Taking smallholder farming to the next level

Evaluating the Farm Incubator Model on its applicability in Sub-Saharan Africa. A mixed-methods approach

Jan van Engelenhoven

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by

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Preface

Dear reader,

This report, titled 'Taking smallholder farming to the next level - Evaluating the Farm Incubator Model on its applicability in Sub-Saharan Africa. A mixed-methods approach' presents the results of the graduation thesis of the masters' programme Water Management - Civil Engineering, at Delft University of Technology. This research was executed by Jan van Engelenhoven and provides insight in the topic of smallholder farming in Sub-Saharan Africa. Thanks belong to Lennart Budelmann, COO of aQysta BV, for providing the opportunity to conduct several interviews with employees, to study the impact of the company's Farm Incubator Model. Lastly, a great amount of gratitude goes to dr. ir. M.W. Ertsen for his inspired supervision and guidance.

Jan van Engelenhoven
Delft, April 2022

Abstract

In developing countries, dependency on the agricultural sector, especially represented by smallholder farmers, is high. Approximately 90% of food in Africa is produced by smallholders. Smallholder farmers are defined as farmers cultivating less than 2 ha. They often run their business relying on traditional farming methods, making limited use of agricultural inputs. In addition, only a small share of smallholder farmers sells part of their produce, whilst the rest only farms for self-sustenance. Many initiatives in past and present times are aimed at increasing the productivity of smallholder farmers, some supplying agricultural inputs, others focusing on the distribution of knowledge.

In this research, one of these initiatives was reviewed, namely the Farm Incubator Model as implemented by aQysta. The goal of this commercially-oriented Farm Incubator Model, based in Malawi, is to enlist smallholder farmers and supply them with seeds for cash crops such as garlic, fertiliser, a hydro-powered pump for irrigation and pesticides. This is combined with regular coaching sessions, to familiarise the farmers with the novel technologies and agricultural inputs they are supplied with. The ultimate aim of the model is to enable smallholder farmers to make the transition towards commercial farming. In this study, a threefold approach was used to review this model, which at the time this study was conducted was still in its pilot phase. First of all, interviews were conducted with extension officers tasked with implementing the model and with aQysta office staff members. These were aimed at the exploration of the functioning of the model, the assessment of the way in which the model assists participating farmers. In addition, other participatory learning initiatives were reviewed and compared with the Farm Incubator Model. Also, a quantitative analysis was performed, using remote sensing data, to analyse the impact of the model. Secondly, an analysis of variance was performed on the fourth Integrated Household Survey, a survey containing over 25,000 entries, focusing amongst others on agriculture in Malawi. The focus of this analysis was to identify whether the smallholder challenges addressed by the Farm Incubator Model are widely recognised. Furthermore, by quantifying them, the severity of these challenges was assessed. Lastly, a literature review focusing on smallholder challenges in Sub-Saharan Africa was conducted, to explore the extent to which the previously found challenges for smallholder farming are recognised in a broader scope. Furthermore, it was reviewed whether the way in which the model is implemented is the best way to reach the goal of commercialising smallholder farmers. It was found that the Farm Incubator Model addresses smallholder farmer challenges accurately and therefore is a very promising way to help smallholder farmers. However, findings suggested that for farmers to be commercial, being independent is imperative. In case of farm incubators, where all inputs are acquired for the participants, this independence can be at stake. For aQysta's Farm Incubator Model this could pose a future challenge.

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Introduction

1.1 Background

Water scarcity has both a physical and an economical aspect (Giordano et al., 2019). The physical aspect of water scarcity can be described as the physical absence of enough water, whereas the economical aspect of water scarcity describes the absence of means to get to the water, even though physically the water is available. This economic aspect comprises a lack of infrastructure, a lack of policy to divide water, or a lack of financial resources in order to be able to afford tools to abstract water from the available source. According to Molden et al. (2007), about 1.6 billion people are impacted by economic water scarcity globally, affecting mainly Sub-Saharan Africa and South-East Asia. Also, the latter type of water scarcity is the one that smallholder farmers are affected by the most (Nakawuka et al., 2018, Burney and Naylor, 2012). Smallholder farmers are typically defined as farmers with less than $2\,ha$ of arable land (Wiggins, 2009, Livingston et al., 2011, Nakawuka et al., 2018). Despite the small land sizes, smallholder farming is responsible for approximately $90\,\%$ per cent of food production in Africa, according to Wiggins (2009), who also reports the presence of 33 million of these smallholder farms in Africa. When offering innovative, cost-saving solutions for these smallholder farmers for water supply in countries where water scarcity is an issue, care should be taken that such solutions extend beyond the physical aspect of water scarcity and also take into account the economical aspects of water scarcity in a country. This might render certain solutions unusable in one context, but usable in another. This variation in the adoption of solutions due to various local circumstances was researched by Llewellyn and Brown (2020). They identified the need for an integrated approach when assessing the feasibility of a solution. This was done in an attempt to determine factors influencing the generally slower adoption of novel technologies by smallholders farmers in developing countries as opposed to developed countries. This approach means that not only the factors directly influencing the feasibility of a solution are taken into account, but also the factors with indirect influence.

One of the novel solutions currently offered to smallholder farmers is the Barsha pump, developed by the start-up aQysta (aQysta, 2021). By using energy from the river flow, this pump functions solely on hydro-power. According to Zambrano et al. (2019), hydro-powered pumps are a largely overlooked solution that is both environmentally friendly and cost-effective. The Barsha pump is one of the few available pumps in this gap in the market. Research has been done by Zambrano et al. (2020) to assess the viability of this Barsha pump in the context of smallholder farmers in developing countries, assessing use cases in both Nepal and Malawi. An integrated approach was taken, such that not only the technical viability of the pump was assessed, but also other factors influencing the adoption of this new pump by the small-holder farmers. It was found that the Barsha-pump offers an environmentally, cost-friendly alternative to the conventional diesel-powered pump, and could therewith be an important contributor to the solution of the economic part of the water scarcity problem. Despite this, there are a lot of factors negatively influencing the adoption of this novel technology by smallholder farmers in developing countries, such as a lack of financial possibilities or a limited amount of agricultural inputs. These factors are preventing farmers to use the full potential of the pump and therefore influence the adoption rates and the effectiveness of the Barsha-pump negatively. Therefore, to rule out these peripheral factors, aQysta BV decided to develop a new business model, called the Farm Incubator Model (after this referred to as Farm Incubator Model or FIM). The core of this model is the supply of not only a hydro-powered pump but also seeds for cash crops, fertiliser, pesticides and market links. Also, regular guidance is offered by aQysta to participating farmers. This model is active in Nepal, India and Malawi. At the time of this study, this model is still its pilot phase.

aQysta is not unique in their use of a farm incubator to introduce new technology. Farm incubators, as well as other participatory learning methods, are globally present in farming communities. According to Smith et al. (2019) and Calo and De Master (2016), farm incubator models often serve as an accessible way for a farmer to start their business, and have the purpose of eventually enabling farmers to be independent. In the US, target groups of farm incubators often consist for a good part of minorities (Calo and De Master, 2016). Also, it was found that oftentimes farm incubators are used as a stepping stone for farmhands to make the step to farm operator. An example of a farm incubator, mentioned by Calo and De Master (2016), is the ALBA (The Agriculture and Land-Based Training Association), based in the USA. For participating farmers, a fee is asked, and in return, farmers can use amongst others farming equipment, receive training, seeds, storage, fertiliser and assistance in selling their produce (New Entry, 2022). Farmers are meant to stay on the model for three seasons, after which they have to make the step to independence. According to Calo and De Master (2016), this transition is the most challenging part of the incubator. In 2013, 45 farmers finished the incubator program. 20 of those farmers did not stay in touch with the organisation, 13 gave up farming, and 12 made a successful transition to independence. One of the challenges impacting the transition from incubator farmer to independent farmer was securing a stable, long-term land lease. Oftentimes, informal lease agreements were provided by landlords to the new farmers, rendering them insecure of a future. Also, in various cases, new farmers were forced to make large upfront investments for i.e. an irrigation system, while uncertain of the longevity of their lease. In another case study, much higher success rates were reported: six years after the start of the VIVA-farms programme in Washington, USA, 77% of the participants were still farming. However, it is unclear whether, in this programme, the land lease ended when the programme ended, or if farmers are allowed to keep leasing their plot after completing the programme (Smith et al., 2019).

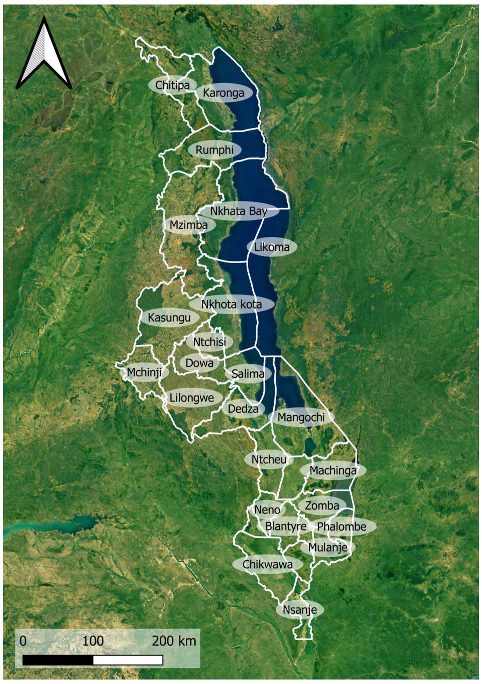


Figure 1.1: Map of Malawi - Basemap: Google Earth (2021)

Another example of a participatory learning method for farmers is the Farmer Field School. Farmer Field Schools (FFS) were introduced by the FAO in the late 80s, aiding Asian farmers with advice on integrated pest management (van den Berg et al., 2020). The FFS is now implemented in more than 90 countries in many variations (FAO, 2016) but always falls back on its core values, which are among others self-empowerment, ownership, and group discovery (Davis et al., 2012). The main concept is that farmers participating in an FFS obtain knowledge and skills that allow them to better assess and deal with situations that they encounter in their daily farming practice. In an FFS, this is approached using participatory learning, or 'learning-by-doing'. This concept is built on the observation that for adults, learning by exchanging experience with peers is very fruitful and sustainable (FAO, 2016). There are some key differences between the FFS and the farm incubator concept. First of all, an FFS is based on bringing existing farmers together and exchanging and emulating knowledge (FAO, 2016), whereas a farm incubator aims to help novice farmers start their businesses. Being novice farmers, farm incubator programme participants are completely dependent on the inputs provided by the programme, until they finished the programme. On the contrary, for FFSs, this dependency is unwanted. In their guide for FFSs, the FAO specifically urges their providers to avoid participating farmers' dependency on the inputs provided by the programme for educational purposes. Furthermore, farmers participating in an FFS as a way to obtain agricultural inputs should be avoided at all costs, as this goes at the cost of the farmers' motivation to learn (FAO, 2016).

In this study, the Farm Incubator Model of aQysta is analysed in the light of these existing participatory learning methods. The Farm Incubator Model located in Malawi is the main focus for this research. The Republic of Malawi, situated in Sub-Saharan Africa, has a little over 19 million inhabitants (World Bank, 2020).

It consists of 28 districts, of which the Farm Incubator Model is situated in Zomba. In figure 1.1 the location of these districts is visualised. According to Tchale (2009), more than 85% of rural inhabitants in Malawi has an agriculture-related job, and over 90% of the agricultural revenue is produced by 1.8 million smallholder farmers. The main cultivated crop is maize, and the main export crop is tobacco. In this research, the influence of the Farm Incubator Model on smallholder agriculture is assessed, and factors leading to the successful adoption of this model are studied, using an integrated approach as suggested by Llewellyn and Brown (2020).

1.2 Research question and approach

The central question addressed by this research is as follows:

How effective is the Farm Incubator Model as implemented by aQysta in Malawi as an approach to take smallholder farmers from self-subsistence to commercial farming?

The approach to answering this research question is as follows. This report starts with exploring the concept of participatory learning methods targeting smallholder farmers. Furthermore, the Farm Incubator Model of aQysta is analysed and put in the context of the concept of participatory learning methods. This is done by conducting interviews with extension officers and aQysta employees involved with the Farm Incubator Model. Additionally, it is attempted to analyse the impact of the Farm Incubator Model in a quantifiable way using remote sensing data. After that, it is assessed to what extent the Farm Incubator Model connects with challenges faced by smallholder farmers in Malawi. This is done by analysing a data set, which is a subset of the fourth Integrated Household Survey. From this data set, challenges faced by smallholder farmers are identified and subsequently compared with challenges addressed by the Farm Incubator Model, as identified in the previous sub-question. Then, zooming out even further, challenges faced by smallholder farmers in Malawi are compared with challenges on a Sub-Saharan African scale. Additionally, the way the model is implemented is assessed. This approach has the goal of identifying how specific the aQysta approach is and how viable it would be in other contexts within this scope. Furthermore, it aims to evaluate the effectiveness of the model in reaching its goal of helping smallholder farmers make the step to commercial farmers.

To summarise, three sub-questions are formulated from this part.

1. What is the impact of the Farm Incubator Model on its participants?
2. To what extent does the Farm Incubator Model connect with challenges faced by smallholder farmers in Malawi?
3. Is the Farm Incubator Model suitable for application in the context of Sub-Saharan Africa

1.3 Methodology

The research question is answered using a mixed-methods approach. Qualitative as well as quantitative methods are utilised. The used methods are explained at the beginning of each chapter.

1.4 Report structure

In this section, the structure of this report is outlined. After that, in Chapter 2, the results of the first research sub-question are described. An in-depth overview is given of the Farm Incubator Model, based on the interviews that are conducted. After that, the performance of the model is quantitatively analysed, using remote sensing data. Intermediate results are discussed briefly at the end of Chapter 2. Then, in Chapter 3, the fourth Integrated Household Survey is analysed, to identify smallholder challenges in Malawi, to answer the second research sub-question. In a brief discussion, the found results are compared with the results of the analysis performed in Chapter 2. This comparison serves as the framework for the answering of the third and last research question, which is addressed in Chapter 4. This chapter consists of a literature review into smallholder farming in Sub-Saharan Africa, and whether challenges found in Malawi are representative of those found in Sub-Saharan Africa. Chapter 5 finishes this rapport with a discussion, aggregating results from previous chapters and comparing them. Finally, looking back at the formulated research question, conclusions are formulated in this chapter.

2

Analysis of the Farm Incubator Model

2.1 Introduction and methodology

What is a farm incubator and in which ways is it deployed in a smallholder farm context? How does the Farm Incubator Model of aQysta relate to other participatory learning methods targeting farmers? What are the challenges that farm incubators in general and the Farm Incubator Model of aQysta are trying to address? This chapter aims to answer these questions, to ultimately answer the research sub-question: 'What is the impact of the Farm Incubator Model on its participants?'. An approach consisting of two parts is followed. First of all, a quantitative analysis is performed using remote sensing data, quantifying the impact of the model on its participants. Secondly, interviews are conducted, obtaining qualitative information on the Farm Incubator Model of aQysta in Malawi. In the next sections, these steps are elaborated.

2.1.1 Measuring the impact of the Farm Incubator Model using remote sensing data

This section explains the used methods to develop a tool to quantify the impact of the Farm Incubator Model. This is done using remote sensing data, in combination with data on participating farms, supplied by aQysta (Fig. D.5, Tab. D.1). Harvest amounts per hectare are used as a proxy for the impact of the model; the higher the harvest amount, the more the impact. The used approach is discussed below.

1. **Analysis of plot data**;
   First of all, the data on participating plots, supplied by aQysta, is analysed. Variables of influence, such as fertiliser use or pesticide use are analysed.
2. **Selecting a satellite mission**;
   Secondly, to obtain remote sensing data, a satellite mission is selected. In order to do this, a literature review is performed on other research projects using satellite imagery for yield analysis on (small) plots. Also, an overview of the available bands for the satellite missions that were found in the literature is given.
3. **Selection of vegetation indices**;
   The next step is to select vegetation indices to analyse biomass/harvest amounts on plots, using the selected satellite mission data. For this, also a literature review is performed in the same way as it is done in the previous step.
4. **Identification of cropland**;
   Cropland is identified using the Random-Forest machine learning algorithm (Google Earth Engine, 2022), which is implemented through the Python API of Google Earth Engine. For this identification, the algorithm is trained with polygons representing four classes: water, cropland, forest, and built-up. From the resulting classification, a cropland mask is constructed and applied on the used remote sensing imagery. The goal of this approach is to filter out unwanted interference from, e.g., trees or sheds.
5. **Analysis of vegetation indices;**
   Finally, the magnitudes of selected vegetation indices are analysed over the course of a growing season and compared with data on harvest quantities provided aQysta. This is done to explore the opportunity of establishing a link between the value of a vegetation index and the harvest amount.

Table 2.1: Codebook

Code group	Code	Code group	Code
Participant information	Experience Participant role	FIM Farmer involvement	Farmer opinion Farmer reward
	Participant tasks Time involved	FIM Extension officers	Tasks Workload
aQysta operation	Core business Focus Profit	FIM Components	Cash Crops Inputs Irrigation technology
FIM General information	Business Model		Training
	Centralised FIM Challenges Decentralised FIM FIM Implementation history Model extent Purpose of the FIM	FIM Workflow	Farmer activities Future development Planting scheme Recruitment Selection

2.1.2 Qualitative exploration of the Farm Incubator Model using interviews

Interviews are conducted to explore and analyse the Farm Incubator Model of aQysta. The type of interviews selected for this study is semi-structured. The first criterion is that the interviews have to be one-on-one, to rule out the convergence of opinions towards the opinion of the most dominant participant. Also, it is important that the interview method encourages elaborated and in-depth answers, therefore ruling out questionnaires. According to Hatry et al. (2015), semi-structured interviews are a very suitable method, fulfilling the mentioned criteria. For these interviews, two target groups are selected.

