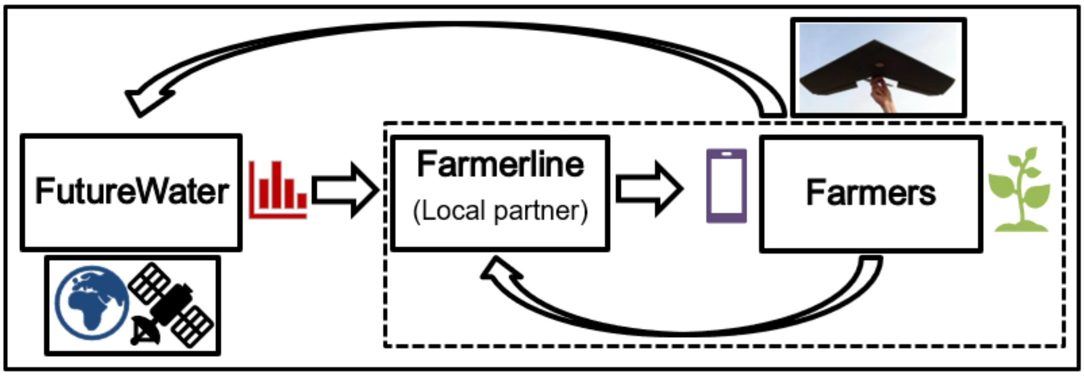


Figure 5. Current Farmerline technology providing information to farmers. Flying sensor technology (Third Eye) and satellites to add information about canopy cover and predict water productivity and crop yield.

In the next sections, the experimental development is set out, leading to first outputs of the tool, and several recommendations for further improvement.

6 Pilot area

In Ghana, the Gold Coast Fruit company is interested in our potential service to provide information to support pineapple production. Initial contacts were made possible thanks to the support of our local partner (Farmerline). Gold Coast Fruits pineapple fields are located 50 km from the capital city Accra, enclosing approximately 400 hectares of farmland (Figure 6). The farmland includes Sugar Loaf and MD-2 variety pineapples. The Gold Coast Fruits company has successfully invested in the MD-2 variety. The pineapple MD-2 production is known for its high export quality. It is planned that the MD-2 variety will replace the Sugar Loaf variety.

In the Gold Coast Fruit farmland, the achieved fresh pineapple yield is between 45 and 55 tonnes per hectare. However, the full production potential has not been achieved yet. According to FAO, pineapple fresh yield can reach up to 90 tonnes per hectares. Using timely flying sensor images can help in monitoring pineapple growth and support field management decisions. In addition, combining this information with yield predictions can potentially fill in the yield gap.

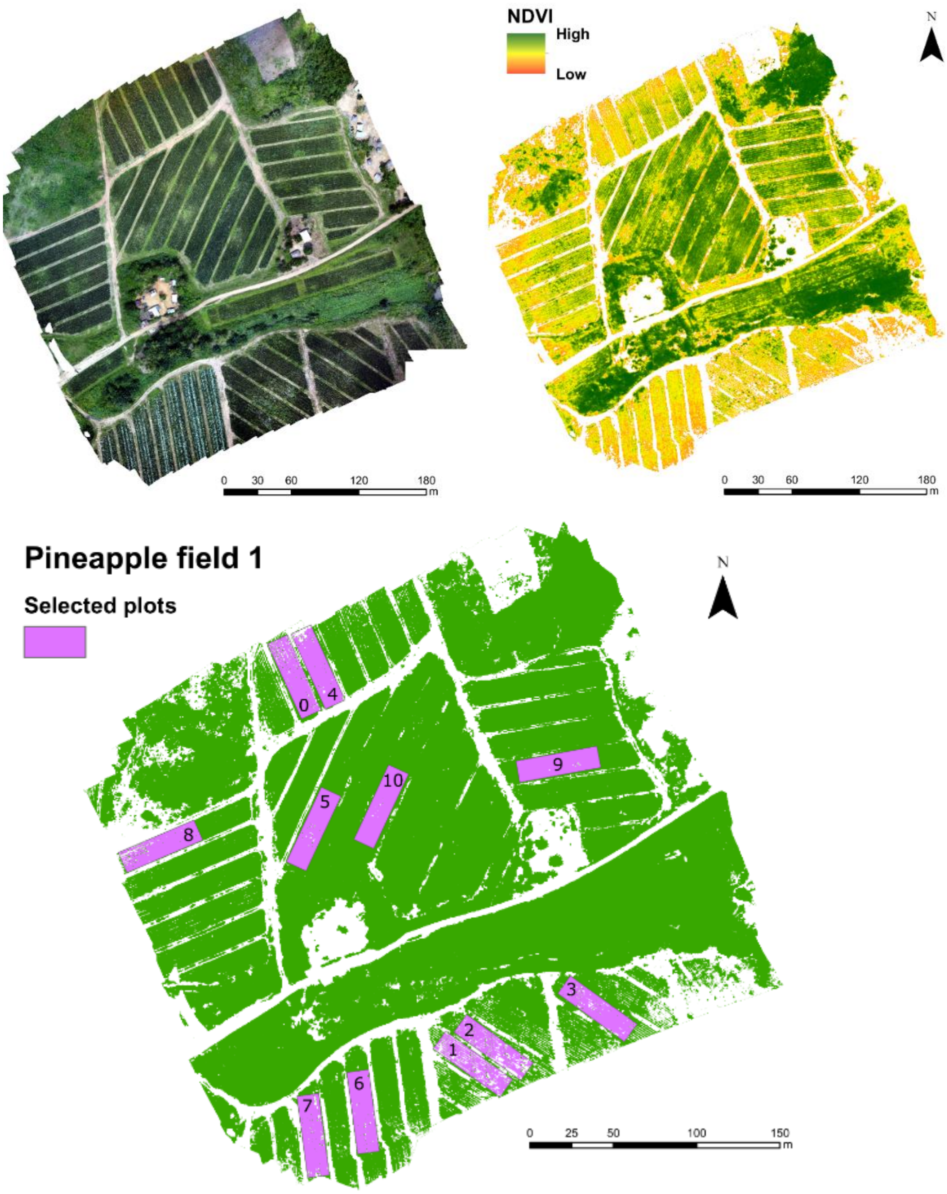
Figure 6. Pineapple fields in Gold Coast Fruits limited.

In the Gold Coast farm, we identified two fields for NDVI measurements with flying sensors. The fields included the MD-2 pineapple variety at two different growth stages, one stage is 2 weeks before harvest and another is 5 months before harvest. In the next section the NDVI information and the corresponding canopy cover values are shown for selected pineapple plots. These canopy cover values are predictors for pineapple yields and water productivity.

7 Back-end information service for semi-commercial pineapple farms

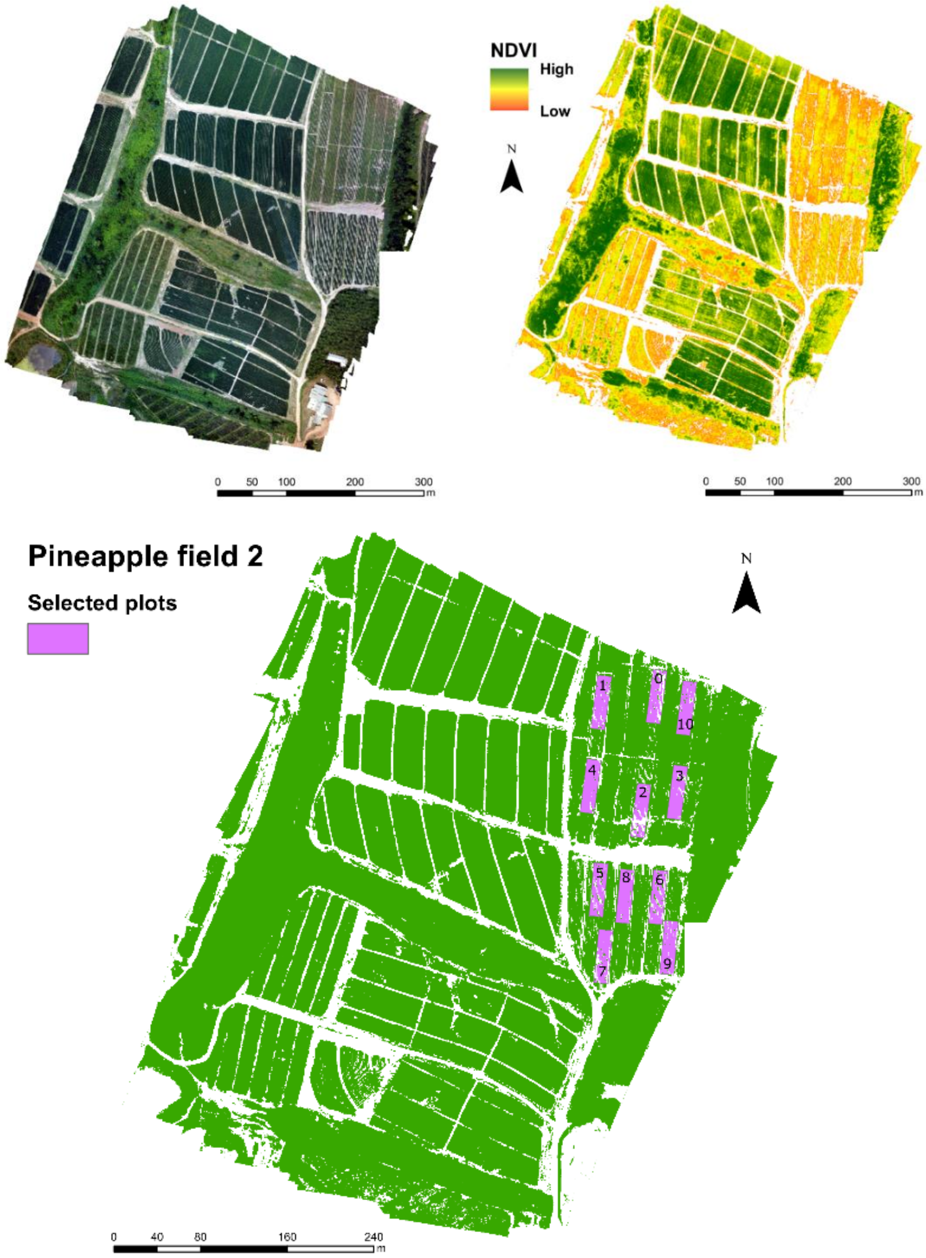
7.1 Flying Sensor information and canopy cover values for pineapple

In the pineapple farm of Gold Coast Fruits Limited, two fields each with a surface area of 7 hectares were selected for flying sensor measurements. In each field, information about NDVI and corresponding canopy cover values in defined pineapple plots were obtained. Rectangular plots of 10 meters x 50 meters were defined according to the rectangular shape area used for pineapple production. Selected plots in Field 1 contain MD-2 pineapples at a growth stage of 2 weeks before harvest (Figure 7). Selected plots in Field 2 contain MD-2 pineapples at a growth stage of 5 months before harvest (Figure 8). The flights were conducted on 1 December 2018 and more details can be found in Appendix 3.



plot	0	1	2	3	4	5	6	7	8	9	10
Canopy Cover (%)	89	73	76	93	92	99	98	93	91	100	100

Figure 7. Field 1 in Gold Coast Fruits Limited, NDVI information, and defined rectangular plots for Canopy Cover evaluation of pineapple (2 weeks before harvest).



plot	1	2	3	4	5	6	7	8	9	10	11
Canopy Cover (%)	74	88	71	92	94	81	78	76	94	88	92

Figure 8. Field 2 in Gold Coast Fruits Limited, NDVI information, and defined rectangular plots for Canopy Cover evaluation of pineapple (5 months before harvest).

7.2 Development of crop yield and water productivity predictions

In Ghana and in the pineapple farm, sufficient local data is available for the information service to generate sufficient reliable AquaCrop model outputs. For instance, meteorological information is available in the case study region thanks to several stations accessible in the online National Oceanic and Atmospheric Administration (NOAA) meteorological system and in the online Trans-African HydroMeteorological Observatory (TAHMO) weather data system. In addition, for potential upscaling purposes in the Ghana's pineapple belt, remote sensing precipitation datasets such as CHIRPS (Funk et al., 2015) and MSWEP (H. E. Beck et al., 2017; H. Beck, Yang, Pan, Wood, & William, 2017) are available worldwide and have shown to be useful for irrigated agriculture purposes at local application (Kaune et al., 2018). Also, WaPOR online services supported by FAO, provide remotely sensed derived datasets for the African continent such as evapotranspiration and biomass information.

At this feasibility stage we used meteorological information from one climatic station located close to the pilot area to simulate the pineapple yield and water productivity with the AquaCrop model. The AquaCrop model requires precipitation data, and various inputs such as air temperature, air humidity and wind speed to calculate the reference evapotranspiration. In Figure 9 the monthly precipitation and reference evapotranspiration is presented. During the year the reference evapotranspiration is higher than the precipitation, thus potential irrigation requirements are needed for satisfactory crop production.

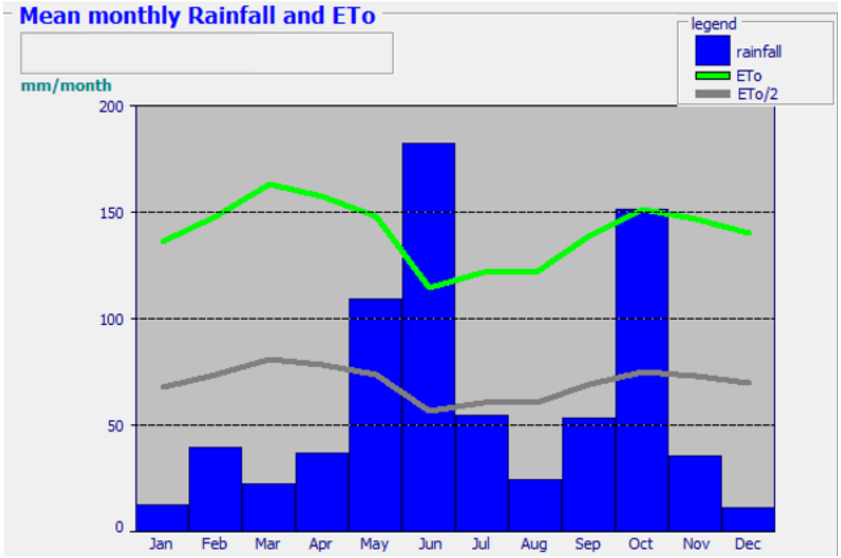


Figure 9. Mean monthly precipitation and reference evapotranspiration (Kotoka International Airport Station).

In addition, the following information is required to simulate the pineapple yield and water productivity with the AquaCrop model:

- Plant density
- Crop growth length and growth stages.
- Field management:
    - Irrigation schedule, method
    - Soil fertility
    - Use of mulches
    - Other field surface practices
    - Weed management
- Soil texture (sand, silt and clay combination)
- Groundwater (meters below soil surface and salinity)

According to local information the pineapple plant density in the Gold farm is 50,000 plants/hectare. The crop growth length is 18 months. Normally, the planting starts at the beginning of December with a total vegetative stage of 9 months until the end of August. The start of the flowering stage is September/October until the end of December (4 months). The last five months the yield formation develops until the maturity of the pineapple and posterior harvest at the beginning of June. Each growth stage is summarized in the following Figure 10.

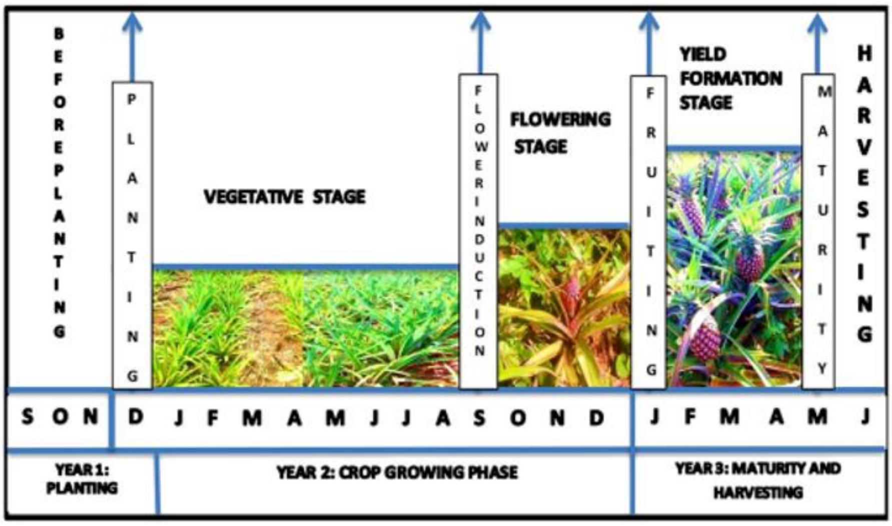


Figure 10. Schematic representation of pineapple growth length and growth stages in Gold Farm (Williams, Crespo, Atkinson, & Essegbey, 2017)

The pineapple fields are irrigated with a pressurized sprinkler irrigation system. The irrigation system is a portable Big Gun sprinklers system, which requires manpower to move the equipment (e.g. pipes and sprinklers) between irrigation plots. The irrigation operation suffers from design and planning limitations, lack of manpower and limited access to water sources. Hence, irrigation application can be better in some plots than in others. In general, the soil texture is sandy loam, which means that the soil is dominated by sand particles but contains enough clay and sediment to provide some fertility. The application of fertilizers is scattered throughout the crop fields meaning that the soil fertility can be better in some plots than in others. Plastic covers around the plants are used in the best way possible to protect from excessive soil water evaporation and weed proliferation. In general, the groundwater level is deep enough to not affect surface soil conditions.

According to Gold Coast Fruits information the range of actual pineapple fresh yield production is between 45 t/ha and 55 t/ha. The dry yield for pineapple corresponds to 9 t/ha and 11 t/ha, considering 80% of water content (Table 2).