1. **Malawian extension officers**
   The first group consists of extension officers in Malawi, who are involved with the implementation of the Farm Incubator Model. The used type of interview for this is semi-structured. The goal of these interviews is to learn about the implementation of the model, as well as to obtain practical information about the functioning of the model. This is done to identify the challenges that the model is trying to address, and to analyse the way in which the model is implemented. The question guide for this target group is shown in Appendix A.1;

2. **aQysta employees**
   The second target group consists of aQysta employees. Two aQysta employees are interviewed, using a semi-structured interview approach, to get to know the functioning of the model. Furthermore, these interviews serve both as a method to identify challenges that the model is trying to address from a management perspective and as a method to explore how the model is implemented. The question guide for this target group is shown in Appendix A.2.

Interview data analysis

After qualitative data is gathered using the described methodology, this data is analysed. A method suggested by Hatry et al. (2015) is proposed for this. This method makes use of so-called coding, which means that after interviews are held, the transcripts are analysed on recurring topics, which are then marked. Consecutively, these codes are grouped into different categories. In Table 2.1, these codes in their respective categories are shown.

In order to further analyse the information abstracted by coding the interviews, a data abstraction form is used. The template for this form is included in Table 2.2. The themes are based on the categories in Table 2.1, but can be adjusted according to the interview results.

2.2 Results of the quantitative analysis

The first step in the analysis of the Farm Incubator Model has a quantitative nature. Remote sensing data is used to model and predict harvest amounts, using vegetation indices. As was learned from the interviews held with aQysta employees and extension officers, (Sections **??**, **??**), which are discussed later, the first growing season 14 or 15 farmers did participate in the model, all growing garlic. Also, data on 15 participating farms is obtained from aQysta, visualised in Figure D.5 and Table D.1. The performance of the model is measured in terms of harvest amount. Therefore, the focus of this part of the research is on linking data obtained from remote sensing imagery with harvest amounts.

2.2.1 Overview of participating farms

In Table 2.3, a modified version of the data obtained from aQysta (Table D.1) is displayed. In this modified table, seed amounts, harvest amounts and manure amounts are converted to $kg/acre$. This allows for a comparison in terms of the performance of the different farms.

In Figure 2.1, the importance of fungicide and the second application of fertiliser becomes clear. The manure application rate does not seem to significantly influence the harvest amount, and neither does the plot size.

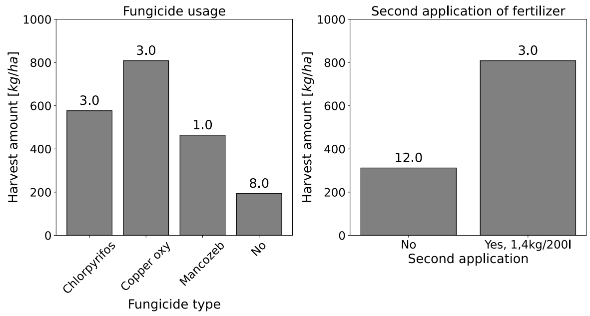


Figure 2.1: Influence of fungicide and second fertiliser application on harvest amount

2.2.2 Assessment of the performance of the FIM with remote sensing

Satellite missions

When considering smallholder farms with small plot sizes ($0-2ha$), a high resolution is an important property of satellite data. The higher the number of pixels in a plot, the more significant the data will be. This section gives an overview of available satellite missions and their use in literature.

In Table 2.4, an overview is given of several currently active satellite missions that are commonly used in literature. It should be noted that not all available bands are displayed here, only those commonly used for vegetation indices. Quality indicator bands are left out, but can be found when visiting the source. Also, the MODIS mission has a lot of additional, precalculated products such as NDVI and land surface temperature which are not included in this overview.

Among the reviewed articles, MODIS is the most used satellite mission. Most of the time, the relatively coarse spatial resolution of this mission made it possible to perform large scale analysis. Also, the fact that a lot of indices are already precalculated (i.e. NDVI, EVI) makes MODIS an easy-to-use mission. The third

Table 2.2: Data abstraction form template

Theme:[...]	Summary	Quotes
aQysta employees		
Extension officers		

Table 2.3: Overview of farms participating in the Farm Incubator Model

Alias	Gender	Location	plot_x	plot_y	Area [ha]	Land clearing	Land prep	First Irrigation	Plant Date	Harvest Date	Seeds [kg/ha]	Harvest [kg/ha]	Manure [kg/ha]	NPK applied	Irrigation [x/week]	Fertilized #2	Fungicide	
Farmer 1	m	Mtwiche	-15.25	35.42	0.25	yes	yes	yes	2021-06-02	2021-12-02	507.19	833.23	2415.17	yes	D-compound	twice/week	No	yes, chlorpyrifos
Farmer 2	m	Machinjiri	-15.28	35.40	0.11	yes	yes	yes	2021-06-04	2021-12-04	952.33	263.02	5441.86	yes	D-compound	twice/week	No	No
Farmer 3	m	Bakali	-15.23	35.43	0.16	yes	yes	yes	2021-05-24	2021-11-24	619.03	934.99	3868.94	yes	D-compound	twice/week	Yes, 1,4kg/200l	yes, copper oxy
Farmer 4	f	Bakali	-15.23	35.43	0.17	yes	yes	yes	2021-06-03	2021-12-03	568.91	557.41	3447.92	yes	D-compound	twice/week	Yes, 1,4kg/200l	yes, copper oxy
Farmer 5	m	Bakali	-15.24	35.43	0.17	yes	yes	yes	2021-06-12	2021-12-12	685.97	0.00	3517.78	yes	D-compound	twice/week	No	No
Farmer 6	f	Bakali	No	No	0.11	yes	yes	yes	2021-05-10	2021-11-10	1085.69	771.41	5714.17	yes	D-compound	twice/week	No	No
Farmer 7	m	Msangeni	-15.28	35.40	0.21	yes	yes	yes	2021-05-18	2021-11-18	637.78	463.84	2899.01	yes	D-compound	twice/week	No	yes, mancozeb
Farmer 8	f	Msangeni	-15.28	35.40	0.19	yes	yes	yes	2021-05-13	2021-11-15	571.69	95.28	4764.11	yes	D-compound	twice/week	No	No
Farmer 9	f	Chibwana	-15.24	35.43	0.23	yes	yes	yes	2021-05-20	2021-11-25	638.47	140.46	2553.88	yes	D-compound	twice/week	No	No
Farmer 10	f	Chibwana	-15.24	35.42	0.23	yes	yes	yes	2021-05-22	2021-11-22	794.52	277.87	2604.99	yes	D-compound	twice/week	No	No
Farmer 11	f	Mtwiche	-15.25	35.42	0.16	yes	yes	yes	2021-06-02	2021-12-02	553.50	645.76	3690.03	yes	D-compound	twice/week	No	yes, chlorpyrifos
Farmer 12	m	Bakali	No	No	0.24	yes	yes	yes	2021-06-03	2021-12-03	491.45	932.50	2520.26	yes	D-compound	twice/week	Yes, 1,4kg/200l	yes, copper oxy
Farmer 13	m	Machinjiri	No	No	0.20	yes	yes	yes	2021-06-01	2021-12-01	939.68	0.00	2936.49	yes	D-compound	twice/week	No	No
Farmer 14	m	Bakali	-15.23	35.43	0.13	yes	yes	yes	2021-05-11	2021-11-11	760.35	0.00	4472.65	yes	D-compound	twice/week	No	No
Farmer 15	f	Mtwiche	-15.25	35.42	0.26	yes	yes	yes	2021-05-19	2021-11-19	348.46	251.66	2323.05	yes	D-compound	twice/week	No	yes, chlorpyrifos

Table 2.4: Satellite missions

	Sentinel-2				MODIS				Landsat 8			
Source	(ESA, 2021)				(NASA, 2021)				(USGS, 2021)			
Used by:	(Frampton et al., 2013, Maleki et al., 2020) (Lobell et al., 2020, Ryu et al., 2020) (Rao et al., 2021)				(Huete et al., 1994, 1997, 2002) (Ghazaryan et al., 2020, Zhang et al., 2021) (Leroux et al., 2019, Petersen, 2018) (Gómez et al., 2021)				(Leroux et al., 2019)			
Operational period	Sentinel-2A: June 23, 2015 - Now Sentinel-2B: March 7, 2017 - Now				MODIS Terra: Dec 18, 1999 - Now MODIS Aqua: May 4, 2002 - Now				Landsat 8: Feb 11, 2013			
Bands overview	**Bands**	**Central wave-length [nm] S2A/S2B**	**Name**	**Res [m]**	**Bands**	**Wave-length range [nm]**	**Name**	**Res [m]**	**Bands**	**Wave-length range [nm]**	**Name**	**Res [m]**
	B1	443.9/442.3	Aerosols	60	B1	620-670		250	B1	430-450	Aerosols	30
	B2	496.6/492.1	Blue	10	B2	841-876		250	B2	450-510	Blue	30
	B3	560/559	Green	10	B3	459-479		500	B3	530-590	Green	30
	B4	664.5/665	Red	10	B4	545-565		500	B4	640-670	Red	30
	B5	703.9/703.8	Red Edge 1	20	B5	1230-1250		500	B5	850-880	NIR	30
	B6	740.2/739.1	Red Edge 2	20	B6	1628-1652		500	B6	1570-1650	SWIR 1	30
	B7	782.5/779.7	Red Edge 3	20	B7	2105-2155		500	B7	2110-2290	SWIR 2	30
	B8	835.1/833	NIR	10					B8	500-680	Panchromatic	15
	B8A	864.8/864	Red Edge 4	20					B9	1360-1380	Cirrus	30
	B9	945/943.2	Water vapor	60								
	B11	1613.7/1610.4	SWIR1	20								
	B12	2202.4/2185.7	SWIR2	20								

advantage of MODIS is the long operation time. Currently, there are more than 20 years of data. However, while sometimes a coarse resolution works in favour of a research, it does not allow analysing individual smallholder farmers' plots. Therefore, for this research, Sentinel-2 will be used. Apart from a high spatial resolution, this mission also presents the opportunity to work with several Red Edge bands, wavelengths that are commonly used in vegetation indices.

Vegetation indices

Vegetation indices are widely used in literature to assess crop health, crop growth, yield and more (Lobell et al., 2020, Petersen, 2018, Zhang et al., 2021, Rao et al., 2021). Therefore, vegetation indices are a valuable tool in reaching the goal of this part of the research, namely translating remote sensing data to harvest amounts. In this section, available vegetation indices are listed, and their applications are assessed. In Table 2.5, an overview of commonly and less commonly used vegetation indices is given based on a literature review. A selection of these will be highlighted in the next section. This selection is based on the applicability as well as the commonness in literature of the index.

NDVI The Normalised Difference Vegetation Index is a very commonly used index to assess vegetation presence, most likely introduced by Rouse et al. (1974). The NDVI is built on the concept that vegetation does absorb visible colour bands (red) but does reflect a big portion of near-infrared. According to Gitelson et al. (1996), NDVI is particularly sensitive for low chlorophyll concentrations and fractional vegetation cover. The weak point of the NDVI is the insensitivity to high chlorophyll concentrations (Gitelson et al., 1996, Dash and Curran, 2004). This was quantified in a study by Gitelson (2004), where it was found that the NDVI was sensitive to changes in the vegetation fraction up to somewhere between 0.4 and 0.5, and a leaf area index (LAI) between 0 and 1.2. However, when the vegetation fraction went above 0.6 and the LAI above 2 (and eventually to a maximum of 6), the NDVI did not rise accordingly. This makes the NDVI suitable for indicating the presence of vegetation, but not for indicating the amount of vegetation.

GNDVI The Green Normalised Difference Vegetation Index is a modification of the NDVI index, proposed by Gitelson et al. (1996). The GNDVI is useful for measuring chlorophyll content at the canopy level. As mentioned, the NDVI is insensitive to high chlorophyll concentrations and is more suitable for indicating the presence of vegetation. The GNDVI takes care of this insensitivity by replacing the red band with a green band ($550 nm$) (Gitelson et al., 1996). They found this index to be way more linked with the chlorophyll content in vegetation, with a correlation between the two with an $R^2 > 0.96$.

Handique et al. (2020), using this index next to NDVI and NDVI Red Edge to assess horticultural productivity with a UAV in a village in India, did not notice any significant improvement by this index over the NDVI. Zhang et al. (2021), assessing maize yields of smallholder farms across China using various indices (NDVI, EVI, GCVI, GNDVI, WDRVI, SR), found that the GNDVI performed slightly better than the NDVI ($\delta r^2 : 1.34 - 3.24\,\%$), after coming in second best behind the GCVI.

Table 2.5: Vegetation indices used in literature

Index	Description	Used bands	Formula	Used in	Found by
NDVI	Normalised Difference Vegetation Index	Near-infrared, Red	$\frac{NIR-Red}{NIR+Red}$	Lobell et al. (2020), Petersen (2018), Ryu et al. (2020), Zhang et al. (2021), Rao et al. (2021), Handique et al. (2020), Ghazaryan et al. (2020), Leroux et al. (2019) Gómez et al. (2021)	Rouse et al. (1974)
GNDVI	Green Normalized Difference Vegetation Index	Near-infrared, Green	$\frac{NIR-Green}{NIR+Green}$	Handique et al. (2020) , Zhang et al. (2021)	Gitelson et al. (1996)
NDVI Red Edge	Normalised Difference Vegetation Index	Near-infrared, Red Edge 2 [$740.2\,nm$]	$\frac{NIR-RE2}{NIR+RE2}$	Barnes et al. (2000), Lobell et al. (2020), Handique et al. (2020)	
GCVI	Green Chlorophyll Vegetation Index	Near-infrared, Green	$\frac{NIR}{Green}-1$	Lobell et al. (2020), Zhang et al. (2021), Rao et al. (2021)	Gitelson et al. (2003)
MTCI	MERIS Terrestrial Chlorophyll Index	Near-infrared, Red, Red Edge 1 [$703.9nm$]	$\frac{NIR-RE1}{RE1-Red}$	Lobell et al. (2020)	Dash and Curran (2004)
EVI	Enhanced Vegetation Index	Near-infrared, Red, Blue	$G*\frac{NIR-Red}{NIR+C1*Red-C2*Blue+L}$	Petersen (2018), Zhang et al. (2021)	Huete et al. (2002)
NDWI	Normalised Difference Water Index	Near-infrared, Green	$\frac{Green-NIR}{Green+NIR}$	Petersen (2018)	McFeeters (1996)
NDWI	Normalised Difference Water Index	Near-infrared, Short-wave Infrared	$\frac{NIR-SWIR}{NIR+SWIR}$		Gao (1996)
SR	Simple Ratio	Near-infrared, Red	$\frac{NIR}{Red}$	Zhang et al. (2021)	Jordan (1969)
WDRVI	Wide Range Dynamic Vegetation Index	Near-infrared, Red	$\frac{a*NIR-Red}{a*NIR+Red}$	Zhang et al. (2021)	Gitelson (2004)
IRECI	Inverted Red-Edge Chlorophyll Index	NIR, Red, Red Edge 1 [$703.9\,nm$], Red Edge 2 [$740.2\,nm$]	$\frac{NIR-Red}{RE1/RE2}$		Frampton et al. (2013)

NDVI Red Edge The Normalized Difference Vegetation Index Red Edge is another modified version of the classic NDVI, used by amongst others Barnes et al. (2000) and Lobell et al. (2020). The difference between the classic NDVI and the Red Edge NDVI is the replacement of the red band with the red edge band. According to Barnes et al. (2000), the red edge band is a wavelength region between red ($680\,nm$) and near-infrared ($780\,nm$). It was found that this wavelength region does capture chlorophyll content in vegetation better than the red band. However, the red edge band used varies per formula. While Barnes et al. (2000) use a wavelength of $720\,nm$ as Red Edge, Lobell et al. (2020) use $740\,nm$. Sentinel-2 has three bands between the red wavelength and the near-infrared wavelength, Red Edge 1 ($703.8\,nm$), Red Edge 2 ($739.1\,nm$) and Red Edge 3 ($779.7\,nm$) (ESA, 2021).

GCVI The Green Chlorophyll Vegetation Index is an index that has strong correlations with the leaf area index as well as with biomass, introduced by Gitelson et al. (2003). Lobell et al. (2020) researching smallholder crop yield measurement via satellite imagery, reported the GCVI being outperformed by the MTCI. In the mentioned case study, Zhang et al. (2021) reported the GCVI as the best performing index.

MTCI The MERIS Terrestrial Chlorophyll Index was developed by Dash and Curran (2004) in an attempt to standardize chlorophyll measurements using the red edge wavelength of multispectral space-borne sensors. Originally, as the name suggests, this index was developed and optimized for the MERIS (Medium Resolution Imaging Spectrometer), using reflection values of wavelengths as described in equation 2.1.

$$\frac{753.75\,nm-708.75\,nm}{708.75\,nm-681.25\,nm} \tag{2.1}$$

However, after the announcement of the Sentinel-2 mission of the European Space Agency, Frampton et al. (2013) suggested the Sentinel-2 wavelengths be used for this index as described in equation 2.2.

$$\frac{[B6]\,740.2\,nm-[B5]\,703.9\,nm}{[B5]\,703.9\,nm-[B4]\,664.5\,nm} \tag{2.2}$$

In literature, there are different interpretations of this index. Frampton et al. (2013), while reporting wavelengths and corresponding Sentinel-2 bands as shown in equation 2.2, describes this equation as $(NIR - Red\,Edge)/(Red\,Edge - Red)$, while a wavelength of $740.2\,nm$ doesn't correspond with the NIR-band on the Sentinel-2 sensor (S2-NIR: $[B8]\,833\,nm$), but with the Red Edge 2 band (S2-RE2: $[B6]\,740.2\,nm$) (ESA, 2021). Lobell et al. (2020) however does use the NIR band of the Sentinel 2 satellite, while Maleki et al. (2020) does take the closest Sentinel-2 band to the original $753.75\,nm$, which is the Red Edge 2 band. In this report, this second approach will be followed, as it is most consistent with the original purpose of the index. Therefore, the index will be calculated as described in equation 2.2. Lobell et al. (2020), in the aforementioned case study, reported the MTCI outperforming other considered vegetation indices, such as NDVI and GCVI.

EVI The Enhanced Vegetation Index was originally developed for MODIS imagery, and its strength lies in an accurate reflection of high biomass regions, a gap left by the NDVI (Huete et al., 2002). The EVI takes four additional scaling factors as can be seen in Table 2.5. The G is a gain factor which is equal to 2.5, L is a canopy background adjustment factor and is equal to 1, and C_1 and C_2 are coefficients used to correct for aerosol resistance, and are respectively 6 and 7.5 (Huete et al., 2002).

SR The Simple Ratio (SR), found by Jordan (1969), makes use of the fact that leaves absorb more red light than infrared light. Therefore, the denser the vegetation, the higher the index.

NDWI The Normalised Difference Water Index comes in multiple variations. Variations used in this research are the one from McFeeters (1996) and the one from Gao (1996). Whereas the first one is meant for the detection of open water bodies, the second one detects the moisture content in vegetation.

WDRVI The Wide Dynamic Range Vegetation Index is also a modification of the NDVI index, introduced by Gitelson (2004). They found that increasing crop density impacts NIR reflection values, whereas red reflection values became stable at a vegetation fraction of 0.6, and that after that, changes in biomass are no longer captured by the red band but can be captured by the NIR band. However, due to the normalised character of this index, the NIR changes aren't reflected in the index value. Therefore, this updated NDVI provides a better correlation between index and biomass by adding a scaling factor to the NIR reflection value, increasing the range of the index to beyond a vegetation cover of 0.6.

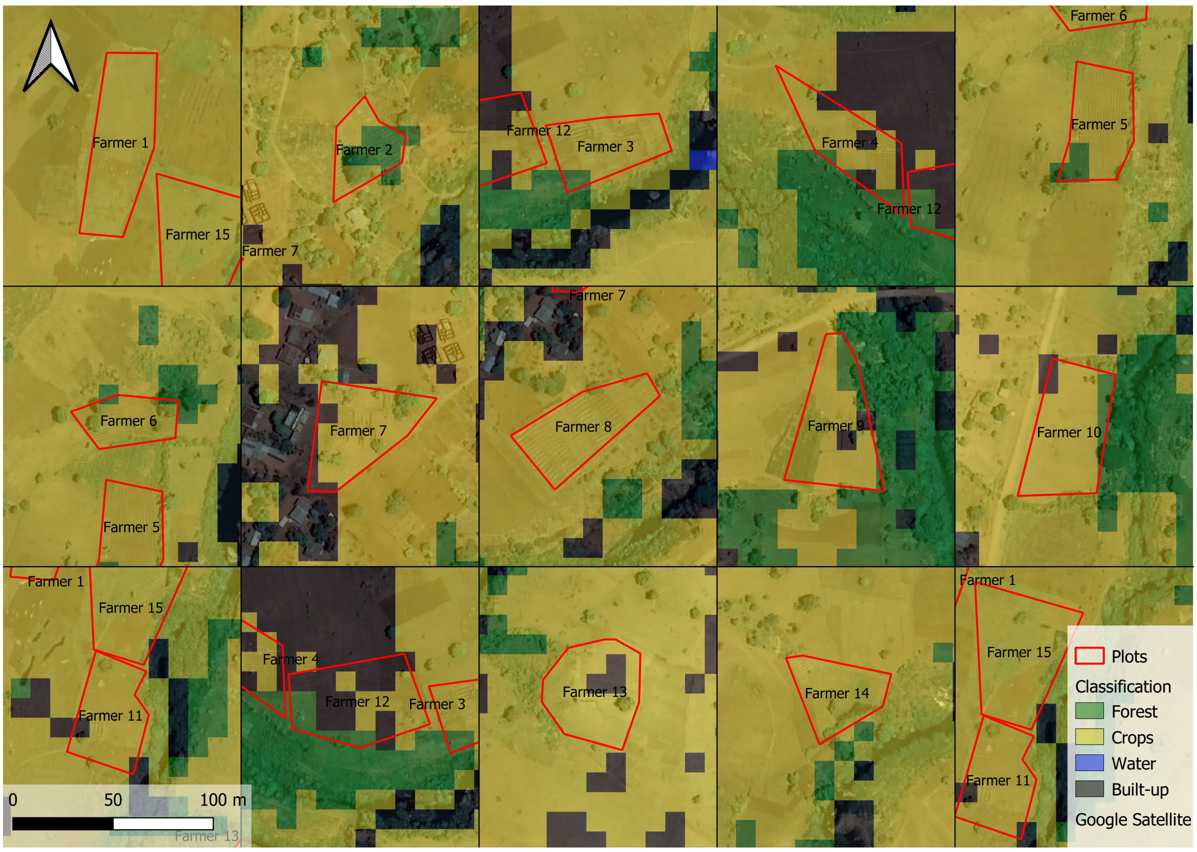


Figure 2.2: Machine Learning: assessment of classification. Basemap: Google Earth (2021)

IRECI The Inverted Red Edge Chlorophyll Index was introduced by Frampton et al. (2013) as a specific index for the to be launched ESA mission Sentinel-2. This index is especially promising due to the number of unique Sentinel-2 bands used.

Selected vegetation indices The following vegetation indices from Table 2.5 are used: NDVI, MTCI, SR and IRECI. The NDVI and SR are selected due to the commonness and simplicity of these indices. However, care should be taken, as mentioned to the non-linearity of this index as a function of the leaf area index (LAI) for higher values of LAI (Gitelson et al., 2003). The MTCI is chosen due to its ability to deal with high chlorophyll levels while still making use of Red Edge bands. Therefore, it is a good addition to the NDVI and SR. Furthermore, strong correlations with chlorophyll concentration (Frampton et al., 2013) and with Gross Primary Productivity (Maleki et al., 2020) are reported. The IRECI is selected because its strong linearity with chlorophyll content (Frampton et al., 2013), and because it was specifically developed for the Sentinel-2 mission.

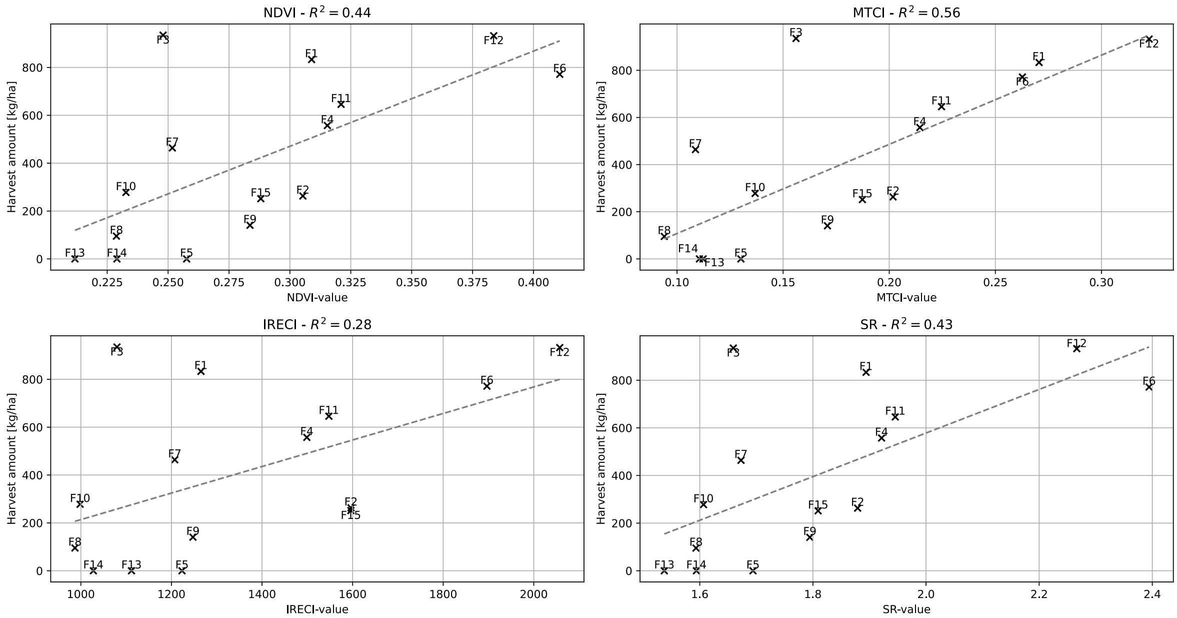
Crop masking

The first step in assessing the relation between vegetation indices and harvest amount is to make sure that all analysed pixels are representing cropland. On occasion, sheds or trees are in the middle of a plot, influencing the reflection values. While the number of plots in this analysis is small enough to select those pixels manually, the goal of this research part is to develop a tool that is used to assess model performance when the model expand in terms of participants. Therefore, machine learning is used to classify pixels as one of the following four classes: cropland, water, forest or built-up. For this purpose, the Random-Forest algorithm (Google Earth Engine, 2022) is trained by supplying training polygons. These polygons are drawn manually using Google Earth data. In Figure D.6, examples of these training polygons are displayed. A total of 59 training polygons are used, of which 19 are classified as built-up, 7 as water, 19 as crops, and 14 as forest. The imagery used for this classification had a spatial extent of $756369.775, 8307971.272 : 762781.150, 8315443.027$ (EPSG:32736). The temporal extent of the classification imagery ranges from 2020-12-01 to 2021-03-30, to classify cropland in the wet season. The mission providing the imagery is Sentinel-2, and used bands are all native bands (see Table 2.4) and the NDVI and NDWI indices. For the NDWI, the formula proposed by McFeeters (1996) is used, which is suitable for detecting open water bodies.

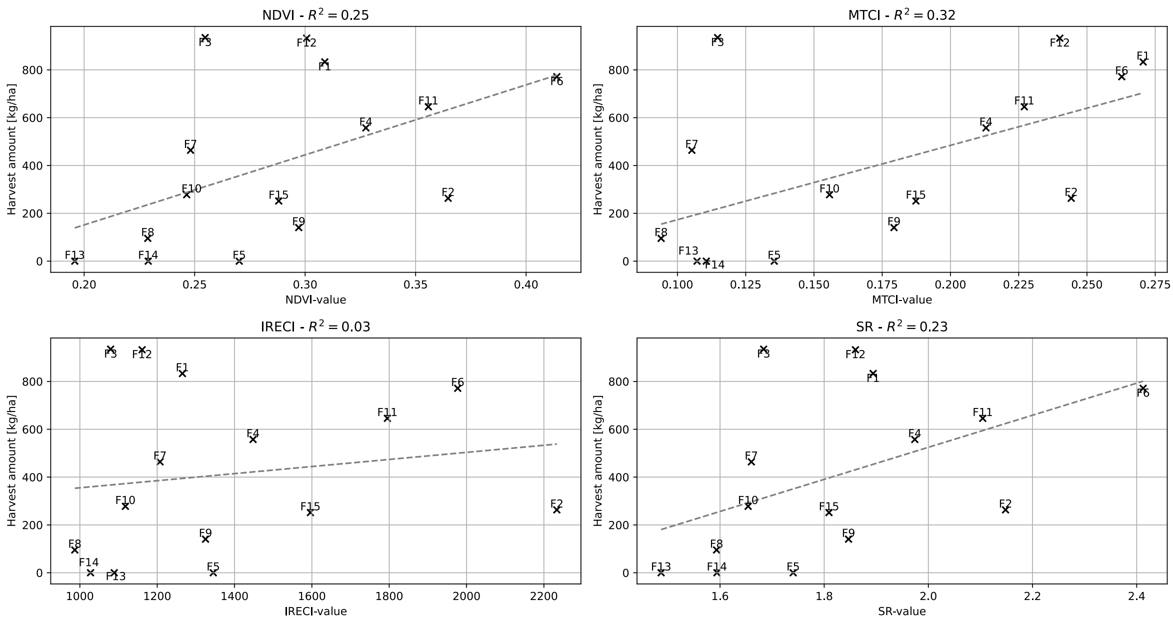
In Figure 2.2, the results of the classification algorithm are displayed. The resolution of the Google Earth basemap is higher than the resolution of the Sentinel-2 imagery used for the classification. Therefore, occasionally, a single tree is not recognised, or a small patch of trees is classified as slightly larger or smaller than it appears visually. Also, some cropland is confused with built-up area. A possible cause for this could

Table 2.6: Statistics of satellite observations of participating plots and buffers (2021-04-01 - 2021-12-31)

Participant	Observations [#]	Plot pixels [#]	Pixel area [m2]	Area [m2]
Farmer 1	76	27	2700	2484.30
Farmer 2	73	6	600	1102.56
Farmer 3	80	13	1300	1550.81
Farmer 4	79	11	1100	1740.18
Farmer 5	77	19	1900	1705.62
Farmer 6	73	11	1100	1050.02
Farmer 7	72	18	1800	2069.67
Farmer 8	75	20	2000	1889.12
Farmer 9	81	20	2000	2349.36
Farmer 10	77	18	1800	2303.27
Farmer 11	75	15	1500	1626.00
Farmer 12	78	3	300	2380.70
Farmer 13	76	18	1800	2043.25
Farmer 14	78	14	1400	1341.49
Farmer 15	75	29	2900	2582.81



(a) Linear regression results



(b) Linear regression results - no classification

Figure 2.3: Linear regression results

be a rocky patch of land or a plot that was left fallow. Apart from these issues, the classification algorithm produces rather accurate results.

Table 2.6 shows the remaining amount of pixels for each plot after non-crop pixels are masked based on the classification algorithm. Furthermore, the area of each plot covered by crop pixels is compared with the area inside the polygons. In this way, it can be assessed if enough pixels remain for the analysis after the classification process.

2.2.3 Calculation of the selected vegetation indices

Satellite imagery from the Sentinel-2 mission, ranging from 2021-04-01 till 2021-12-31, is used to calculate the vegetation indices throughout the growing season. In Table 2.6, the number of satellite observations is shown.

The course of the selected vegetation indices is displayed in Figure D.1 (SR), Figure D.2 (NDVI), Figure D.3 (IRECI) and Figure D.4 (MTCI). Also, the ratio of $usable\,pixels/total\,pixels$ is displayed, indicating how many pixels are cloud-free. Furthermore, the planting date and the harvest date are visualised for each plot, and the time series depicting the median of the vegetation index for cropland over the entire crop classification area is added for reference. To assess the connection between the vegetation indices and the harvest amount, linear regression is performed between the maximum vegetation index value of the last 30 days of the growing season and the harvest amount for each plot. It is noted that the course of the reference vegetation index is not used in this calculation. The results of this linear regression are depicted in Figure 2.3a. For reference, in Figure 2.3b the same linear regression is performed, only this time, the vegetation index value used to predict harvest amounts is based on unclassified imagery. From these results, it is observed that the MTCI performs the best out of these four vegetation indices, with an R^2 of 0.56. Furthermore, when comparing results from Figures 2.3a and 2.3b it is observed that classification of satellite imagery increases the prediction accuracy of the linear regression.

2.3 Results of the qualitative analysis

In order to get an image of aQysta's Farm Incubator Model, four interviews are conducted, two with extension officers, following the question guide in Table A.1, and two with aQysta employees, following the question guide in Table A.2. The transcripts of these interviews can be found in Appendix B.

Following the codes, as indicated in the codebook (Table 2.1), the four interviews are coded. In Appendix C, the interviews are analysed based on the following themes:

- Model focus and purpose
- Model extent
- Model components
- Costs versus benefits
- Extension officers
- Farmer recruitment and selection
- Challenges
- Future development
- Centralised versus decentralised

This analysis is done by selecting interview quotes on their relevance based on the codes and categories that were assigned to them. Furthermore, the selection is made in such a way, that input from all four participants is taken into consideration for each theme, as much as possible. It is noted that due to the focus of the given answers, not all themes correspond with the identified categories from Table 2.1. In Table 2.7, the quotes are compiled in a summary for each theme according to the data abstraction form template as shown in Table 2.2. This is done in such a way that the viewpoint of the two extension officers is reflected separately from the viewpoint of the two aQysta employees. The quotes on which this summarising table is based are referred to using the tags that are included in the tables in Appendix C.