Table 2. Fresh and dry pineapple yield in Gold Coast Fruits farm for 80% water content

Fresh yield pineapple	
Minimum	Maximum
45	55
Dry yield pineapple	
Minimum	Maximum
9	11

To adequately predict crop yield and water productivity with the AquaCrop model, the actual conditions of the farm must be incorporated in the model parameters. The AquaCrop model uses key model parameters such as soil fertility stress, and irrigation scheduling. In the Gold Coast Fruit farm, as irrigation application and soil fertility are variable among plots it is necessary to include this variability in the model. Hence, a range of parameter values are used for the fertility stress, the irrigation volume and the irrigation day interval (Table 3). A total of 90 simulations were obtained for pineapple from the established combination of model parameters.

Table 3. Model parameter combination for crop yield and water productivity simulation covering the field variability.

Model parameter	Minimum	Maximum	Step (-)
Fertility stress (%)	10	90	10
Irrigation day interval (-)	1	5	1
Irrigation volume (mm)	5	10	5

The AquaCrop model simulates the daily crop growth from planting to harvesting to obtain the dry yield and water productivity. The model output includes daily values of the canopy cover. In Figure 11, one simulation using 50% fertility stress and daily irrigation application of 5mm is shown. For this simulation the maximum canopy cover was 45% and the dry yield and water productivity was 10.5 t/ha and 0.65 kg/m³, respectively. These values correspond to observed pineapple yields in the Gold Farm. However, the full potential of the pineapple yield is between 15 t/ha to 18 t/ha and a water productivity between 1 kg/m³ and 2 kg/m³.

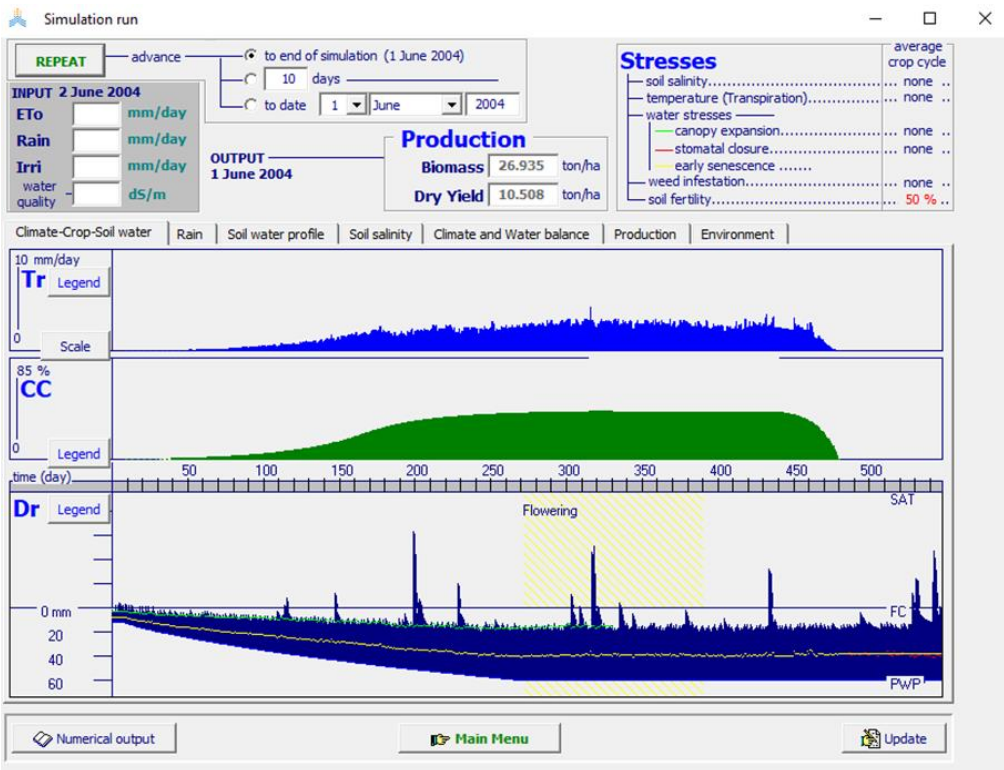


Figure 11. One simulation run of the AquaCrop model using 50% fertility stress and daily irrigation application of 5mm.

For the 90 pineapple simulations we focus our attention in daily canopy cover values in the vegetative growth stage from day 120 to day 240 after planting. The vegetative growth stage includes the highest rate of vegetative growth among stages, which would allow useful canopy cover monitoring with flying sensors. In addition, it is crucial to monitor the pineapple plant during this stage, because the pineapple plant is more sensitive to water deficit compared to other stages.

In Figure 12 the simulated dry yield and water productivity for pineapple against the canopy cover is shown for different days after planting (120 days, 150 days, 180 days, 210 days and 240 days). In Figure 13 the derived trendlines and correlation between dry yield vs canopy cover and water productivity vs canopy cover are shown. The results show a high correlation between dry yield vs canopy cover and water productivity vs canopy cover. Hence these trendlines can be used to predict pineapple yield and water productivity based on flying sensor observed canopy cover at specific days during the vegetative stage. These predictions would allow Gold Farm improve field management practices like irrigation and fertilizers application in those plots where it is needed the most and fill in the gap in water productivity.

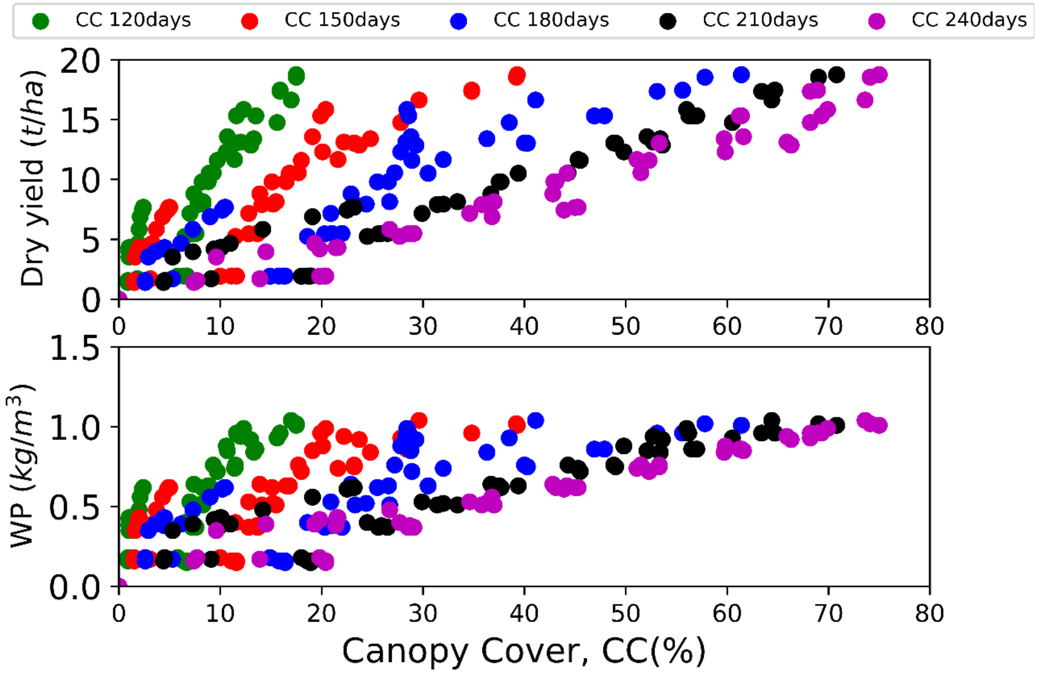


Figure 12. Simulated dry yield and water productivity for pineapple against canopy cover for 60days, 150 days, 180 days, 210 days and 240 days after planting.

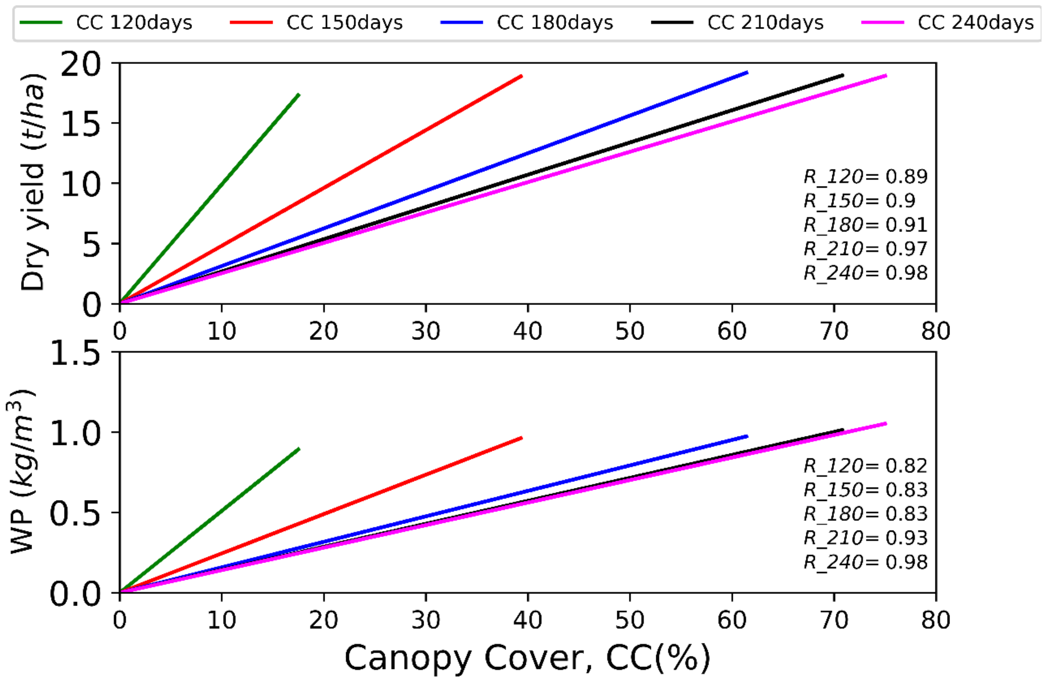


Figure 13. Derived trendlines from Figure 1 to predict dry yield and water productivity for pineapple based on canopy cover information from flying sensors

7.3 Technical bottlenecks in incorporating the proposed back-end information service into the existing front-end information system

In this section the technical bottleneck in incorporating the proposed back-end information service into the existing front-end information system in Ghana are discussed.