Table 2.7: Summary of interview analysis

Theme	Summary	Quotes
Model focus and purpose		
aQysta employees	The model aims to assist smallholder farmers to make the step from self-sufficient to commercial while making profit, and secondarily, to prove that helping smallholder farmers make the step from self-sufficient to commercial can be a profitable business as opposed to charitable. aQysta aims to make the transition to commercial farmer risk-free by supplying financial services, market linkage, irrigation systems, training and more.	??: A1-A5
Extension officers	The model aims to promote smallholder farmers, passing knowledge in a sustainable way, impacting communities.	??: E1-E3
Model extent		
aQysta employees	Currently, the Farm Incubator Model has around 50 participating farmers in Malawi. Each farm has a plot of around half an acre, which is a good size to maintain.	??: A1,A2
Extension officers	Currently, the Farm Incubator Model has 43 participating farmers in Malawi, or at least between 40 and 50.	??: E1,E2
Model components		
aQysta employees	**Crops** Crops included in the Farm Incubator Model are garlic, watermelon, groundnuts mixed with pigeon peas, potato and ginger. Last growing season, garlic was grown, and since November groundnuts mixed with pigeon peas are grown, which will be harvested in March/April 2022. Then potatoes will be grown. After that, consecutively, ginger, watermelon, groundnuts/pigeon peas will be grown, after which the cycle starts over again.	??: A1,A2
	Inputs All inputs necessary to farm (such as seeds, fertiliser, manure) are included in the Farm Incubator Model.	??: A1
	Training A growing manual is developed for each crop, in which is described for each week of the growing season what needs to be done. Extension officers then pay weekly visits to check if these so-called 'milestones' are reached. Furthermore, in the first week of each month, the milestones that have to be reached that month are discussed in a training session.	??: A1-A4
Extension officers	**Crops** The model aims to use high-value crops as opposed to local crops, in order to maximise profit. These high-value crops are groundnuts, ginger, watermelon, tomato, green maize and vegetables. Last year, garlic was grown. Currently, ginger and groundnuts are grown. After that, watermelons and Irish potatoes will be grown.	??: E1-E5
	Inputs All other necessary inputs are provided as well, such as crops and fertiliser.	??: E1, E2
	Irrigation technology Furthermore, irrigation technology is provided in the form of a Barsha pump. The main advantages of these pumps are that it is environmentally friendly and that it has no operational cost because it uses the flow of the river to obtain energy. Only at the end of a dry season sometimes other pumps (i.e. solar pumps) are used as an alternative.	??: E1-E4
	Training Training is provided on the production of different crops, as well as how to use the Barsha pump.	??: E1, E2
Costs versus benefits		
aQysta employees	The Farm Incubator Model provides various services to farmers and finances itself by collecting around 60% of the harvest revenue, depending on the crop type. Through the growing season, farmers initially were granted a monthly allowance. However, starting with the growing season November 2021 - April 2022, this will change to a milestone-based allowance.	??: A1-A4
Extension officers	Farmers are provided with a monthly allowance, because due to participating in the Farm Incubator Model they don't have time to engage in other money-making activities, and therefore need an allowance to cover the period until harvest revenue comes in.	??: E1
Extension officers		
aQysta employees	There are two extension officers active for aQysta, which translates to one officer monitoring 25 farmers. Extension officers are the ones visiting and training the farmers in the field.	??: A1, A2
Extension officers	Extension officers advise farmers with regards to best practices. Furthermore, they correct farmers when something is not going according to the process described by the Farm Incubator Model. It consists of roughly twenty per cent of office work and the rest of the time is spent in the field. The farmers participating in the Farm Incubator Model are located rather close together, which makes visiting them easier.	??: E1-E5

Table 2.7: Summary of interview analysis (continued)

Theme	Summary	Quotes
Recruitment and selection		
aQysta employees	**Recruitment** Recruiting farmers to participate in the Farm Incubator Model is done by visiting villages, talking to the village chiefs, explaining to them the model, and interested farmers can apply.	**??**: A1
	Selection Farmers who are interesting in participating in the Farm Incubator Model are subjected to a survey which inquires after past farming experience as well as future ambition. Also, a technical assessment of the plot is performed in this survey, considering the plot size, plot orientation, soil type, proximity to rivers and soil characteristics (i.e. pH-value). Based on these parameters, suitable plots are selected for participation.	**??**: A1
Extension officers	**Recruitment** The recruitment of farmers is done by visiting villages, talking to local chiefs, introducing them to the Farm Incubator Model, talking about objectives and milestones. Then the leaders introduce aQysta employees to the local farmers who are interested.	**??**: E1, E2
	Selection Interested farmers are interviewed on their aspirations and motivation. Farmers are asked what they would like to achieve if they were commercial farmers. Furthermore, the selection procedure looks at plot characteristics, such as proximity to rivers and proximity to the aQysta office, to ease transportation.	**??**: E1, E2
Challenges		
aQysta employees	The main challenge that the model is experiencing is the lack of ownership of the farmers. Farmers often only farm to receive their monthly allowance. Furthermore, the information flow from the field to the office is challenging.	**??**: A1-A3
Extension officers	Main challenges experienced in the model are a lack of punctuality by farmers, hampering the activities of extension officers. Also, sometimes allocation of resources (i.e. fertiliser) could be more timely.	**??**: E1, E2
Future development		
aQysta employees	The Farm Incubator Model started on 8 acres in Malawi in 2021. In Nepal and India, the model did start at the end of 2021. Next year, a scale-up to 150 acres is envisioned, of which 60 acres in Malawi, translating to a total of 120 farmers. If everything goes according to planning, 50 farmers will be added in April 2022, 50 farmers in June/July 2022, and 50 farmers in September 2022, bringing this to a total of 200[1]farmers at the end of 2022.	**??**: A1-A3
Extension officers	The Farm Incubator Model has a lot of potential, as few farmers use irrigation. Therefore, expanding the model might better the agricultural sector.	**??**: E1
Centralised versus decentralised		
aQysta employees	Comparing India or Nepal with Malawi, the main difference is that in those countries farmers are more advanced. Therefore, they feel more at home with novel technologies and have a greater sense of ownership than Malawian farmers. This makes a centralised model less suitable in Malawi, as farmers who aren't farming on their own land but on a common piece of land do not feel responsible for implementing the novel technologies. Furthermore, in India and Nepal oftentimes farmers are already organised in communities, farming centralised on a large plot of land, as opposed to Malawi, where farming is a mostly individual business. This decreases the feasibility of the centralised incubator model in Malawi. However, despite invoking increased ownership, the decentralised Farm Incubator Model is less sustainable, as it increases the complexity of processes such as the supply of inputs and training.	**??**: A1-A7
Extension officers	The decentralised Farm Incubator Model has the advantage that farmers have more ownership of the plots. The centralised Farm Incubator Model has the advantage of easier operations. One extension officer prefers the decentralised Farm Incubator Model, and the other one prefers the centralised Farm Incubator Model.	**??**: E1-E3

[1]200 farmers seems contradictory to the earlier mentioned amount of 120 farmers. Both numbers are from different interviews, and it is a possibility that different time spans are considered.

2.4 Discussion

2.4.1 Quantitative results

In this section, the results of the quantitative analysis on the impact of the Farm Incubator Model are discussed. The results of this analysis can be found in Appendix D. It has been chosen not to include these results in the main report, due to their inability to answer the main research question. Despite this, promising results are found for a future re-examination, when more participating plots are present and multiple growing seasons have passed.

aQysta plot data - quality and quantity Data supplied by aQysta consisted of polygons delineating the plots of farmers that are participating in the Farm Incubator Model (Fig. D.5) and a database on plot details (Tab. D.1). The polygons are used for the remote sensing analysis, and the database did provide data on harvest amounts and more. Both data sources contain a value for the plot area. It should be noted that there is significant variation regarding the reported plot area between the database and the supplied polygons (Tab. 2.8). Furthermore, the fact that only 15 plots are present in this data set makes it impossible to build on the results of the linear regression. When so little data is present, it is hard to detect outliers and deal with them, as the natural extent of the variation within the data set cannot be properly identified.

Satellite data - quality and quantity In the quantitative analysis on the impact of the Farm Incubator Model, Sentinel-2 data was used. This satellite mission was selected amongst others due to its versatility regarding bandwidth and due to its relatively high spatial resolution of $10\,m$ for most bands. The performed analysis has shown that the number of observations is around 10 per month (Tab. 2.6), which is plenty to analyse the course of a vegetation index over the growing season. Also, from Figures D.1, D.2, D.3 and D.4, it follows that only occasionally, part of a satellite image is unusable due to clouds. Furthermore, for the majority of the analysed farms, the spatial resolution was high enough to allow individual plot analysis based on multiple pixels for each plot (Tab. 2.6). In this research, no pixel threshold was defined due to the limited number of farms participating. From the time series in Figures D.1, D.2, D.3 and D.4 it is learned that the vegetation index of the plot does not differ much from the reference vegetation index. Interestingly, it is found that at the start of the growing season, many plots report vegetation index values much lower than the reference measurement. A possible cause for this is the tillage that happens at the start of a growing season; crop remains from previous season will be ploughed under, while the reference area most likely will not be cultivated, as the analysed growing cycle is in the dry season, and thus crop remains are left on the plot. Two possible reasons are mentioned for the observation that the vegetation indices of the cultivated cropland only show marginal differences with barren cropland. Firstly, a garlic plant is rather small, which negatively influences the biomass detected by the remote sensing analysis. Tian et al. (2020), in an analysis of winter

Table 2.8: Variation in the plot area

Participant	Area [ha] (table)	Area [ha] (poly)	Area [ha] (alg.)
Farmer 1	0.17	0.25	0.27
Farmer 2	0.14	0.11	0.06
Farmer 3	0.13	0.16	0.13
Farmer 4	0.13	0.17	0.11
Farmer 5	0.16	0.17	0.19
Farmer 6	0.15	0.11	0.11
Farmer 7	0.18	0.21	0.18
Farmer 8	0.15	0.19	0.20
Farmer 9	0.20	0.23	0.20
Farmer 10	0.25	0.23	0.18
Farmer 11	0.12	0.16	0.15
Farmer 12	0.16	0.24	0.03
Farmer 13	0.26	0.20	0.18
Farmer 14	0.14	0.13	0.14
Farmer 15	0.12	0.26	0.29

garlic, reports NDVI values of garlic barely exceeding 0.5. Secondly, from the results of the interviews, it was learned that the harvest this growing season was rather disappointing. This adds to the previously mentioned fact that the amount of to be detected biomass is rather small.

Pixel classification algorithm performance Cropland pixels were distinguished from other pixels with a pixel classification algorithm. Inspecting the results visually, it is concluded that the algorithm, combined with high-resolution Sentinel-2 data, has a lot of potential in detecting cropland and distinction between cropland and patches of trees and sheds. In Table 2.8, the area left after the pixel classification is denoted. The spatial resolution is not high enough to identify plot borders (roads, small tree lines). Therefore, when analysing individual plots, manual plot delineation is required. Due to the small plot sizes, when some of the pixels are erroneously classified as non-crop pixels, a lot of valuable data can be lost, as small plots are only covered by a few pixels, to begin with. Farms 2 and 12 illustrate this problem, as can be observed in Table 2.8. Despite this loss of data, within the current data-set, no significant correlation between accuracy and pixel amount is observed (Fig. 2.4).

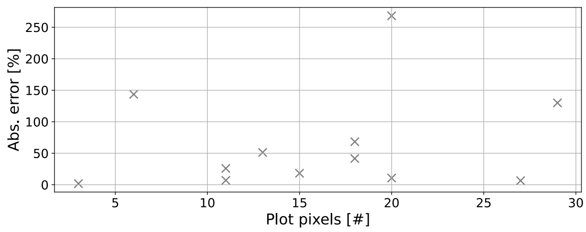


Figure 2.4: Pixel amount versus error[%]

2.4.2 Qualitative results

In Table 2.9, characteristics of participatory learning methods aimed at farmers, as described in Chapter 1, are summarised. It is evident that the FIM seeks a middle ground between the traditional farm incubator and a farmer field school. While checking most of the boxes of a farm incubator according to Table 2.9, it aims at existing instead of novice farmers. This puts aQysta's FIM in a unique position. Where normal farm incubators aim at starting farmers with no farm management experience, aQysta's FIM aims at farmers with existing farming businesses and tries to transform these businesses. This is a more challenging setup, as participating farmers already have a functioning business. Therefore, the challenges experienced by aQysta's FIM greatly resemble the ones experienced when implementing a farmer field school, in that participating farmers need to be intrinsically motivated and understand the value of the added knowledge for the model to work.

The current setup of the Farm Incubator Model has a significant advantage over traditional farm incubators, namely that in Malawi, due to the decentralised character, farmers farm on their own plot. Therefore, one of the challenges of the farm incubator as found in literature, namely acquiring a plot after participating, is already conquered. However, to put this into perspective, findings from the interviews suggest that the decentralised character of the FIM is most likely not feasible in the long term, due to the increased operating costs.

To summarise, farmers participating in the FIM are aided in the approach to the following challenges:

1. **Becoming profitable;**
   The FIM aids farmers in making the step from self-sustaining to commercial farmers, and therefore, seeds for cash crops are provided. This increases the revenue per hectare;

Table 2.9: Summary of farm incubator model and farmers field schools in literature

Farm incubator model	Farmer field school
Aimed at starting farmers	Aimed at existing farmers
Provides everything	Provides training and some inputs, but builds on farmers' experience and collaboration
Difficult to make the step towards independency	Aimed at staying independent during participation
Builds farming knowledge from the ground up	Adds to and builds on existing knowledge, focusing on a topical subject related to the local situation.
Prepares farmers for independency	Prepares farmers for passing and applying knowledge, functioning in a community

2. **Obtaining agricultural inputs;**
   Farmers are assisted in overcoming challenges regarding obtaining agricultural inputs, which are fertiliser, pesticides and seeds. This relieves farmers from the burden of doing a large upfront investment in inputs and furthermore aids with the transportation of inputs to the farm.

3. **Cultivating year-round;**
   Farmers are enabled to cultivate year-round as opposed to only in the rainy season. This is made possible by supplying irrigation technology with no running costs.

4. **Acquiring knowledge;**
   Knowledge is valuable to farmers, for example for the identification of diseases and implementation of technologies. The FIM aids participating farmers with the implementation of their new crops, agricultural inputs and irrigation systems by supplying training.

5. **Connecting to the markets;**
   The Farm Incubator Model aids farmers with connecting to markets and getting a good price for their produce.

Conversely, aQysta has to deal with the following challenges while implementing the FIM:

1. **Participant ownership versus operating costs;**
   As mentioned before, the FIM can be implemented in a decentralised and in a centralised way. While a decentralised Farm Incubator Model gives farmers more ownership and accountability of their own farm, it also increases the amount of labour required for aQysta for training and transport. It is a (future) challenge to keep farmers accountable and motivated and at the same time keep labour costs feasible.

2. **Motivation of the farmers;**
   Currently, the lack of ownership of participating farmers is a challenge. aQysta has to deal with the fact that providing supplies does not always motivate farmers to do their best, as they might get the impression that inputs and monthly allowances will be provided with or without their effort. This challenge reflects a difficulty that arises with the mixture of components from a farmer field school and a farm incubator. As participants are existing farmers, it is hard for aQysta to determine whether farmers participate to easily receive inputs or to elevate themselves to a new level. The former could be a danger for the independence of the farmers and for the functioning of the model, as was noted by the FAO guide for farmer fields schools referred to earlier in Chapter 1.

3

Agricultural challenges in Malawi

3.1 Introduction and methodology

Having established both the challenges being addressed by the Farm Incubator Model and the challenges occurring when implementing the Farm Incubator Model, the next step in this research is to find out to what extent the Farm Incubator Model connects with challenges faced by smallholder farmers in Malawi. Smallholder challenges experienced in Malawi are assessed by analysing the fourth Integrated Household Survey (IHS4) (National Statistical Office, 2021). The IHS4 is a survey held by the Malawian National Statistics Office, recurring every three years. The survey used in this research was held between 2016-04-15 and 2017-04-30. The data set consists of four segments, a household questionnaire, an agriculture questionnaire, a fisheries questionnaire and a community questionnaire. Each of these segments is subdivided into modules, and each module in turn contains a number of variables. For this research, mainly the agriculture questionnaire results are used. The modules and variables that are used, are listed in Appendix E. In this appendix, also the steps that were taken to convert variables to usable formats are described for each variable. Furthermore, the followed approach to ensure data quality is explained. To use this data for the identification of challenges faced by smallholder farmers, a two-step approach is used. These steps are described in Sections 3.1.1 and 3.1.2.

3.1.1 Using ANOVA to detect inter-variable relations

The statistical tool ANOVA (ANalysis Of VAriances (Larson, 2008)) is used to analyse the relations between variables. This is done by selecting one dependent continuous variable and one or more independent categorical variables. Then, for each category (group) of a categorical variable, the variance of the continuous, dependent variable within this group is compared with the total variance of the continuous, dependent variable. This is done to distinguish between the variance that is caused by a group and the natural variance of a variable. This analysis of variance is performed to examine whether the difference between the means of the groups of a categorical variable is significant, and thus if the characteristics of the groups influence the dependent variable. The ANOVA test is a so-called hypothesis test (Larson, 2008). The null hypothesis (H_0) is that all group means of an independent categorical variable are the same, indicating that the group characteristics of the independent variable have no influence on the dependent variable. This hypothesis is rejected if at least one of the group means is differing significantly from the others. In this ANOVA, significant variance is defined as $p \leq 0.05$ for a variable. The ANOVA is implemented by utilising the Python-library Statsmodels (Statsmodels, 2019). Apart from performing the actual ANOVA, this library also allows for the so-called Tukey-HSD test, a posthoc analysis (Abdi and Williams, 2010), which is a valuable addition to ANOVA. The ANOVA algorithm either rejects or confirms H_0. When H_0 is rejected, it is only known that one or more of the group means of the categorical variable differs significantly from other group means. However, this does not indicate patterns between the groups of an independent categorical variable. In order to identify these patterns between categorical variable groups, the Tukey Honestly Significant Difference (Tukey HSD) test is performed. This test, being very similar to Student's T-test, performs a pairwise analysis of all group means of the independent categorical variable, either rejecting or accepting H_0 for each individual pair of groups (Abdi and Williams, 2010). In this way, a pattern is identified. Four dependent parameters are analysed: harvest amount, sold crop value, fertiliser use and land tenure. These parameters are selected based on the focus of the Farm Incubator Model as defined in Chapter 2.4. Combinations of these dependent continuous variables and independent categorical variables to perform these tests are selected based on the literature review in Chapter 4.

3.1.2 Using GIS to spatially identify challenges

When the ANOVA and the Tukey HSD tests are complete, QGIS is used to map variables that were found to have a significant relationship with the dependent variable, per district. This gives an overview of the challenges that are present for each district. For example, if a relation is found between the dependent variable 'yield amount' and the independent variable 'fertiliser use', the fertiliser use is visualised per district, in order to indicate the amount of yield that could be added per district when using more fertiliser.

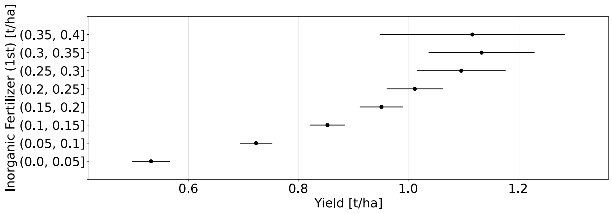
3.2 Analysis results of the fourth Integrated Household Survey

3.2.1 Harvest amount

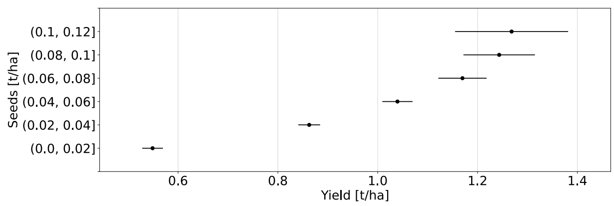
The harvest amount of plots participating in the IHS4 is dependent on various variables. Contrary to analysis further in this process, the variables possibly influencing the yield are chosen based on common logic. Those are crop type, inorganic fertiliser use, organic fertiliser use and seed use. Additionally, according to observations by Holden et al. (2009), Nakawuka et al. (2018) and Honig (2017), which are further elaborated in Chapter 4, security of ownership influences productivity. However, the way in which this tenure security is obtained varies per situation and is therefore hard to express in a variable. According to Singirankabo and Ertsen (2020), oftentimes, the largely unfounded claim is made that statutory land tenure increases tenure security. To analyse this claim for the specific situation of Malawi, the possession of an ownership document will be taken into account as a proxy for the type of land tenure, customary or statutory. An analysis of variance (ANOVA) is run, taking into account the variables mentioned above. The results are displayed in Table 3.1. Based on the results, the null hypothesis can be rejected for the variables crop type, the first application of inorganic fertiliser and for seed amount, with $p \leq 0.0001$. Furthermore, the null hypothesis can be rejected for the variables 'irrigation method' and 'ownership document', with $p = 0.036$ and $p = 0.012$ respectively. In order to assess the usability of these results, a pairwise Tukey HSD test is performed to assess the means of each group per variable. Group means and confidence intervals are plotted, and it is observed that the type of cultivated crop indeed has a large impact on yield (Fig. 3.1c). It is noted that some crop types are less commonly occurring than others, therefore having large confidence intervals which complicates analysis for these groups. The first fertiliser application as well as the seed amount (Figs. 3.1a and 3.1b) also show increasing yield for increased use of the respective agricultural inputs. The pairwise analysis of the method of irrigation (Fig. 3.1d) shows intuitive results, indicating higher yields for pump users. However, due to the small number of data points present for this variable, the confidence intervals are rather high, and therefore it is hard to establish the impact of irrigation methods on harvest amount in an accurate way. When analysing the impact of the type of ownership document, the same problem is encountered. Therefore, it is hard to identify a significant difference between the statutory, documented types of tenure (title deed, certificate of lease, offer of lease), and types of tenure not ratified by a document, due to the large confidence intervals (Fig. 3.1e).

Table 3.1: Analysis of variance - DV: Harvest amount [t/ha]

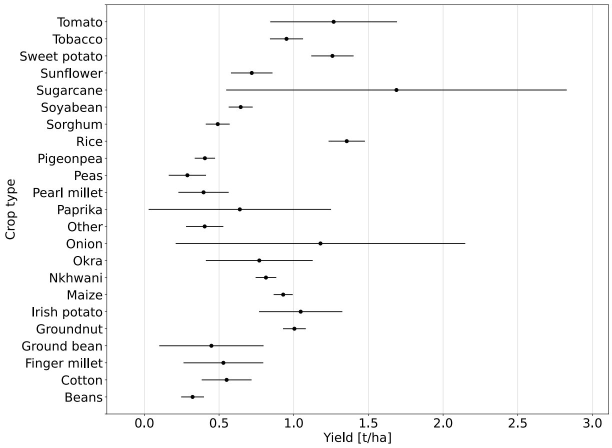
	DF	Sum of squares	Mean squares	F	PR(>F)	Reject H_0
Crop type	24.0	73.92	3.08	9.06	0.000	True
Irrigation method	6.0	4.62	0.77	2.27	0.036	True
Inorganic fertiliser (app. 1) [t/ha]	9.0	31.22	3.47	10.21	0.000	True
Inorganic fertiliser (app. 2) [t/ha]	9.0	4.18	0.46	1.37	0.200	False
Organic fertiliser [t/ha]	7.0	4.24	0.60	1.78	0.088	False
Seeds [t/ha]	6.0	11.27	1.88	5.53	0.000	True
Ownership document	4.0	4.40	1.10	3.24	0.012	True
Residual	605.0	205.60	0.34	-	-	



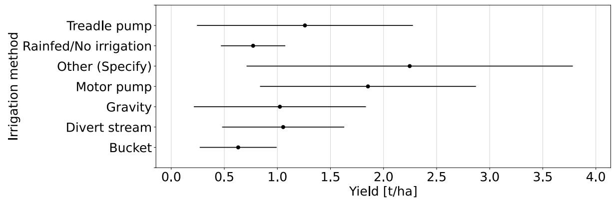
(a) Tukey: Inorganic fertiliser (app. 1) [t/ha] vs. harvest amount [t/ha]



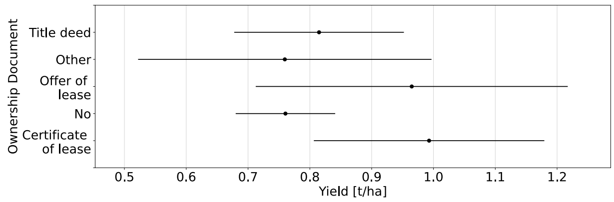
(b) Tukey: Seeds [t/ha] vs. harvest amount [t/ha]



(c) Tukey: Crop type vs. harvest amount [t/ha]



(d) Tukey: Irrigation method vs. harvest amount [t/ha]



(e) Tukey: Ownership document vs. harvest amount [t/ha]

Figure 3.1: Tukey pairwise analysis of variables - DV: Harvest amount [t/ha]

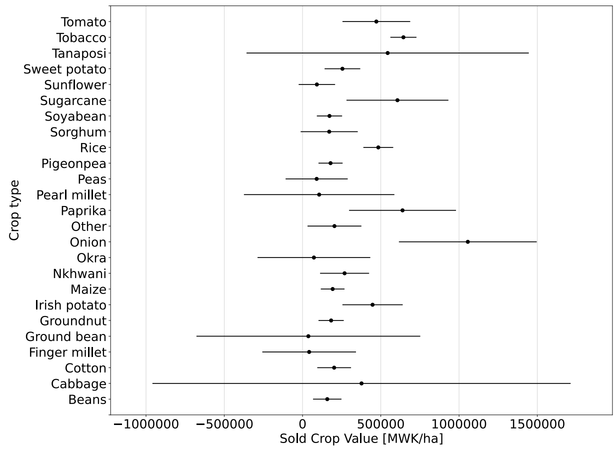
Table 3.2: Analysis of variance - DV: sold crop value [MWK/ha]

	DF	Sum of squares	Mean squares	F	PR(>F)	Reject H_0
Crop type	24.0	4.64e+13	1.93e+12	26.03	0.000	True
Distance to city (> 20,000p) [km]	10.0	1.07e+12	1.07e+11	1.44	0.157	False
Harvest amount [t/ha]	7.0	3.70e+13	5.29e+12	71.13	0.000	True
Main transportation method	5.0	6.35e+12	1.27e+12	17.10	0.000	True
Residual	4361.0	3.24e+14	7.43e+10	-	-	

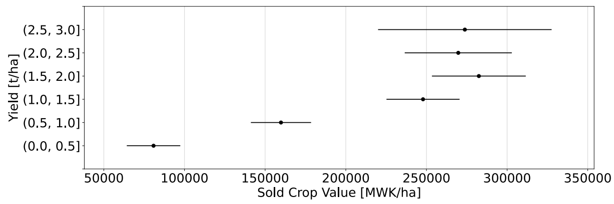
3.2.2 Value of sold crops

The next parameter that is assessed is the value of the sold crops of each farm. This expands on the harvest amount parameter analysis in the previous section, additionally taking into account factors influencing the process occurring in the time between harvesting and selling, such as transportation and accessibility to a selling location. Firstly, the previously analysed harvest amount parameter is taken into consideration. Since the variables influencing the harvest amount are already established in the previous section, they are neglected by this ANOVA, to avoid unwanted interaction between variables. An exception to this is the crop type since this variable not only influences the harvest amount, but also the selling price (Burney and Naylor, 2012, Radchenko and Corral, 2018). Apart from that, the variable indicating the distance to the nearest city with a population greater than $20,000$ will be taken into consideration, as well as the variable indicating the mode of transportation for taking the crops to the market (Nakawuka et al., 2018). In Table 3.2, the results from the ANOVA for the mentioned variables are printed. Except from the variable 'distance to city ($>20,000p$)', for all variables, the null-hypotheses are rejected with $p \leq 0.0001$.

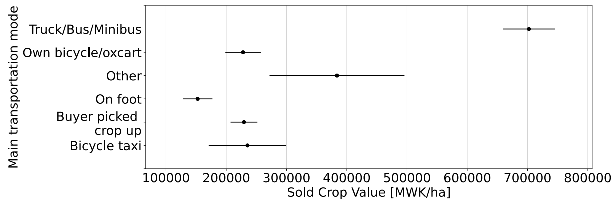
The variables for which the null hypothesis is rejected are visualised. Figure 3.2a displays the variable 'crop type'. High-value cash crops such as tobacco, sugarcane, paprika and onion can be clearly identified. Some crop types have too few data points, resulting in a rather wide confidence interval for these groups. Figure 3.1c, displaying the yield, shows a proportional increase of the sold crop value and the yield. Reaching yield amounts higher than roughly $2.0\ t/ha$, this increase stagnates, and the confidence intervals increase



(a) Tukey: Crop type vs. sold crops value [MWK/ha]



(b) Tukey: Yield [t/ha] vs. sold crops value [MWK/ha]



(c) Tukey: Main transportation mode vs. sold crops value [MWK/ha]

Figure 3.2: Tukey pairwise analysis of variables - DV: Sold crop value [MWK/ha]

in size, making it impossible to draw conclusions for higher yield amounts. Figure 3.2c shows the means and confidence intervals of the different groups of the 'main transportation mode'-variable. From this figure, it follows that transport modes with a greater range and capacity tend to give higher returns per hectare. Interestingly, since the distance to a large city did not turn out to be of significant influence, it is observed that ability of high range and high capacity transportation is a better way to generate income than living close to a selling point.

3.2.3 The use of fertiliser

Next up, fertiliser use is analysed. The use of fertiliser is highly influenced by the accessibility of markets (Mutambara and Munodawafa, 2014, Nakawuka et al., 2018). Also, the level of tenure security influences the motivation of farmers to invest in their businesses (Mutambara et al., 2016, Shah et al., 2002, Nakawuka et al., 2018, Nkomoki et al., 2018). Following the same reasoning as in Section 3.2.1, the ownership document is used here as well as a proxy for land tenure security.

Analysing the results for three fertiliser factors, inorganic fertiliser (appl. 1) [Tab. 3.3], inorganic fertiliser (appl. 2) [Tab. 3.4], and organic fertiliser [Tab. 3.5], it turns out that for all three types of fertiliser use, the mean fertiliser use for the various crop types differs significantly from each other ($p \leq 0.0001$). In Figure 3.3d, the Tukey HSD test results are shown for the first application of inorganic fertiliser versus crop type. It is observed that crops identified in Figure 3.2a tend to receive more inorganic fertiliser. Furthermore, the distance to an agricultural market does significantly influence the use of fertiliser with respective p-values of $\leq 0.0001, \leq 0.0001$ and 0.025. The pairwise Tukey HSD test results are displayed in the respective Figures 3.3a, 3.3b and 3.3c. Interesting patterns emerge, as the use of inorganic fertiliser, which needs to be purchased at a market, declines with increasing distance to a market, while organic fertiliser, which is produced locally by cattle, shows an increase with increased distance to a market. Lastly, it is observed that the mean fertiliser use does not significantly differ between the types of ownership document, with respective p-values of $0.49, 0.57$ and 0.17.

Table 3.3: Analysis of variance - DV: Inorganic fertiliser (app. 1) [t/ha]

	DF	Sum of squares	Mean squares	F	PR(>F)	Reject H_0
Crop type	24.0	1.29	0.054	9.38	0.000	True
Distance to agricultural market [km]	5.0	0.28	0.056	9.72	0.000	True
Ownership document	4.0	0.020	0.0049	0.85	0.494	False
Residual	12392.0	71.25	0.0058	-	-	

Table 3.4: Analysis of variance - DV: Inorganic fertiliser (app. 2) [t/ha]

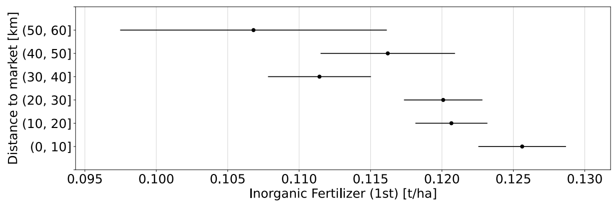
	DF	Sum of squares	Mean squares	F	PR(>F)	Reject H_0
Crop type	24.0	0.58	0.024	4.11	0.000	True
Distance to agricultural market [km]	5.0	0.52	0.10	17.77	0.000	True
Ownership document	4.0	0.017	0.0043	0.73	0.573	False
Residual	5486.0	32.39	0.0059	-	-	

Table 3.5: Analysis of variance - DV: Organic fertiliser [t/ha]

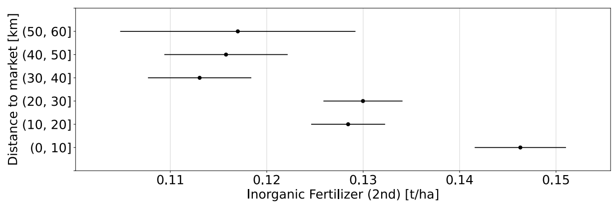
	DF	Sum of squares	Mean squares	F	PR(>F)	Reject H_0
Crop type	24.0	32.19	1.34	3.47	0.000	True
Distance to agricultural market [km]	5.0	4.98	0.10	2.58	0.025	True
Ownership document	4.0	2.47	0.62	1.60	0.172	False
Residual	3840.0	1484.35	0.39	-	-	

3.2.4 The importance of land tenure

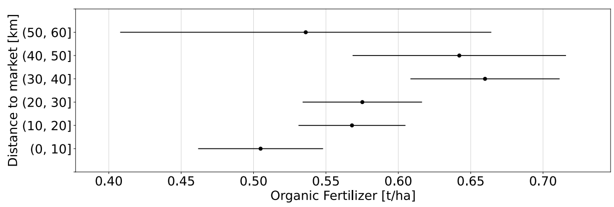
The last analysed parameter is land tenure. Previously, the type of ownership document was used as a proxy for land tenure, to verify the hypothesis that registered land tenure leads to more agricultural productivity. This section aims to explore tenure security, going beyond the mere division between statutory and customary land tenure as security indicator. This is done by exploring which variables affect tenure security and how tenure security could be expressed. As the dependent variable, the time of ownership of the plot is analysed. This variable is interesting for two reasons. Firstly, it represents tenure security, based on the assumption that when a plot is owned for a longer time, land tenure is more secure. Secondly, it shows development