In general terms, the following factors need to be evaluated to understand the service limitations in the existing front-end information system (Baumüller, 2018; CGIAR, 2014; Tall, Coulibaly, & Diop, 2018):

i) Phone service
ii) Information delivery and conveying
iii) Users understanding the information
iv) Technical limitations of the potential user

7.3.1 Phone service

In the past years, mobile phone network as well as ownership of these communication assets have been improved at a high rate in Sub-Sahara Africa (Tall et al., 2018). In 2008, 60% of the population had access to a mobile phone network compared to a rate of less than 10% in 1999 (Aker & Mbiti, 2010). Thanks to the accessibility to mobile phones, diverse information services are currently available. In Ghana, our local partner (Farmerline) is providing information services to registered farmers about weather conditions, crop prices and market trends for their specific needs. Farmerline has been successful in reaching out to semi-commercial farms and smallholder farmers and providing them with information for better decision making. Information is being send to the farmers via mobile phone.

7.3.2 Information delivery and conveying

The limitation of Farmerline service is that information is delivered through SMS messages, thus no smart phone app service. This means that only text messages can be send, which can include values for specific indicators, but no images or maps. For FutureWater contribution, images or maps would allow showing the spatial distribution in a farm and provide visual information about the spatial variability of the variable of interest (e.g. canopy cover, predicted yield). However, due to the described information service limitation, the variable of interest (value) will be provided per plot. The plots in our pilot area (Gold Coast Fruits) do include a number classification, thus the user will understand easily to which plot the value is assigned to. Companies such as Gold Coast Fruits will be responsible in conveying the crop information among decision makers to improve field practices.

7.3.3 Users understanding the information

FutureWater processes the information measured with flying sensors and provides data for the variables of interest (Figure 1). For example, the percentage of canopy cover and the crop yield in tons per hectare can be delivered. Different values can be provided over agreed time steps (e.g. hourly, daily, monthly) for a given growth period in a defined agricultural plot. The time steps should be agreed on depending on the type of crop and field management procedures, and certainly based on preferences of the farmers. Decision makers such as Gold Coast Fruits company are trained to understand what the specific values mean for translating it into useful information.

7.3.4 Technical limitations of the potential user

In this section the technical limitations of the semi-commercial pineapple farms are discussed. It is key to understand the possible constrains which can inhibit the successful adoption of the information service of crop yield and water productivity predictions.

The technical limitations for the farmer will depend on their educational background and experience. Current semi-commercial farms which receive the service from Farmerline are technically able to understand the information that is provided true their phones. This information, is related to crop prices, market variations and weather. They should be able to understand new information about the canopy cover or other indicator provided by the flying sensors to improve field management conditions. In addition, information obtained from satellites which can be the actual transpiration of the crop can be translated to useful information when comparing to target values. This target values need to be preestablished with the farmers. From the survey, we identify that the farmers feel more comfortable in using yield values in tonnes per hectare. This units should be included in the information services. Farmers do not feel comfortable in using mm units to identify water loss (Actual ET).

Available platforms such as Google Earth Engine provide datasets from remote sensing missions such as Sentinel and Landsat. Information about NDVI can be retrieved, which may be used as an indicator for the canopy cover of crops. Retrieving information from remote sensing requires certain technical capacity. FutureWater provides this service, including the adequate processing of the datasets to convert it into useful information.

7.4 Form and frequency of new information to support farm decisions

In this section the form and frequency in which the new information (e.g. canopy cover, crop yield, water productivity) should be delivered is discussed. It is key to guarantee the adoption of the service given the local needs and capacities.

The proposed back-end information service consists of monitoring canopy cover through flying sensors and predicting crop yield and water productivity. One key outcome from previous experiences of FutureWater show the importance of planning timely flying sensor monitoring with the local partner and farmers. Monitoring crops with flying sensors (FS) during the growing season are to be planned cost effectively. The necessary flights need to be planned according to the crop characteristics. Depending on the sensitivity due to water deficit, water excess and soil fertility during the growth, development flights can be optimized to maximize benefits and minimize costs.

For this study, the selected crop is pineapple. In Ghana, the total growth period for pineapple is 18 months. During this period, key measurements of the canopy cover with flying sensors are recommended in each growth stage. Pineapple is sensitive to water deficit especially during the vegetative growth stage. The vegetative stage is 9 months between December and August. Flying sensor flights should be prioritized in these months for an interval of 20 days. After August measurements can be done every 40 days, with special attention at the beginning and end of the flowering stage, to monitor excess water supply. In total, between December and August the pineapple farm will receive 14 SMS messages, and between September and May it will be 7 (Table 4).

Table 4. Interval and amount of SMS messages for pineapple monitoring

December – August (9 months) Pineapple vegetative stage		September – May (9 months) Pineapple flowering and yield formation stage	
Interval of SMS messages (days)	Amount of SMS messages per pineapple plot	Interval of SMS messages (days)	Amount of SMS messages per pineapple plot
20	14	40	7

In addition, predicting dry periods and water scarcity conditions provides further information for prioritizing flying sensor flights. Dry periods can be predicted by evaluating historical data on precipitation. Also, for irrigated pineapple, the periods with the highest probability of water scarcity can be determined by evaluating historical data on available water (e.g. river discharge) and irrigation demand. Local data can be provided, but the period of record may not be fully available. In that sense a solution is using earth observation datasets to complete the necessary information for these periods and prioritize flying sensor flights.

8 Future improvements

This feasibility phase of the water productivity tool revealed several issues that can be further improved, principally:

- The post-processing of the FS imagery, considering weeds. Other vegetation indices could be more appropriate and other threshold values could be studies to obtain more accurate estimates of canopy cover.
- More information of the canopy cover curve can be used or combined with the crop growth model: calibrating the curve using the observations.
- An uncertainty assessment can evaluate the influence of local variability, errors in FS-data collection and modelling uncertainties (inputs, parameters, processing and outputs) on the output accuracy.

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Appendix 2: Local Needs Assessment and Economic Feasibility report

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Executive Summary

This project evaluates the feasibility of an information service that aims at enhancing food security by increasing productivity and profitability of the most significant fruit crop in Ghana: pineapple. There is a huge potential to boost irrigation water productivity of pineapple, which is currently unfulfilled as farmers lack the required information to optimize their practices.

The proposed solution consists of a combination of the ThirdEye flying sensor service, successful elsewhere in Sub-Saharan Africa, extended with crop modelling for seasonal yield forecasts, and integrated with the existing Farmerline information service that provides advice to farmers in Ghana. The integration of these components requires further development and tailoring to the local needs, the production system, and local capacities. Before a development phase can start, risks and opportunities were assessed during this feasibility study.

From the study, the team discovered that the market for irrigation advisory services is largely untapped, given that not much is being done in Ghana. Particularly among pineapple farmers, very little is done. While smallholder pineapple farmers do not irrigate at all, a majority of the commercial farms practice supplementary irrigation or fertigation only. This position on irrigation among pineapple producers is based on the high costs of irrigation and perceived drought resistance of pineapples.

It is therefore recommended that intensive sensitization should precede the introduction of the proposed solution. To enhance understanding, demonstration fields should be set up to serve as an initial reference of the effectiveness of the service.

Table of Contents

1 Introduction

Traditionally, the largest share of the Ghanaian national pineapple production is generated by semi-commercial smallholders. However, large companies are increasingly taking over the market as they have easier access to capital for inputs and sophisticated technology such as irrigation systems. For smallholders, pineapple yields are still very much below their potential level, as they do not have access to information or the required capital to improve their practices. At the same time, there is a huge national demand and export potential for pineapple.

The solution proposed in this project aims at closing this yield and information gap by co-creating an information service based on an innovative combination of proven technology in Sub-Saharan conditions. The solution will lead to increased productivity, profitability, and ultimately a higher self-sufficiency of smallholder farmers. The increase in water productivity will lead to lower production costs, a more reliable household income, and improved food security for the bottom of the pyramid.

The integration of Future Water's Third Eye and Farmerline's Information Services requires a bottom-up and participatory co-design process. This is necessary to tailor the solution to the local needs and capacities of the typical Ghanaian pineapple farmers.

The Farmerline Team drew from years of relevant experience to make use of the most appropriate techniques in the engagement of stakeholders. Broadly, the approach was to interview key stakeholders in Ghana's agriculture sector and major actors in the pineapple value chain. In their respective settings, stakeholders including smallholder pineapple farmers, commercial pineapple farms and experts readily offered their knowledge of existing practices and gaps, while assessing risks and opportunities with the proposed solution.