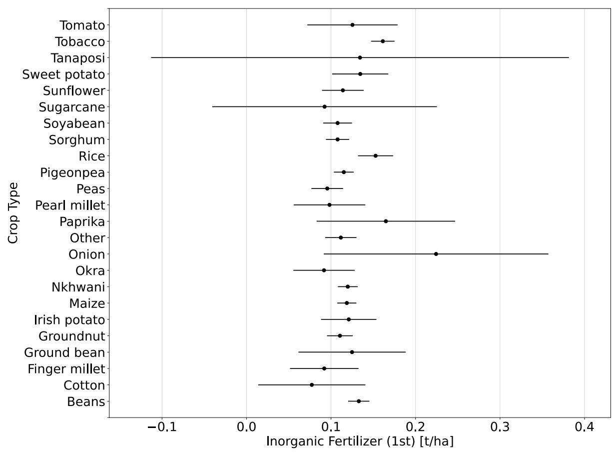
(a) Tukey: Distance to agricultural market [km] vs. inorganic fertiliser (app. 1) [t/ha]



(b) Tukey: Distance to agricultural market [km] vs. inorganic fertiliser (app. 2) [t/ha]



(c) Tukey: Distance to agricultural market [km] vs. organic fertiliser [t/ha]



(d) Tukey: Crop type vs. inorganic fertiliser use [t/ha]

Figure 3.3: Tukey pairwise analysis of variables - DV: fertiliser usage [t/ha]

Table 3.6: Analysis of variance - DV: time of plot ownership [years]

	DF	Sum of squares	Mean squares	F	PR(>F)	Reject H_0
Plot purchasing method	11.0	2.80e+05	25496.30	152.88	0.000	True
Ownership document	4.0	1.00e+03	250.03	1.50	0.200	False
Residual	21091.0	3.52e+06	166.77	-	-	-

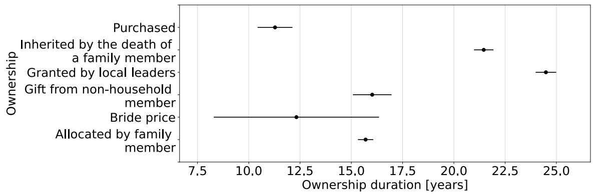


Figure 3.4: Tukey: Plot purchasing method vs. Ownership duration [year]

Table 3.7: Overview of significant independent variables found with ANOVA

Dependent variable	Quantitative independent variable(s)	Qualitative independent variable(s)
Yield [t/ha]	Inorganic fertiliser (app. 1) [t/ha] Seeds [t/ha]	Crop type Irrigation method Ownership document
Sold crops value [MWK/ha]	Yield [t/ha]	Crop type Main transportation mode
Inorganic fertiliser (app. 1) [t/ha]	Distance to agricultural market [km]	Crop type
Inorganic fertiliser (app. 2) [t/ha]	Distance to agricultural market [km]	Crop type
Organic fertiliser [t/ha]	Distance to agricultural market [km]	Crop type
Time of plot ownership [years]		Plot purchasing method

over time with regard to the analysed independent variables.

For the analysis of this parameter, the factors 'Plot purchasing method' and 'Ownership document' are taken into account. In Table 3.6 the results of the ANOVA are visualised. It is clear that the plot purchasing method has the most influence, with a $p \leq 0.0001$. The ownership document did not show significant variance in mean time of ownership between the various types of documents ($p = 0.199$). In Figure 3.4, the results for the Tukey HSD test are shown. As mentioned, there are two ways to interpret these results. Firstly, the ownership duration could say something about the durability of the method of purchasing the plot; the longer the plot is in possession, the more secure is the land tenure resulting from the method of purchasing. Secondly, it could show development in methods of purchasing over time. While 25 years ago the main methods were primarily based on customary land tenure (i.e 'granted by local leaders', Fig. 3.4), eleven years ago land purchasing as a method to obtain a plot was also common. This leads to the observation that tenuring land in a statutory way is rather new, which is corroborated by various other sources (Holden and Otsuka, 2014, Honig, 2017, Nakawuka et al., 2018).

3.3 Identification of challenges

In Table 3.7, an overview is shown of all independent variables significantly influencing the selected dependent variables, found with ANOVA. This section is meant to indicate for each district in Malawi which of the analysed dependent variables pose a challenge for Malawian agriculture, by analysing the mean value of the independent variables per district. By categorising districts according to the groups of the various independent variables, for each district, a quantitative picture can be drawn regarding performance and room for improvement for harvest amount, sold crops value, fertiliser use and so on.

3.3.1 Quantitative independent variables

In Figure 3.5, for each district, the means of the four quantitative independent variables as indicated in Table 3.7 are given. To categorise the means, the same groups as in the ANOVA are used, in order to link the situation per district with results found with the ANOVA. It is observed that in the case of yield, seeds and inorganic fertiliser, all districts are categorised in the lower half of the groups. With regards to distance to an agricultural market, some districts are rather well connected to agricultural markets, while others are less connected.

3.3.2 Qualitative independent variables

The three qualitative independent variables that have shown a significant difference in variable group means are the main mode of transportation and the crop type, showing variance in sold crop value, and the plot purchasing method, showing variance in the time of plot ownership. These respective variables are summarised per district in Tables 3.8, 3.9 and 3.10. The shown values in the tables represent the number of occurrences of a group in a district. It is noted that the qualitative variables 'irrigation method' and 'ownership document' are neglected here since the respective posthoc analyses did not yield clear results for these variables, due to an insufficient number of data points.

When comparing the frequency of transportation modes per district (Tab. 3.8) with the transportation modes that yield the highest revenue per hectare (Fig. 3.2c), it is evident that high-yielding transportation methods, such as trucks, buses and minibuses, are scarcely used in districts. Analysing the frequency of plot purchasing methods (Tab. 3.9), it is observed that customary purchasing methods such as land allocation by local leaders or a family member are predominant in all districts. With regards to cultivated crop types, it turns out that the predominant crop types in each district (Tab. 3.10) perform mediocre regarding revenue per hectare (Fig. 3.2a). In other words, cash crops are uncommon in all districts.

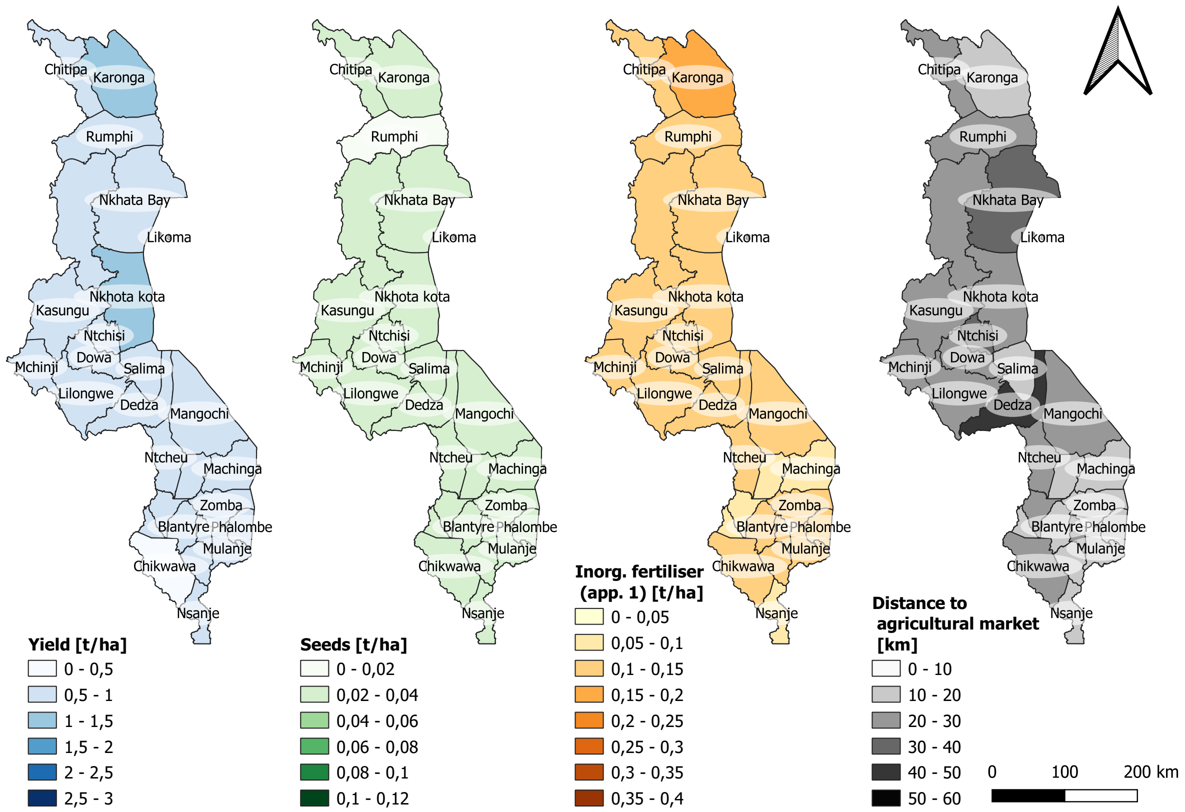


Figure 3.5: Visualisation of districts and their corresponding groups per quantitative independent variable

Table 3.8: Overview of significant qualitative independent variables found with ANOVA - Main transportation mode

District	Balaka	Blantyre	Chikwawa	Chiradzulu	Chitipa	Dedza	Dowa	Karonga	Kasungu	Likoma	Lilongwe	Machinga	Mangochi	Mchinji	Mulanje	Mwanza	Mzimba	Neno	Nkhata Bay	Nkhota kota	Nsanje	Ntcheu	Ntchisi	Phalombe	Rumphi	Salima	Thyolo	Zomba
Bicycle Taxi	6.00	1.00	1.00	11.00	10.00	9.00	19.00	10.00	18.00		25.00	5.00	1.00	10.00	8.00	5.00	3.00		5.00	8.00		12.00	16.00	2.00	6.00	4.00	4.00	
Buyer picked up the crop	74.00	53.00	62.00	46.00	79.00	102.00	182.00	81.00	167.00		239.00	78.00	53.00	87.00	56.00	136.00	257.00	44.00	63.00	158.00	39.00	75.00	379.00	65.00	102.00	59.00	85.00	8.00
On Foot	18.00	65.00	38.00	81.00	110.00	69.00	88.00	38.00	56.00	2.00	105.00	33.00	6.00	73.00	75.00	138.00	76.00	72.00	12.00	17.00	15.00	61.00	50.00	74.00	47.00	29.00	91.00	22.00
Other	2.00	7.00	1.00	7.00	1.00		1.00	2.00			10.00	1.00		15.00	3.00	3.00	6.00			4.00		3.00	7.00	3.00	1.00	1.00		1.00
Own Bicycle or Oxcart	23.00	5.00	14.00	22.00	64.00	48.00	61.00	59.00	43.00		116.00	28.00	7.00	96.00	67.00	17.00	17.00	9.00	8.00	11.00	2.00	27.00	18.00	63.00	8.00	25.00	13.00	12.00
Truck/Bus/ Minibus		7.00	2.00	3.00	33.00	8.00	56.00	14.00	51.00	1.00	43.00	5.00		6.00		4.00	32.00	2.00	5.00	12.00		11.00	38.00	2.00	68.00	6.00	1.00	2.00

Table 3.9: Overview of significant qualitative independent variables found with ANOVA - Plot purchase method

District	Balaka	Blantyre	Chikwawa	Chiradzulu	Chitipa	Dedza	Dowa	Karonga	Kasungu	Likoma	Lilongwe	Machinga	Mangochi	Mchinji	Mulanje	Mwanza	Mzimba	Neno	Nkhata Bay	Nkhota kota	Nsanje	Ntcheu	Ntchisi	Phalombe	Rumphi	Salima	Thyolo	Zomba
Allocated by family member	475.00	625.00	353.00	819.00	430.00	507.00	535.00	303.00	437.00	26.00	775.00	660.00	302.00	552.00	828.00	688.00	407.00	514.00	114.00	288.00	272.00	595.00	529.00	1025.00	310.00	192.00	698.00	107.00
Borrowed for free	5.00	37.00	12.00	13.00	23.00	4.00	31.00	41.00	68.00	4.00	27.00	30.00	17.00	32.00	46.00	18.00	134.00	18.00	24.00	26.00	20.00	13.00	19.00	29.00	32.00	17.00	29.00	1.00
Bride price	6.00	8.00		10.00				2.00	5.00		11.00	5.00		8.00					2.00						2.00	2.00	7.00	
Farming as a tenant		8.00							15.00		2.00				5.00	2.00		2.00	1.00	7.00					5.00		2.00	
Gift from non-household member	2.00	11.00	5.00	52.00	22.00	37.00	113.00	8.00	101.00		47.00	2.00	6.00	6.00	42.00	7.00	99.00	1.00	22.00	1.00	6.00	3.00	56.00	36.00	48.00	51.00	12.00	
Granted by local leaders	130.00	115.00	73.00	194.00	388.00	52.00	68.00	195.00	124.00	5.00	120.00	168.00	103.00	47.00	38.00	85.00	75.00	189.00	108.00	148.00	86.00	63.00	105.00	49.00	195.00	103.00	168.00	37.00
Inherited by the death of a family member	131.00	159.00	115.00	207.00	119.00	141.00	221.00	135.00	135.00	3.00	364.00	182.00	93.00	173.00	58.00	95.00	244.00	108.00	44.00	59.00	85.00	22.00	123.00	60.00	179.00	91.00	146.00	51.00
Leasehold						1.00			2.00				1.00				3.00						4.00		1.00			
Moved in without permission		13.00	20.00	3.00	25.00	3.00	3.00	4.00	8.00		11.00		1.00	6.00	2.00		4.00		4.00	2.00	5.00		4.00		4.00	4.00	14.00	
Other	1.00	21.00	9.00		4.00	8.00	2.00		26.00		9.00	1.00		5.00	4.00	2.00	33.00	3.00	2.00		1.00				15.00	2.00	10.00	1.00
Purchased	33.00	27.00	37.00	25.00	8.00	11.00	33.00	35.00	66.00	14.00	61.00	24.00	19.00	27.00	35.00	27.00	39.00	82.00	27.00	37.00	14.00	35.00	35.00	39.00	14.00	14.00	50.00	
Rent short-term	29.00	43.00	91.00	54.00	20.00	36.00	77.00	65.00	85.00		194.00	52.00	32.00	82.00	49.00	60.00	55.00	27.00	14.00	70.00	96.00	41.00	59.00	27.00	54.00	65.00	57.00	17.00

Table 3.10: Overview of significant qualitative independent variables found with ANOVA - Crop type

District Crop Type	Balaka	Blantyre	Chikwawa	Chiradzulu	Chitipa	Dedza	Dowa	Karonga	Kasungu	Likoma	Lilongwe	Machinga	Mangochi	Mchinji	Mulanje	Mwanza	Mzimba	Neno	Nkhata Bay	Nkhota kota	Nsanje	Ntcheu	Ntchisi	Phalombe	Rumphi	Salima	Thyolo	Zomba
Beans		40.00	12.00	93.00	171.00	109.00	97.00	4.00	107.00		108.00	1.00	5.00	28.00	6.00	14.00	107.00	35.00	14.00	4.00	21.00	101.00	85.00	4.00	81.00	1.00	37.00	
Cabbage																											1.00	
Cotton	38.00	3.00	71.00				2.00	11.00	1.00		1.00	8.00	4.00			1.00	1.00	17.00		6.00	16.00	8.00				26.00		
Finger millet	4.00	4.00		7.00	5.00	2.00			1.00			4.00	5.00			1.00	8.00	1.00			1.00	8.00			1.00			
Ground bean		1.00		1.00	1.00		3.00		2.00	1.00	3.00			1.00		2.00	5.00		2.00			1.00						
Groundnut	29.00	40.00	9.00	23.00	58.00	81.00	93.00	23.00	98.00		157.00	57.00	36.00	118.00	15.00	23.00	78.00	26.00	14.00	59.00	22.00	48.00	77.00	14.00	57.00	48.00	8.00	11.00
Irish potato					2.00	16.00	1.00				4.00			2.00			5.00	1.00				5.00	16.00					
Maize	397.00	461.00	207.00	523.00	445.00	423.00	414.00	291.00	399.00	29.00	747.00	428.00	365.00	396.00	441.00	440.00	500.00	459.00	181.00	265.00	195.00	460.00	373.00	524.00	385.00	300.00	474.00	86.00
Nkhwani	67.00	180.00	38.00	218.00	152.00	71.00	215.00	160.00	203.00	18.00	299.00	122.00	52.00	200.00	67.00	143.00	143.00	153.00	64.00	120.00	27.00	63.00	120.00	115.00	172.00	102.00	193.00	35.00
Okra	1.00	2.00	1.00	3.00		1.00	8.00	1.00	7.00		4.00	1.00		4.00	2.00			3.00	7.00	4.00	3.00			1.00	2.00	3.00		2.00
Onion					4.00	2.00																	1.00	1.00				
Other	30.00	11.00	52.00	19.00	9.00		10.00	13.00	4.00		6.00	18.00	5.00	5.00	7.00	7.00	3.00	16.00	8.00	5.00	40.00	1.00	2.00		5.00	16.00	52.00	3.00
Paprika						1.00	2.00		1.00								2.00		1.00	1.00					3.00			
Pearl millet			45.00	4.00	1.00				1.00			14.00	11.00		1.00		1.00	2.00			67.00			3.00				
Peas	50.00	1.00	11.00	12.00	1.00	3.00	11.00		18.00		4.00	23.00	2.00	5.00	21.00	8.00	1.00	22.00	1.00	2.00	10.00	6.00		11.00		2.00	7.00	1.00
Pigeonpea	158.00	250.00	72.00	311.00	4.00		1.00	29.00	1.00		7.00	289.00	63.00	1.00	312.00	328.00	2.00	166.00		4.00	36.00	23.00	2.00	302.00	3.00		330.00	51.00
Rice	4.00	1.00	22.00	6.00	4.00			213.00	1.00	1.00	3.00	52.00	5.00		17.00		1.00	1.00	43.00	134.00	22.00			23.00	1.00	14.00		6.00
Sorghum	27.00	50.00	164.00	124.00	1.00	9.00	1.00	2.00			1.00	77.00	9.00		125.00	5.00		21.00			118.00	4.00		137.00		2.00	54.00	12.00
Soyabean		3.00	1.00	8.00	15.00	58.00	91.00		102.00		126.00		4.00	122.00	10.00		107.00	4.00		6.00		24.00	156.00	34.00	24.00	1.00	2.00	
Sugarcane							1.00		2.00		5.00			2.00	4.00					1.00								
Sunflower					61.00				12.00					10.00	25.00		20.00					1.00		31.00	1.00			
Sweet potato	1.00	6.00	3.00	6.00	46.00	5.00	10.00	10.00	8.00	2.00	15.00	3.00	3.00	7.00	13.00	9.00	34.00	7.00	10.00	3.00	3.00		11.00	4.00	11.00	1.00	12.00	3.00
Tanaposi								1.00			1.00						1.00										1.00	
Tobacco	1.00			4.00	27.00	7.00	96.00	1.00	79.00	1.00	93.00	4.00	2.00	27.00			50.00	1.00	5.00	1.00		8.00	72.00	16.00	89.00	2.00		
Tomato	1.00		1.00	4.00			1.00	4.00	2.00		3.00				8.00		2.00			1.00	2.00	3.00			2.00		3.00	

3.4 Discussion

This chapter described and quantified challenges faced by farmers in Malawi, based on data from the fourth Integrated Household Survey. In this section, the results are discussed and compared to the previous chapter, where challenges addressed by the Farm Incubator Model of aQysta were defined.