2 The Service

The service seeks to satisfy pineapple farmers' demand for key agricultural information by means of an extension service based on analysed information captured by a flying sensor (drone). The deployment of flying sensors is unique in its ability to provide farmers with real-time, high-resolution, and on-demand information.

A flying sensor is a combination of a flying platform and camera. Typically, a flying sensor flies at a height of 100 meter and overlapping images are taken about every 5 seconds. This results in individual images covering about 50 x 50 meter and an overlap of 5 images for each point on earth. Based on the analysis of the images captured, the service would inform smallholder farmers when to irrigate their fields at thresholds or levels critical to the drought stress of the crops to prevent loss in productivity. The information/advice may be sent as SMS/Voice messages periodically, using Farmerline's Mergdata platform.

For irrigation scheme managers and commercial farmers, the service can provide aggregate field advice that helps with monitoring water demand of fields to ensure necessary interventions are taken to address water needs. The system will provide daily updates on crop water needs per field aggregated per user group (e.g. an irrigation block) and supports the monitoring and planning of off-farm water supply. The insights delivered would include the following:

- Water consumption
- Water need – calculated to (adjusted) target capacity and frequency
- Water productivity
- Rainfall
- Planned water distribution

3 Technology

3.1 Irrigation Advice Service

The Irrigation Advice Service is derived from the combination of Future Water's ThirdEye, which is responsible for data acquisition and processing and Farmerline's Mergdata platform which possesses the technology to disseminate content via various mobile outlets. The flying sensor captures ultra-high spatial resolution (NDVI[1]) images which are on wavelengths not observable by the human eye. In addition, they have an unprecedented flexibility in location and timing with a country-specific business-oriented approach.

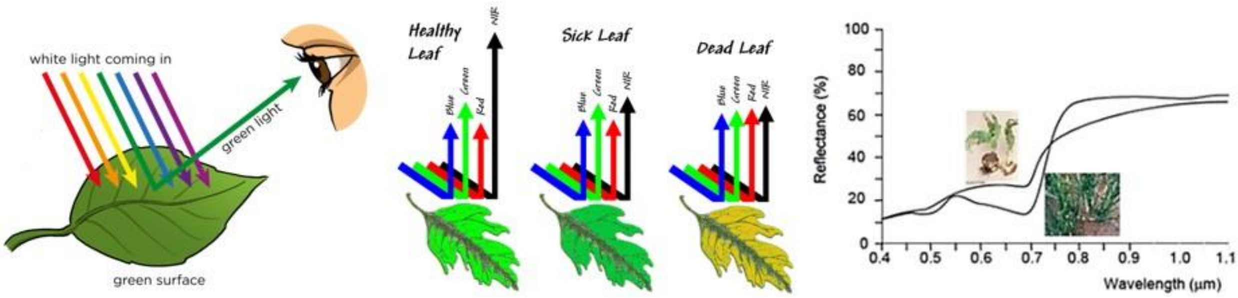

Figure 1. FutureWater's NDVI technology is able to distinguish damaged plant material from healthy plant material.

3.2 The Irrigation Planner

Irrigation Planner is one of Farmerline's product offerings that allows organizations to visualise on a dashboard, fields that require attention with respect to the amount of water needed. Managers can filter information per region, district, irrigation site/fields. In addition, the platform can send reminders to farmers on the need to irrigate their farms via Voice/SMS messages.

<u>The value offering to smallholder</u>:

- Communicates critical information on water needs for a given period

<u>Value offering to Scheme Managers/ Commercial farmers:</u>

- Monitor individual farmlands and send advice
- Automates measuring water use and efficiency

[1] Normalised Difference Vegetation Index (NDVI), is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not.

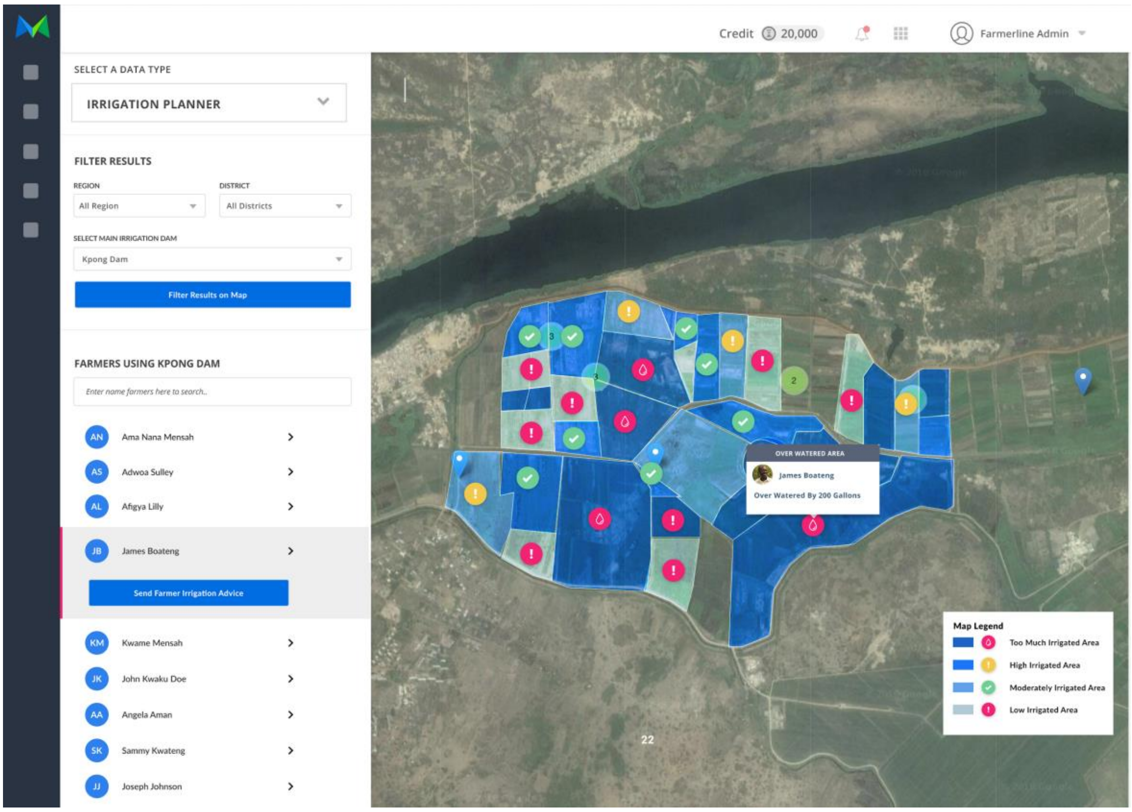

Figure 2. Irrigation Planner Platform Screenshot

4 Stakeholder Mapping and Analysis

a) Enabling Environment Actors

The study noted that a number of government ministries, departments and agencies are very active in the irrigation sector to ensure a conducive policy environment and regulatory framework for proper use of land and water resources in Ghana for crop production. These include the Ministry of Food and Agriculture (MoFA), Ghana Irrigation Development Authority, Lands Commission, Hydrological Services, Local Government, and Ghana Meteorological Agency. In addition to the ministries, departments and agencies, consist of bilateral and multilateral donor-funded projects and programmes (such as GIZ, IFDC). These institutions enhance the sector by focusing on infrastructure, capacity building, research, farm/farmer productivity and income interventions.

b) Production Actors

These actors within the value chain are considered as a central focus, as they use the allocated water and land resources to produce pineapple, the focus of this feasibility study. The actors here include smallholder, semi-commercial and commercial pineapple farmers. Commercial pineapple farms such as Jei River Farms, Gold Coast Fruits and Bomarts Farms are among the largest producers and exporters of pineapple in Ghana and are relevant in offering useful insight.

c) Service Provision Actors

These actors are either public, private or non-governmental organizations. Their aim is to deliver support services to farmers to ultimately increase productivity and incomes. Several of these service provision actors have business arrangements with farmers to deliver services for which there is compensation. Examples of these actors are Callighana, Ministry of Food and Agriculture extension officers, financial and lending institutions and farmer education or information providers.

d) Market Access Actors

The role of these actors in the value chain is to offer farmers market for their produce either at guaranteed or negotiated prices. Here, the activities of off-takers / market aggregators are most active. Examples of actors include Blue Skies and HPW Fresh and Dry Limited.

4.1 Power/interest analysis

The power/interest analysis of stakeholders identified shows the level of interaction needed to ensure that stakeholders are managed well so that their role and influence on the project does not affect implementation. The four section of the matrix are listed below:

- Low power and interest - Stakeholders identified in this section need to be monitored with minimal effort
- Low power and high interest - Stakeholders need to be kept informed of developments for the service availability
- High power and low interest - stakeholders require that they are kept satisfied
- High power and high interest - stakeholders are groups which need to be managed closely.