The following challenges for Malawian agriculture are identified.

1. **Lack of agricultural input usage**
   It turns out that mainly inorganic fertiliser and seeds highly influence the yield amount (Figs. 3.1a and 3.1b). At the same time, the average use of inorganic fertiliser and seeds is shockingly low in all districts. (Fig. 3.5)

2. **Lack of cash crops**
   From Figure 3.2a, it turns out that cash crops (i.e. tobacco, onions) have a higher revenue per hectare. However, it turns out that in all districts, the predominant crop types (Tab. 3.10) do not perform well in terms of revenue per hectare.

3. **Lack of proper harvest transportation methods**

The method of crop transportation to markets is greatly affecting the sold crop revenue per hectare (Fig. 3.2c). Comparing this with Table 3.8, it is observed that transport methods with low revenue are predominant in almost all districts;

4. **Lack of connection to agricultural markets**
   It is observed that distance to an agricultural market can be a barrier for acquiring agricultural inputs, if too big. In Figures 3.3a and 3.3b, inorganic fertiliser use declines if the distance to a market increases. Following from Figure 3.3c it can be assumed that farmers use organic fertiliser as an alternative to inorganic fertiliser if the distance to an agricultural market grows. As mentioned earlier, inorganic fertiliser has a higher impact on the harvest amount than organic fertiliser. From Figure 3.5 it is learned that this challenge is not present in all districts, as the average travel distance to an agricultural market varies a lot per district.

Comparing these results with the previous chapter, it is concluded that the Farm Incubator Model takes care of these four challenges. Agricultural inputs are provided in the form of fertiliser and seeds for cash crops, therewith also addressing the lack of cash crop cultivation. Also, aQysta takes care of transportation of inputs to the farm, as well as transportation of the harvest to a selling point. Theoretically, the components of the Farm Incubator Model make for a comprehensive approach to smallholder challenges in Malawi. However, the implementation of the Farm Incubator Model is not without its challenges, as was stated in the discussion of Chapter 2. Therefore, it must be investigated whether the way in which these smallholder challenges are addressed by the model is a sustainable way, or if it is just a short-term alleviation of the experienced challenges. Therefore, in Chapter 4, apart from evaluating the theoretical components of the Farm Incubator Model on their compatibility with smallholder challenges on a Sub-Saharan African scale, also the way in which the Farm Incubator Model deals with these challenges is investigated.

Furthermore, it should be noted that while the irrigation method has an influence on the means of yield per hectare (Tab. 3.1), it was not included in the list above, as the number of data entries for this variable is too low to perform an accurate analysis on which irrigation method results in the best yield. This is reflected in the large confidence intervals in Figure 3.1d. Despite these large confidence intervals, the results are still intuitive, and since the variable also turned out to be significant, it is included in the literature review of Chapter 4. The same holds for land tenure. Interesting observations are done with regards to ownership duration and purchasing method. Also, it is found that the type of ownership document influences the harvest amount (Tab. 3.1). Even though in post-hoc analysis (Fig. 3.1e) no clear link could be established between different types of ownership documents and harvest amounts, due to large confidence intervals, land tenure is included in the literature review of Chapter 4.

4

Smallholder challenges in a Sub-Saharan African context

4.1 Introduction and methodology

Until now, this research has described the ins and outs of the Farm Incubator Model, compared the Farm Incubator Model to other participatory learning programmes for farmers, and found that from a theoretical point of view, the challenges addressed by the model are experienced by farmers all over Malawi. This last chapter forms the final stage of assessment of the Farm Incubator Model, and answers the third research sub-question, describing the extent to which the Farm Incubator Model would be suitable to be implemented in other Sub-Saharan countries. This is done in two parts. Firstly, the challenges described in Chapter 3.4 are compared with challenges found in literature on smallholders in Sub-Saharan Africa. The first and last identified challenge, which are the lack of agricultural input usage and the limited access to agricultural markets, are discussed in Section 4.2. Secondly, the lack of cash crop usage is handled in Sections 4.3 and 4.4. The third identified challenge, the difficulty of harvest transportation and selling, is also discussed in Section 4.3. Then, in Section 4.4, the challenges arising around irrigation are discussed. Lastly, in Section 4.5, the influence of tenure security on smallholder agriculture is discussed. Secondly, it is assessed if the way in which the Farm Incubator Model aids farmers in these challenges is a sustainable way. As is mentioned, in earlier chapters it is concluded that the Farm Incubator Model theoretically addresses the main challenges found in Malawian smallholder agriculture. Apart from this, it is important to assess the way in which these challenges are addressed. Discussions of previous chapters (Sections 2.4 and 3.4) already briefly touched upon this and this topic is further addressed in Section 4.6.

4.2 Agricultural inputs and market accessibility

In their research, Mutambara and Munodawafa (2014) found that agricultural inputs are hard to acquire. Researching three small agricultural regions in South-East Zimbabwe, they found that for instance fertiliser was unavailable on the local market. Regionally, albeit overpriced, fertiliser was sometimes available in a city nearby. Similar findings by Nakawuka et al. (2018) in East-Africa indicate that improved seeds and fertiliser are predominantly being imported. Therefore, these are expensive and out of reach for farmers with limited access to large markets. A lack of agricultural inputs not only causes bad harvests but also land degradation in the long term, as nutrients in the soil eventually deplete.

Baiphethi and Jacobs (2009) state that oftentimes agricultural inputs are acquired informally. This comprises trading with neighbours, unregulated sales, and more. In Southern Africa, only 10% of used seeds are acquired via markets. Furthermore, the purchasing of high-value agricultural inputs requires secure conditions. This entails access to credit services, which allow a farmer to invest in agricultural inputs. However, most smallholder farmers lack collateral and therefore do not have access to credit services (Nkomoki et al., 2018). Furthermore, access to irrigation reduces the risk of bad harvests, thereby improving farmers' opportunity to invest in agricultural inputs (Shah et al., 2013).

4.3 Harvest selling and transportation

Smallholder produce is in most cases used for self-sustenance. Only in case of excess produce, goods are sold. For a smallholder farmer, several issues arise when trying to sell excess produce. The first problem encountered is the fact that farmers tend to harvest in a similar time period and sell to the same market, resulting in price inelasticity due to the fluctuation of prices along with yield amounts (Burney and Naylor, 2012). According to Nakawuka et al. (2018), it is also not uncommon that most of the farmers produce the same crop, which means that in order to get a good price for the produce, selling must be done at larger, regional markets, which then brings up the issue of transportation. When transportation options are limited, often the selling is outsourced to an external party, which means it is hard to check if fair prices are paid for produce. Burney and Naylor (2012) noted that only 20-35% of smallholder farmers in Southern and Eastern Africa sell any produce. This indicates that most smallholder farmers only produce for self-sustenance and experience challenges when it comes to selling produce.

On the topic of self-sustaining versus market-oriented farming, generally, self-sustaining farmers cultivate staple crops for their own consumption, and at most some excess produce is sold. Market-oriented farmers mainly cultivate cash crops, intended for selling (Tittonell et al., 2010). Cash crops require more intense attention, and generally cannot be grown without irrigation. Therefore, they require a certain level of advancement. Market-oriented farmers tend to have a higher degree of food self-sufficiency, as was found by Tittonell et al. (2010) in a case study among 250 farmers in Kenya and Uganda. These barriers, faced when selling produce at a market, cause farmers to reevaluate their crop choice. Radchenko and Corral (2018) found that the willingness of farmers to grow cash crops decreases when it gets harder to sell these on the market.

4.4 Irrigation systems

Irrigation use in Sub-Saharan Africa

An overview of irrigation statistics for the top 25 Sub-Saharan countries in Africa with the highest cultivated area is given in Figure 4.1. Regarding these 25 countries, an average proportion of 16% of the cultivated area has irrigation potential. As can be seen in Figure 4.1a, not all of this potential is made use of, as on average, 4% of cultivated land is equipped for irrigation. Of this small share, 11% is equipped for power irrigation. FAO (2017) defines power irrigation as situations where a pump is used to get water from source to scheme.
Regarding distribution systems, Figure 4.1b gives an overview of five irrigation methods and the frequency of their use in different countries. It should be noted that these methods do not consider transport to the field. These methods are defined as follows (FAO, 2017):

- Surface irrigation: water is applied to the soil manually (i.e. bucket, can) and gravity is used to distribute it over the field;
- Sprinkler irrigation: a pipe system equipped with sprinklers, also known as overhead irrigation systems;
- Localised irrigation: low-pressure irrigation system using pipes to distribute water to each plant (i.e. drip irrigation);
- Equipped lowland irrigation: cultivated wetland or structures to retain floodwater;
- Spate irrigation: diversion of (flood) water to cropping area.

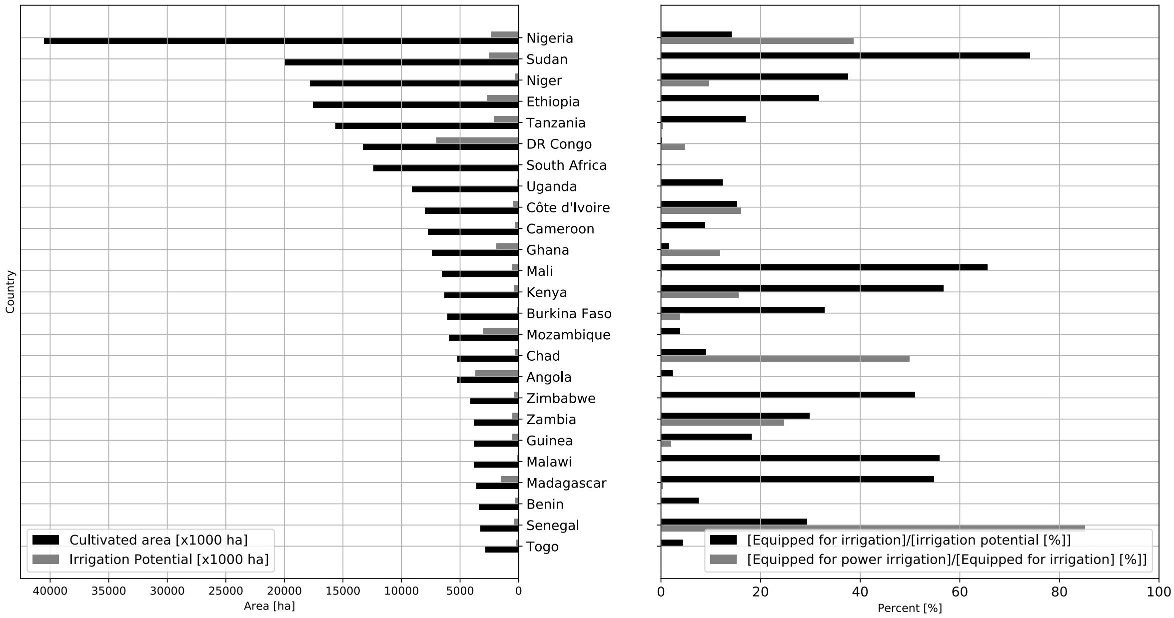
Implementation and maintenance of irrigation technologies

The way new technology is introduced, is of influence of the adoption process. Mangisoni (2008) reviewed the adoption of the treadle pump in two districts, Blantyre and Mchinji, in Malawi. The introduction procedure was as follows: the treadle pumps were fabricated in rather large cities in the region, then transported to the districts' agricultural offices, where they were stored. After that, the pumps were transported to a field office in the vicinity of the target farmers. Farmers who then chose to purchase a pump received maintenance training and received bi-monthly visits from field officers to help with any occurring problems. In a comparative study, it was found that adopters of the treadle pump benefited from the approach, as they generated more income than non-adopters.

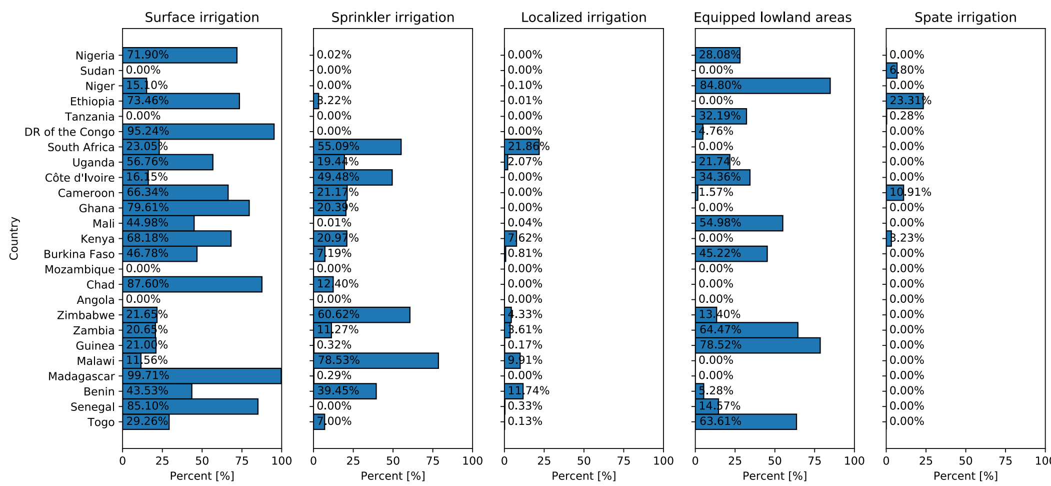
A key requirement for the sustainable use of an irrigation scheme is to have access to maintenance. In South-Eastern Zimbabwe, Mutambara and Munodawafa (2014) found that overall, only 21% of the interviewed smallholder farmers had received training in pump maintenance. Nakawuka et al. (2018) also found the lack of maintenance to be an important cause of discontinued use of irrigation technologies in East Africa.

Sometimes basic maintenance training was given, but a lack of trouble-shooting capability and the absence of spare parts caused many farmers to eventually abandon the technology.

Cultivation of cash crops as cause and effect of a successful irrigation system
According to Burney and Naylor (2012), in order for a smallholders' irrigation system to be successful, three system components are necessary. These are a water abstraction technology (i.e. a pump), a water distribution technology (i.e. a drip tube system) and a profitable application (i.e. cash crops). The absence of one or two of these three components inevitably causes a range of problems. The absence of a proper water abstraction technology will cause a decrease in irrigation capacity and will render the system unprofitable. The absence of a good distribution system will either mean a heavy workload, inefficient irrigation or both and will also render the system unprofitable. Also, when irrigation is not used to cultivate cash crops but staple crops, it is hard to make the system profitable. In some contexts, one or more of the system components might already be present. However, when introducing a novel technology that only covers one of these three



(a) Irrigation potential



(b) Irrigation methods

Figure 4.1: Overview of irrigation presence in Sub-Saharan Africa (FAO, 2017)

components, attention must be paid to the additional coverage of the other two, or it will be hard to make the system viable. An important note that Burney and Naylor (2012) make, is that while incorporating a water distribution technology encourages the incorporation of a water abstraction technology and vice versa, cash crops aren't technically required to let the other two components function. Therefore, the promotion of cash crop cultivation is structurally ignored in development packages, as was revealed by case studies in Ghana, Zimbabwe and Zambia, where implementing water abstraction and distribution technologies did not appear to lead to the implementation of cash crops. This makes it hard to get long-term returns on investment.