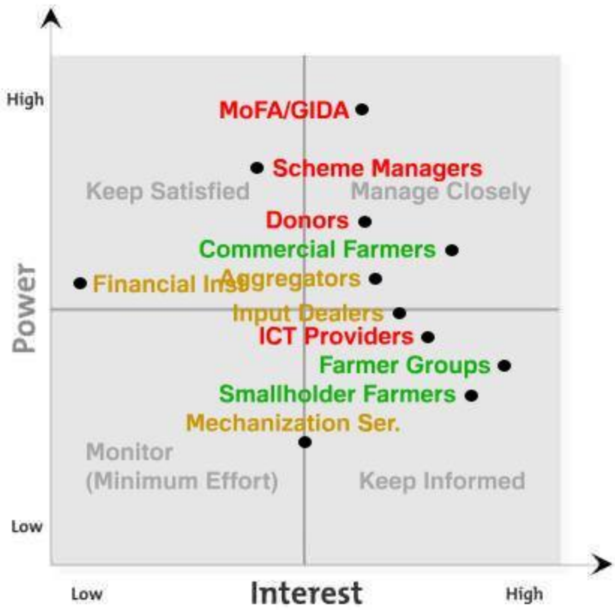

Figure 3. Stakeholder power/interest matrix

4.2 Stakeholders Engagement

From the initial stakeholder mapping and analysis, the team sampled a representative number to engage in interviews. As expected, respondents were selected from each of the categories identified above, to enhance the comprehensiveness of insights. Stakeholders who were engaged in the feasibility study are identified below.

- Albe Farms
- Jei River Farms
- Gold Coast Fruits
- Bomarts Farms
- Smallholder Pineapple Farmers in Bawjiase, Central Region
- GIZ Ghana
- IFDC
- Callighana
- Ministry of Food and Agriculture
- HPW Fresh and Dry Ltd

The details of all respondents engaged in the feasibility are captured in Tables 1 & 2 in the Appendix.

The survey instruments as designed by the Farmerline Team and approved by FutureWater largely guided the field discussions. Based on the expertise of the team, conversations were not strictly limited to the interview guide. The flexibility allowed for probing and discovery of further insights relevant to the subject of study.

The key issues pertaining to local needs and the design of the solution as derived from the field interviews are discussed in the next chapter.

5 Key Findings

5.1 Overview of Pineapple Production in Ghana

Based on the various stakeholder interviews, commercial pineapple farmers in Ghana switched from production of Smooth Cayenne to MD2 variety in 2007. The feasibility study, however, revealed that MD2 is only produced by commercial farms and their outgrowers for exports. Commercial farms and processors, like HPW Fresh and Dry Ltd, confirmed the international demand for MD2 and unanimously attested to the seemingly unbeatable competition with Costa Rica in the international market.

Competition with Costa Rica has driven some commercial farms including Jei River Farms and Gold Coast Fruits to truncate their outgrower schemes. In the words of the Farm Manager of Jei River Farms "***We are unable to compete with them because their cost of production is very low***." They, in particular, have decided to shift some resources to passion fruit production.

Focus Group discussions and interviews with some farmers pointed to the production of Sugar Loaf variety among smallholder farmers. Evidently, the limited demand for MD2 by exporters and processing factories, coupled with the local preference for the Sugar Loaf, account for the choice. Additionally, smallholder farmers believe the Sugar Loaf is more resistant to various conditions making it cheaper to produce.

5.2 Pineapple Market

The survey team made significant observations regarding the market and marketing of pineapples by farmers in Ghana. The divide between smallholder and commercial farmers is such that, no intersection exists in their respective market spaces. All the commercial farms including Bomarts Farms and Albe Farms primarily produce for exports. With Costa Rica being the market leaders of the international pineapple market, small market players like Ghana are subjected to price fluctuations among other unfavourable market conditions. These challenges have compelled farmers to cap their production capacity. The secondary market for these farms is the major processing factory in Ghana, Blue Skies.

Smallholder farmers on the other hand, only have the local market to actively compete in. With more producers than buyers, smallholders are seemingly powerless in the pricing of their produce. During the Focus Group Discussions, farmers indicated that though local buyers quoted very low prices, they have no option than to sell at those prices; otherwise, bear the risk of their produce perishing. They lamented that local buyers paid as low as GHS0.50 per pineapple while processing factories bought similarly sized pineapples from suppliers at a unit price of GHS2.00 This phenomenon has compelled smallholder farmers to prioritize market over other needs. The market need of the farmers is interestingly expressed in some respondents coming along with some pineapples to the focus group discussion, after clear communications of the purpose of the interview. They hoped their samples would move us to buy or recommend some buyers.

5.3 Existing Information Needs/Services

The feasibility study has uncovered huge gaps in information services, especially among smallholder pineapple farmers. The commercial farms make up for the dearth of advisory services with periodic training. Gold Coast Fruits, for instance, admitted during the interview that they have not subscribed to any information service but they are beneficiaries of skills development training funded by Sustaining Competitive and Responsible Enterprises (SCORE).

HPW Fresh and Dry Ltd which supports 300 outgrowers to produce for their processing factory, organises training for their farmers periodically. This was confirmed by some outgrowers interviewed.

Apart from the periodic training received by outgrowers, smallholder pineapple farmers do not receive any advisory services at all. The Ministry of Food and Agriculture (MoFA) extension officers are expected to offer some guidance and training to farmers in the areas assigned. Some pineapple farmers interviewed at Bawjiase confirmed receiving some information and training from the erstwhile MoFA Extension Officer in the area, but none from the current.

5.4 Current Irrigation Practices

Irrigation System Used

The team sought to understand existing irrigation practices among pineapple farmers in Ghana. This expected to enhance the team's appreciation of the extent of irrigation needs. Some significant disparity was observed between commercial and smallholder farms. Although commercial farms agree on the relevance of irrigation to productivity, variations exist in practice. Commercial farms interviewed largely practice what they call "supplementary irrigation". By the practice, commercial farms rely principally on rains for plant water needs. In the dry seasons (4-5 months), some minimal irrigation is carried out.

On the type of irrigation system used, Jei River Farms strongly asserted that the sprinkler is the most prudent and efficient irrigation system for pineapple production. They remarked that pineapple production which is done in cycles of blocks makes the drip alternative inefficient. The cycle would mean leaving the drip lines idle during the period when pineapple stalks are left to shoot suckers. This they believe is not as cost effective as the sprinklers which are moveable.

Bomarts Farms sharply disagreed with Jei River Farms' position on the most effective irrigation system for pineapples. Although done only for parts of their fields, they are convinced drip irrigation is best. "*You realise that under drip, the water usage is very efficient, you don't just splash water like with sprinkler, with a lot of runoffs.*" Bomarts Farms confirmed that they experimented with the drip irrigation "*...and the area with drip produced extra 25% yield compared to where we didn't. And that informed our decision to go drip*." They currently have 70% of their 400 acres of pineapple fields under drip irrigation.

Although both Albe Farms and Gold Coast Fruits agree with the others on the need for irrigation, they do not practise accordingly. Albe Farms does not carry out any irrigation at all. They reckon that water used in fertilizer application (fertigation) which is done bi-monthly is enough to meet the needs of pineapples. Gold Coast Fruits, one of the largest pineapple producers in Ghana says they are unable to afford an irrigation system.

Smallholder farmers who mainly produce the sugar loaf variety for the local market do not irrigate at all. They indicated the costs of equipment and challenges with water sources as reasons for producing without irrigation. Additionally, these farmers are confident that the sugar loaf variety is more drought-resistant, requiring no irrigation efforts.

Drones in Irrigation

Both Bomarts Farms and Gold Coast Farms made mention of a drone irrigation project that has been proposed to them "recently". The proposed service used drones in pesticide application. On both farms, field demonstrations have been carried out much to the satisfaction of the respective farm managers. The company providing the service is identified as AquaMeyer. Bomarts observed that their service is "faster and cost effective" as their proposed charge is GHS 50 per acre. They specified that, this purely is pesticide application with drones, and does not come with any advisory services.

Similarly, GIZ is partnering with a drone service provider, to introduce the use of drones in spraying crops with pesticides.

Irrigation Need Testing

On the existence of any similar technology to accurately measure crop stress and water need, the study revealed none. Some of the commercial farms improvised with some kits to help test moisture level in the soil: Jei River Farms uses garden moisture test kits and Bomarts Farms uses tensiometers. Both admitted these kits neither match the proposed solution nor provide sufficiently accurate data on plant water needs. They confessed they only make do with these kits in the absence of a rigorous tool or solution, as proposed in this project.

Smallholder pineapple farmers do not have any means of testing water needs of their crops, as majority of them do not irrigate. The few who do irrigate, have no means of measuring crop water need. Generally, all respondents acknowledged that the proposed solution would fill a major gap in their production.

5.5 Acceptance and Willingness to Pay

Mostly, the respondents expressed appreciation of the proposed intervention and agree to the relevance thereof. Although IFDC training services are not paid for by farmers, they agree the concept of farmers paying for the proposed service is a "sound sustainability" element. Key stakeholders however predicted that, willingness to pay will be contingent on some conditions. These are identified as follows:

- ***The intervention should be initiated with intensive sensitization:*** Stakeholders believe farmers should first receive some intensive education on the relevance of irrigation, and the role of timely accurate information in maximizing irrigation. Seeing that irrigation is hardly practiced among pineapple farmers, introduction of the technology without adequate education would not be advised.
- ***Advisory Service accompanied by equipment and water source support:*** Key stakeholders including the Ministry of Food and Agriculture recommended that, the proposed information service be supplemented with some support services. Realising that many smallholder farmers do not have water sources nor capital for irrigation systems, the information on irrigation would be needless. A partnership is suggested to make this possible.
- ***Proven Effectiveness:*** Farmers interviewed indicated a willingness to pay for proven results. Key stakeholders accordingly recommended the set-up of demonstration fields to prototype the solution. It is expected that the outcomes of implementation on these farms should enhance uptake among farmers. In the words a GIZ respondent, *"...let them see how efficient it is."* A gradual approach in coverage is also proposed. Farmer cooperatives could be the first point of call as they are more likely not to be deterred by the capital needed to adopt irrigation systems as capital can easily be pooled among members.
- ***Conveniently paced payment schedule:*** Smallholder farmers foresee challenges with paying upfront. They recommend that payments be made after harvest, by which time they can attest to effectiveness with results. Another option is to have payments made in installments or per information.

6 Conclusion & Recommendations

From the study, it was observed that farmers' willingness to pay for advisory services is highly dependent on how efficient the scheme operates and supports their farming activities. The study also noted that a partnership with related product/service providers in the value chain offers potentially stronger commitment to adoption of the use of advisory services to benefit farmers. Again, the market for irrigation advisory services is largely untapped given that not much is being done in Ghana.

Based on the findings of the study, following recommendations came up for implementing the project:

- Intensive sensitization should precede implementation of the project. Farmers and farmer groups should be mobilized and educated on irrigation in pineapple production. This exercise would be a good foundation, facilitating need for the intervention. It is expected that with an enhanced understanding of the relationship between irrigation and crop yield, uptake will be easier.
- For successful market entry, we recommend that private sector organizations which offer tangible products such as inputs and irrigation systems be made implementing partners for the proposed solution. Cost of these products can be bundled together with that of the advisory service as an incentive to farmers. This can include borehole drilling services, and sale/installation of irrigation systems among others. IFDC has indicated willingness to collaborate in the implementation of the project, if called on.
- Demonstration fields would significantly help farmers to appreciate the effectiveness of the intervention. This could be done with existing fields and/or newly cultivated fields for reference. Locations for such fields have already been devised.
- As a revenue driver for both the service and business partners, we propose to develop two additional services to the irrigation information. These services (an Input Demand Forecaster and a Crop Stress Forecaster), will make use of ground data on farms/fields, combined with modules for pest and disease forecasting. Data from these forecasters can be licensed to relevant businesses looking to access such insights. Initial contacts with such businesses are ongoing.

Appendix 3: Cost-benefit analysis

Benefits

Farmer characteristics

Average household size (persons/houshold)	4.5
Average area (ha/farmer)	2.5

Yield (per season)

Control yield (tonnes/ha)	45
Control production (tonnes)	19,195,538
Change in yield (%)	20
Serviced farmers' yield (tonnes/ha)	54
Serviced farmers' production (tonnes)	23,034,645
Yield increase (kg)	3,839,108
Proportion sold on market (%)	100
Average price (GHS/kg)	1.00

Revenue per farmer (per season)

Control revenue (GHS/farmer)	112,500
Control revenue (EUR/farmer)	20,250
ThirdEye farmers' revenue (GHS/farmer)	135,000
ThirdEye farmers' revenue (EUR/farmer)	24,300
Total financial benefits (GHS/farmer)	22,500
Total financial benefits (EUR/farmer)	4,050

Total potential revenue (per season)

Potential farmers served (persons)	170,627
Control revenue (GHS)	19,195,537,500
Control revenue (EUR)	3,455,196,750
ThirdEye farmers' revenue (GHS)	23,034,645,000
ThirdEye farmers' revenue (EUR)	4,146,236,100
Total financial benefits (GHS)	3,839,107,500
Total financial benefits (EUR)	691,039,350
Total financial benefits (EUR/year)	460,692,900

Costs

Service costs

Service price (GHS/ha/service)	60
Average area (ha/farmer)	2.5
Costs (GHS/farmer/service)	150
Service amount	21
Total costs (GHS/farmer)	3150

Appendix 4: Flight information details

Location and date: Bawjiase (Ghana), Gold Coast Fruits Limited, 01 December 2018
Objective: Measurements in two pineapple fields
Number of flights: 4

Flight 1
Mavic: Farmerline (Mavic Pro Platinum)
Area: 1. Pineapple: MD2. 2 weeks from harvest (Coord.-0.475738, 5.723813)
Cams: NIR+RGB
Height: 80m
Surface: 230x240m
Overlap: 80%
Speed: 40%
Weather: Sunny

Flight 2
Mavic: Farmerline (Mavic Pro Platinum)
Area: 2. Pineapple: MD2. +- 5 months from harvest (not fruited yet) (Coord. -0.480674, 5.724478)
Cams: NIR+RGB
Height: 120m
Surface: 300x400m
Overlap: 80%
Speed: 40%
Weather: Sunny + cloudy

Flight 3
Mavic: Farmerline (Mavic Pro Platinum)
Area: 2. Pineapple: MD2. +- 5 months from harvest (not fruited yet) (Coord. -0.480674, 5.724478)
Cams: NIR+RGB
Height: 120m
Surface: 300x400m
Overlap: 80 %
Speed: 40%
Weather: Sunny + cloudy

Flight 4
Mavic: Farmerline (Mavic Pro Platinum)
Area: 3. Pineapple: Sugarloaf 2 weeks from harvest (Coord. -0.480674, 5.724478)
Cams: NIR+RGB
Height: 100m
Surface: 170x180m
Overlap: 80 %
Speed: 40%
Weather: Sunny

Appendix 5: Stakeholder survey

FARMER QUESTIONNAIRE / DISCUSSION GUIDE

1. Background

Name	
Sex	
Age	
Location	
Farming experience in Years	
Do you own a phone? Indicate type.	
What are you able to do with your phone?	

2. Farm Information

Are you the sole owner of your farm?	
If No, who is/who else is?	
Who makes farm decisions?	
Farm Size:	
What pineapple variety do you cultivate?	
What is the harvest time/period?	
Sources of inputs	

3. Irrigation Plan

Do you think you can increase your productivity through practices?	
What is the connection between irrigation and yield?	
How do you irrigate currently?	
How often do you irrigate?	
How much does irrigation cost you?	
Do you have any challenges related to your current irrigation practices?	
Do you receive any information/guidance on farming?	

If YES, paid or free?	
If YES, what medium?	
If YES, do they use any type of innovative technology?	
If YES, how often?	

4. Information and Willingness to pay

Do you think more and timely information would improve productivity?	
On a scale from 1 to 10 how interested would you be in receiving crop stress information from drones?	
How often would you want information provided?	
Which medium do you prefer?	☐ **SMS** ☐ **Automated voice call** ☐ **Extension officer giving in-field advice** ☐ **Other, …**
Are you willing to pay for such a service?	
If YES, how much per advice?	
What payment structure do you prefer? Subscription/Pay-per-use?	
Are you willing to participate in an demonstration workshop?	

5. Market & Sales

How do you market your produce?	
Who are your most consistent buyers?	
Do you make profits?	
What's your assessment of the pineapple market size?	
Are you able to meet demand? If no, why?	
What challenges do you have with your buyers?	

COMMERCIAL PINEAPPLE FARM INTERVIEW GUIDE

1. Name of Farm
2. Name of respondent
3. Size of farm
4. Variety of pineapple
5. Do you have any information on the yield?
6. What is the harvest period/time?
7. What sources of water are available (borehole, reservoir, irrigation canal)
8. How is water distribution to fields organized? (scheduling, how organized)
9. What irrigation systems are used? (gravity, drip)
10. Is there an energy source required for irrigation and what is the source?
11. How often do users irrigate?
12. How is this frequency determined?
13. How is the quantity applied determined?
14. How is the irrigation efficiency determined?
15. Is water metered? If not, how is the amount of water used determined?

Do you think more and timely information would improve productivity?	
On a scale from 1 to 10 how interested would you be in receiving crop stress information from drones?	
How often would you want information provided?	
Which medium do you prefer?	☐ **SMS** ☐ **Automated voice call** ☐ **Extension officer giving in-field advice** ☐ **Other, …**
Are you willing to pay for such a service?	
If YES, how much per advice?	
What payment structure do you prefer? Subscription/Pay-per-use?	
Are you willing to participate in an demonstration workshop?	

SECTOR EXPERT INTERVIEW GUIDE

1. Name of respondent:
2. Organization
3. Designation
4. Agric related experience of respondent (years)
5. How does your organization relate with farmers?
6. What are your general observation on pineapple production?
7. What are the potentials of an increase in pineapple production?
8. What factors limit the productivity of semi-commercial pineapple farmers in Ghana?

9. What information services/interventions are currently available for semi-commercial pineapple farmers in Ghana?
10. What irrigation services/interventions are currently available for semi-commercial pineapple farmers in Ghana?
11. What gaps are there in the current irrigation services/interventions?
12. What bottlenecks exist in the current irrigation services/interventions?
13. Which technological solutions are needed to increase productivity and profits for farmers?
14. What is your opinion on the proposed FutureWater/Farmerline irrigation project using drones to monitor crop stress?
15. What is the form and frequency with which this information should be delivered to guarantee the adoption of the service, given the local needs and capacities?
16. What challenges do you foresee in the implementation of the FutureWater/Farmerline irrigation project?
17. What are the different possible service agreements with the end-user?
18. How can the initial business model be improved to match the local context and needs?
19. Are there any possible legal, institutional or political bottlenecks that may affect the successful deployment or adoption of the solution?

FARMERLINE

1. What are the technical bottlenecks of embedding ThirdEye into the existing information services provided by the local partner?
2. For delivering the irrigation water productivity forecasts: is sufficient local data available as input for the information service, to generate sufficiently reliable outputs?
3. Are there technical limitations for the farmer that possibly inhibit successful adoption of the irrigation water productivity advice?
4. What is the form and frequency with which this information should be delivered to guarantee the adoption of the service, given the local needs and capacities?
5. What is the foreseen cost of the solution, or different possible variants of the solution, depending on the interface with the farmer, type of information, frequency, etc.
6. What is the foreseen economic benefit for farmers using the service, given current challenges the farmers face and given the current yield gap?
7. What is the expected willingness-to-pay of end users?
8. What are the different possible service agreements with the end-user?
9. How can the initial business model be improved to match the local context and needs?
10. Are there any possible legal, institutional or political bottlenecks that may affect the successful deployment or adoption of the solution?
11. Are there any other agricultural drone services in Ghana? Do they target the pineapple farmers?
12. What would be the most suitable area for a demonstration project (phase 2)?

Table 1: Stakeholder and Respondent Details

No	Organization	Respondent(s)	Designation	Key Observations
1	Albe Farms	Albert Atua Amponsah	Owner/Manager	• No irrigation (Fertigation only)
2	Jei River Farms	Yeboah Samuel	Farm Manager	• Established 40 years ago • 4 farms measuring over 6,000 acres. • 8 man-made dams • Do not work with smallholder farmers
3	Gold Coast Fruits	Sampson Ameyaw	Farm Manager	• Operating for 13 years now. • Production is 3,000-4,000 tonnes of pineapples/ year. • 100 hectares cultivated. • 11 hectares under drip irrigation • Staff strength is about 200. • Do not work with smallholder farmers
4	Bomarts Farms	Daniel Asherow	General Manager	• Established 23 years ago • Cultivating 400 of 1400 acres • 70% of pineapples on drip • Enrolling 50 outgrowers
5	HPW Fresh & Dry	Veronika Hofer	Leader of Technical Sourcing	• Exports dried fruits • Works with 300 outgrowers • 2 Factories in 6 years • No irrigation by their farmers
6	Ministry of Food & Agriculture	Emmanuel Agyei Odame	Deputy Director (Extension Services)	• EMQAP and GIDA will be useful partners • Recommended initiation with farmer groups and cooperatives
		Sampson Dorcoo	Agric Officer	
7	GIZ Ghana	Lydia Baffour-Awuah	Agricultural Expert	• Provides support for farmers • Strongly recommend sensitization and subsidization initially
		Michael von Stackelberg	Advisor	
8	Callighana	Linejy Tavars	Product Manager	• Sale of irrigation systems • Training of Farmers
9	IFDC	Dr. Ekwe Dossa	Crop Agronomist and Soil Fertility Expert	• Payment by farmers is a sound sustainable concept • No projects with pineapple farmers yet

Table 2: Focus Group Discussion Participation

No	Name	Lead Participant	No. of Participants	Average Farm Size (Acre)	Average Experience (Yrs)	Variety
1	Bawjiase 1	Gladys Tetteh	7	1.5	6	Sugar Loaf: 7 MD2: 0 Smooth Cayenne: 0
2	Bawjiase 2	George Anim	6	3	4	Sugar Loaf: 6 MD2: 2 Smooth Cayenne: 1
3	Swedru Group	Benedict Simpson	9	2	6.5	Sugar Loaf: 9 MD2: 0 Smooth Cayenne: 0

Appendix 6: List of commercial pineapple farms

Below is a list of commercial farmers our team is having initial contacts with. The Gold Coast Fruits company is interested in our potential service to provide information to support pineapple production. Initial contacts were made possible thanks to the support of Farmerline and first flights were conducted at this commercial farm.

- Gold Coast Fruits - Located in the pineapple belt of Ghana, about 50 km from Accra, GCF has 400 hectares of farmland. In 2013, the applied and won a grant through the Skills Development Fund, supported in part by the World Bank's Ghana Skills and Technology Development Project. With the 247,920 GHC (US$61,220) grant, they hired a consultant from Costa Rica who thought them to grow a new MD2 pineapple variety, known for its cylindrical shape for easy packing on grocery store shelves, and long shelf life. They also implemented drainage beds and adopted automation for fertilization and other activities. Now, they are known for their high quality pineapples, and are Ghana's fourth largest exporters, exporting 45 tonnes of the 55 tonnes per hectare they now produce. GPS Coordinates : 5.719817, -0.478138

- Jei River Farms - Covers over 7,500 acres of farmland and produced over 3,500 metric tons of pineapple for export last year with a target of 5,500 metric tons this year. JRF grows MD2, Smooth Cayenne and Sugar Loaf varieties of pineapples, and their labour intensive style of farming has made them the leading pineapple exporter in Ghana. GPS Coordinates : 5.596568, -0.486428

- Peelco Ltd - Grow both pineapples and papaya on a total of about 500 hectares of land. Under German ownership and management, and export fruits, fresh-cuts, and juice to Europe, Asia, and North America. GPS Coordinates : 5.688311, -0.526346

- Awutu/Senya District - situated between latitudes 5o20'N and 5o42'N and longitudes 0o25'W and 0o37'W at the eastern part of the Central Region of Ghana. Large scale pineapple farmers found in this area include Grand mill farms, Jei River Farms and George field farms. Most of these large Scale farmers use irrigation system powered by pumps along river banks, dams and dugouts.

- Golden Exotics Limited - Ghana's largest banana and pineapple exporter. GPS Coordinates : 6.059596, 0.229519

Appendix 7: Drone permit

Ghana Civil Aviation Authority

GCAA

Our ref: AIR 4157/Vol. 9/048/115

Your ref:

Dig Add: GL-135-7377

13th November, 2018

Ghana Customs and Excise Authority
Private Mail Bag
Kotoka International Airport
Accra

Dear Sir/Madam,

PERMIT TO CLEAR A DJI MAVIC PRO PLATINUM DRONE FROM CUSTOMS

Jan Van Til has appealed to the Ghana Civil Aviation Authority (GCAA) concerning acquiring Authorization to use his drone for Private purposes in Ghana.

The process for granting the aforementioned Authorization requires a physical inspection and registration of the drone and as a result, the GCAA humbly requests, that you allow the above-named person to clear the drone under the harmonized commodity codes and tariff schedule from customs to achieve this purpose.

Counting on your usual cooperation.

Yours faithfully,

DANIEL ACQUAH
DIRECTOR, SAFETY REGULATION
FOR: DIRECTOR-GENERAL

CC: DIRECTOR-GENERAL
AG. DEPUTY DIRECTOR-GENERAL (TECHNICAL)

Private Mail Bag
Kotoka International Airport
Accra, Ghana

Tel: (233)-(30) 2776171
Fax: (233)-(30) 2773293
E-mail: info@gcaa.com.gh

Sita: ACCXTYF
AFTN: DGAAYFYX
Website: www.gcaa.com.gh

Safety & Security, Our Priority

Appendix 8: Project evaluation

SBIR-projectnummer: SB1SH18040

1. **Het directe effect van de SBIR opdracht:** Zonder SBIR opdracht was dit project:

☐ Ongewijzigd uitgevoerd

■ Niet gestart

☐ Kleiner geweest

☐ Later uitgevoerd

☐ Uitgevoerd zonder partners

☐ Uitgevoerd met andere partners

2. **Samenwerking en netwerkvorming**

2.1 Vul hieronder voor elk van uw samenwerkingspartners de gevraagde kenmerken in.

Naam samenwerkingspartner	Gevestigd in (land)	Deze partner is bekend / nieuw voor mij	Soort bedrijf (MKB met < 250 werknemers of GRB ≥ 250 werknemers	Soort kennisinstelling (universiteit, TNO, HBO, MBO of anders)
FutureWater	■ Nederland ☐ …	■ Bekend ☐ Nieuw	■ MKB ☐ GRB	Bedrijf
HiView	■ Nederland ☐ …	■ Bekend ☐ Nieuw	■ MKB ☐ GRB	Bedrijf
Farmerline	☐ Nederland ■ Ghana	■ Bekend ☐ Nieuw	■ MKB ☐ GRB	Bedrijf

2.2 Verwacht u in de toekomst nog vaker met de in het project betrokken organisaties te werken?

Ja, de samenwerking verliep uitstekend.

3. Het instrument SBIR.

3.1 Wat vindt u sterke punten van het SBIR instrument in fase 1?

De verschillende fases, waarbij langzaam een transitie wordt gemaakt naar een commerciële service werkt erg prettig.

3.2 Heeft u nog suggesties hoe SBIR in fase 1 als instrument verbeterd zou kunnen worden?

Nee.