The importance of cash crops is also underlined by a large case study among 1554 smallholders of nine countries in Sub-Saharan Africa, performed by Shah et al. (2013). They found that crop choice is highly influenced by the choice of irrigation system. They concluded that when farmers have large control over their water, they are very likely to choose cash crops as their main crop, instead of staple crops. Obtained results are summarised in Table 4.1, showing that farmers who use pumping technology for irrigation generally tend to grow cash crops. Farmers who possess advanced irrigation technology were rarely seen to be having a staple crop as the main crop. This is reflected in the returns achieved, with farmers owning a motor pump getting almost tripled returns compared to farmers relying on rain-fed irrigation, after subtraction of running costs (Shah et al., 2013).

4.5 Land tenure

The way land is tenured wildly varies per country in Sub-Saharan Africa. Oftentimes, land tenure is not officially registered. For example, in Uganda and Tanzania, land registration only has been done for 10% and 3% of land respectively (Nakawuka et al., 2018). Basically, land tenure can be divided into two categories, which are customary land tenure and statutory land tenure (Chimhowu, 2019). Customary land tenure is granted through family lines and tradition within a community and is often overseen by a local chief. Statutory land tenure is land tenure that is registered and acknowledged by the government, often in the form of a long-term lease, according to Honig (2017).

Scholars' views vary with regard to the pros and cons of both statutory tenure and customary tenure. Honig (2017) performed a case study in Zambia amongst more than 8000 smallholder farmers on customary land. They found that wealthy people, people with a large piece of land, or people at a low position in the pecking order of a customary community were more likely to opt for statutory land tenure. Nkomoki et al. (2018) found adoption of sustainable agricultural practices to be influenced by land tenure. They interviewed 400 smallholder farmers in southern Zambia, of which 200 fell under statutory tenure and 200 under customary tenure. Four sustainable agricultural practices were selected (crop diversification, intercropping, agroforestry, planting basins), and the number of farmers that adopted them under both tenure categories was investigated. For all four practices, it was found that farmers under statutory tenure had a higher adoption rate, of 81.5%/59.5%, 34.0%/29.5%, 40.0%/21.0% and 35.0%/27.5% respectively. Holden et al. (2009) performed a case study in the Tigray region in Ethiopia, based on three surveys which were executed in 1998, 2001 and 2006, assessing long-term impact of land reforms in 1998. These reforms consisted of, among others, low-cost (1 USD per plot) and quick land registration. The case study consisted of 400 households spread over sixteen districts. Results of the first survey after the reforms (2006) indicated that over 80% of the participants found the risk of eviction being reduced due to land certification. Furthermore, they found that production (output value per hectare) increased with 45% due to land certification. However, a significant influence of land tenure on the purchasing of inputs was not found. In a comparative review of management of different irrigation systems in Asia and Africa, Mutambara et al. (2016) found that a form of land tenure is needed to ensure willingness to invest among farmers. However, no distinction between customary or statutory land tenure was made. Shah et al. (2002) came to the same conclusion while studying irrigation management transfers in Africa. In addition, reviewing irrigation technologies among 1554 smallholders in

Table 4.1: Crop choice per irrigation method (Shah et al., 2013)

Most important crop:	Staple crop	Cash crop
Rainfed irrigation		<15%
Gravity-flow irrigation	44%	
Manual pump irrigation		81%
Motor-pump irrigation		75%

nine countries, Shah et al. (2013) found that while land tenure security did determine whether advanced technologies were possessed by a household (i.e. motorised pump, flexible pipes), this tenure security could ensue from both customary and statutory land tenure. Nakawuka et al. (2018), studying smallholder irrigation opportunities in East Africa, state that statutory land tenure has a positive influence for several reasons. Under statutory land tenure, land can be purchased legally by large-scale and more efficiently working farming companies. Also, credit services can be accessed with a land title. At the same time, statutory land tenure leads to plenty of issues, for example, land conflicts. Also, the mentioned advantage of transferring the land to the most efficient user begs the question of whether implementing statutory land tenure like this would unfavourably sideline traditional, customary farming communities in favour of efficient, large farming businesses.

In a large comparative literature review, Singirankabo and Ertsen (2020) analysed literature on customary and statutory land tenure. Their target was to investigate the claim that land tenure increases productivity and willingness to invest in agricultural inputs. Their main findings were that oftentimes, studies on land tenure security present inconclusive evidence. Furthermore, multiple studies show ambivalent results, indicating that land tenure is part of a complex network of variables influencing productivity and willingness to invest. Moreover, spatial variety exists within these results, as each country has its own specific circumstances surrounding land tenure. Therefore, it is impossible to draw a general conclusion based on several spread-out case studies.

4.6 Smallholder farmer independence and ownership

4.6.1 Irrigation schemes

Irrigation scheme management

According to a review by Mutambara et al. (2016), a lot of smallholder irrigation schemes fail because of management issues. Often, due to the absence of a thorough, long-term strategy of maintenance and management, schemes are built, then neglected, and eventually, they will need to be rebuilt. A lot of countries do have policies regarding water management in place, but lack the institutions to execute these policies on the level of an irrigation scheme. Mutambara et al. (2016) compared smallholder irrigation in Africa and Asia, finding the latter, though far from optimal, to be characterised by long-lasting schemes (Mukherji et al., 2012). Furthermore, the key difference between the two appeared in management styles. Smallholder irrigation schemes in Asia are characterised by a decentralised management style, leaving funding, maintenance and management to the farmers involved in the scheme, thereby creating an incentive for farmers to stay involved and to contribute. Conversely, smallholder irrigation schemes in Sub-Saharan Africa are characterised by less participation of involved farmers, and by funding from donor agencies and the government, causing an unsustainable, disincentivising way of farmer participation. The consequence of this difference is best visualised by the statistic that in Asia, 40% of the cultivated land is irrigated, whereas in Sub-Saharan Africa this is only 4% (Nakawuka et al., 2018). The same conclusion was reached by Namara et al. (2014), finding that many irrigation schemes fail due to centralised management. They argue that while many governments increasingly invest in irrigation schemes, under the umbrella of different initiatives, this is mostly in large-scale, centrally managed schemes. Privately owned irrigation equipment, on the contrary, is often neglected by these investment projects. Similarly, in a research on irrigation management among African smallholders, it was noted by Shah et al. (2002) that publicly managed irrigation schemes in developing countries almost never reach their potential, due to schemes being managed in such a centralised way that farmers have become merely workers on their own plot. Moreover, it was stated that governments or other agencies, managing these irrigation schemes, often fail to incorporate water and maintenance charges that make the scheme cost-effective and sustainable.

To summarise, it is more sustainable if farmers have enough resources to manage their own irrigation scheme than if schemes are managed by a government body. Therefore, privatising institutions is a commonly heard solution for making smallholder irrigation schemes successful. Institutions can be defined as formal or informal incentive structures that determine economic performance (Burney and Naylor, 2012). Examples of such structures are farmer cooperative organisations, in which working together can be an incentive to invest. According to Ferrand et al. (2004), privatisation of institutions in supply chains is crucial for the involved markets to function properly, and for smallholder businesses to fare well. On the contrary, managing those institutions centrally or with donor funds does not allow participants partaking in these institutions to also participate in a functioning economy and to thereby achieve development. This stresses the importance of independence for farmers when they make the step to a commercial, market-oriented farmer. Earlier, Brown and Nooter (1992) came to the same conclusion in studying successful irrigation schemes around the Sahel, defining, among others, private individual ownership and farmers participating in project design as success factors. Burney and Naylor (2012), evaluating smallholder irrigation in Sub-Saharan Africa, found that irrigation schemes that were built on existing long-term relationships, thereby eliminating the need to set up a new water user association, are the most promising.

Transferring irrigation management to the farmers

Shah et al. (2002) reviewed irrigation management transfers worldwide to abstract lessons for smallholder farms on how to approach this and came up with several conditions that must be fulfilled for the transfer to be a success. First of all, there must be potential for a significantly improved livelihood for smallholders. Secondly, irrigation must be the main reason for this improvement. Thirdly, the costs of management must not be too big of a share of the improved income. Lastly, water usage costs must not be too high. Furthermore, according to Shah et al. (2013), farmers should have decision-making capacity regarding their irrigation scheme. Institutional arrangements should support this, whether it concerns a farmer individually or as part of local farmer groups. Furthermore, affordability and accessibility of irrigation technology are important criteria.

Vermillion (1996) reviewed 24 case studies of irrigation management transfers all over the world, in both developing and developed contexts, to assess the performance of the irrigation system before and after the transfer. They defined a management transfer as successful when a government saves money by it, the cost-effectiveness of operation and management is improved, and agricultural productivity is not weakened. They concluded that transferring irrigation scheme management to farmers has a lot of upsides. These are the increased efficiency of individual farmers (increased yield) and the farmers' increased feeling of responsibility for and involvement with the collective (increased equity, increased fee collection rates). Also, especially when involved governments do not stop all support (subsidies, advice), this way of management can be very profitable and sustainable. A possible danger of privatising would be extensive cost-cutting by farmers, which could lead to faster deterioration of irrigation infrastructure and equipment.

Irrigation scheme management in a community

Burney and Naylor (2012) implemented three solar pump systems in two villages in Benin with existing farmer communities, with the purpose of finding out whether or not existing communities would be able to profit from such a technology. After a year of use, the photovoltaic system was deemed cost-effective, with low operating costs. However, investing in such a system requires credit, and therefore it was concluded that adopting this technology was mainly suitable for farmer groups. Community-based institutions such as smallholder farmer groups managing a private irrigation scheme face several challenges. One of them can be found in the burden of managing a lot of rather small plots within an irrigation scheme. In terms of managing costs, Shah et al. (2002) argue that smallholder farmers are at a significant disadvantage as opposed to farmers with larger landholdings. When two irrigation schemes are compared with an identical coverage area, the one that is divided into a multitude of small plots will be more difficult and expensive to manage than the one that consists of just a handful of farmers with rather large plots.

4.6.2 Farmer independence versus aid

When it comes to giving aid to smallholder farmers, one must be aware of various potential negative side effects. For example, giving aid to smallholder farmers while preserving their autonomy is easier said than done. Also, initiatives that help farmers in the short-term, often have adverse effects over a longer time span. Farmers lacking a perspective of a better future are often hesitant to invest in suggested improvements for their farm since they fear losing their access to food aid and being forced to independency (Belete, 2006). This over-dependency on direct aid and the fear to accept aid in the form of long-term investments in, e.g., agricultural practices disables farmers to make the step to independence. With regards to the already mentioned topic of irrigation scheme management, a similar process occurs. First, the government constructs an irrigation scheme without consulting farmers. Then the government provides a few years of support. When this support terminates for any reason, farmers are left with an irrigation scheme of which they do not feel the ownership, as the only thing binding participating farmers together was the government. Therefore, the scheme will fall apart. When direct aid is given, farmers expect this to continue (Nakawuka et al., 2018), and aren't challenged to develop themselves into independent farmers. In this section, two examples are given of aid programmes and their impact.

Subsidy programmes

In 2005/2006, the Malawian government introduced the Farm Input Subsidy Programme (FISP) (Lunduka et al., 2013). According to Denning et al. (2009), this programme doubled maize yields in 2006 and almost tripled it in 2007, also influenced by favourable weather conditions. The FISP was aimed at the so-called 'productive poor', referring to full-time farmers unable to afford enough agricultural inputs on their own. However, according to a comparative review by Lunduka et al. (2013), oftentimes the 'productive poor' were unable to benefit because of other circumstances hindering them from exploiting the supplied inputs potential, such as bad soil quality and small plot size.

Farmer field schools

The concept of farmer field schools was already briefly touched upon in Chapter 2. In this section, some use cases of the FFS are discussed. Use cases of farmer field schools were reviewed by van den Berg et al. (2020), amongst others in Malawi. After various adaptations, the farmer field schools were accepted by the government as an approach to extension services. Eventually, a combined approach of using so-called lead farmers -farmers who graduated FFS and received additional training- was deployed to set up a new FFS in other regions. Through this approach, FFS achieved local successes. Key to this success was the continuous adaptation of the curriculum of the FFS to the challenges that were faced by farmers at the time. In Tanzania, a similar implementation took place. According to Owenya et al. (2011), 31 FFS groups were founded. Being provided small amounts of inputs for various interventions, such as seeds for intercropping and pesticides, the participating farmers were encouraged to collaborate and employ their experience in order to figure out the best way to, in this case, prevent soil erosion. Participating farmers reported increased yield, which, more importantly, translated into better circumstances for them. Similar to the aforementioned Malawian case, graduated farmers were enabled to start their own FFS. A quasi-experimental impact evaluation of several use cases of the FFS in Uganda (349 cases), Tanzania (379 cases) and Kenya (398 cases) was performed by Davis et al. (2012). In Kenya and Tanzania, a significant average increase in agricultural productivity was reported (Kenya: $+81\%$, Tanzania: $+23\%$). In Uganda, a slight decrease was reported (Uganda: -10%), possibly due to a coincidence with another program. For all countries, an increase in agricultural income was reported (Kenya: $+21\%$, Tanzania: $+104\%$, Uganda: +18%). However, the change in Uganda was deemed insignificant. Furthermore, Davis et al. (2012) found that households headed by females or by lower-educated persons profited significantly more from the FFS than male-headed households and higher educated farmers. Both quantitative and qualitative use case reviews included in this research indicate that farmer field schools are a proven example of empowering minority groups and delivering knowledge and aid where it is needed the most while maintaining the independence of the farmer.

5

Discussion and conclusion

5.1 Discussion

This chapter aims to aggregate and discuss the results from previous chapters. In Table 5.1, findings from each chapter are reported and grouped per topic.

Farm Incubator Model analysis

The analysis of the Farm Incubator Model is versatile, as it combines an in-situ analysis of the functioning of the model through interviews with a quantitative assessment using remote sensing. This broad approach ensures that the exploration of the Farm Incubator Model is done from both a theoretical perspective and a practical perspective. The fact that the interviews involved both extension officers and office staff members of aQysta adds to this versatility. It should however be noted that, since the model has only run for approximately a year now, many processes are still in the implementation phase. Therefore, the interviewees did not have lots of experience with the model yet. Furthermore, this meant that the extent of the model is still rather small, resulting in only four interviewees (two extension officers, two office staff members).

Quantifying the impact of the FIM, the spatial resolution of Sentinel-2 imagery was sufficient to analyse harvest amounts on individual smallholder plots, with an average size of around 0.5 acres. Additionally, the temporal resolution of this satellite mission benefited the analysis: around 10 observations per month (in the dry season) could be used. Therefore, in theory, crop growth throughout the entire growing season could be monitored almost in real-time. Furthermore, due to the large number of bands, this satellite mission allowed for the analysis of a lot of different vegetation indices. However, the earlier mentioned problem that the Farm Incubator Model is still in its infancy also played a role here; due to the small extent, only 15 plots could be analysed, which made it impossible to draw a solid conclusion based on the obtained results.

A cropland mask was applied on the used satellite imagery to filter unwanted interference from e.g. trees and sheds. This mask was created using machine learning, which turned out to be a promising method for this purpose, especially when extending the size of the FIM in the future. However, due to the small plot sizes, it turned out that when a pixel was erroneously considered a non-crop pixel, this had a huge impact on the results, because there were only a limited amount of pixels per plot to begin with. Therefore, the error margins are small for this technique.

Fourth Integrated Household Survey analysis

The accuracy of the inspection of the fourth Integrated Household Survey data set using ANOVA was influenced positively by the large size of this data set: it contains over 25,000 entries. However, it was observed that several survey questions were not answered by all participants. For some variables, this resulted in large confidence intervals, decreasing the usability for those variables. The performed post-hoc test, the Tukey HSD test, did add to the reliability and strength of this analysis by enabling a pairwise comparison of groups within the categorical independent variables and therefore an internal analysis on the coherence of variables. This analysis of coherence did however yield several cases of variables with surrealistic values. It was decided to filter out these values beforehand.

Variables included in this data set drew a rather complete picture of smallholder farming. Therefore, this analysis can be regarded as thorough. Another strength of this analysis is that data entries were geographically referenced. This allowed for the addition of a spatial factor to the analysis, enabling a district-wise analysis.

Table 5.1: Overview of the outcomes of all research sub-questions

	Farm Incubator Model analysis - Ch. 2	IHS4 analysis - Ch. 3	Literature review - Ch. 4
Agricultural inputs and market accessibility	Zomba, Malawi The Farm Incubator Model provides participants with agricultural inputs, such as seeds for cash crops, fertiliser and pesticides. Furthermore, training is given on how to use these inputs.	Malawi Several agricultural inputs were taken into account: two applications of inorganic fertiliser, organic fertiliser and seeds. The findings suggest that the amount of the first application of inorganic fertiliser and the seed amount are mainly of influence on yield. Furthermore, it is found that for all districts, the use of these two inputs is very low. Additionally, it is observed that an increasing distance to an agricultural market leads to decreasing use of both applications of inorganic fertiliser and to increasing use of less effective organic fertiliser.	Sub-Saharan Africa It was found that agricultural inputs are hard to acquire for farmers, due to limited access to agricultural markets, an insecure financial position and uncertainty about their effectiveness due to external factors such as rainfall.
Harvest selling and transport	aQysta provides participants of the Farm Incubator Model with the service of selling their produce.	The results indicated that crop types with higher revenue per hectare are infrequently used. It is found that in all districts, maize is the predominant crop, followed by nkhwani. In most districts, all other crops are sparsely occurring. Additionally, it is noted that most crops identified as cash crops also had an increased inorganic fertiliser use rate. Lastly, it is observed that the used method of transportation highly influences the revenue, e.g., when harvest selling is done with a minibus, bus or truck instead of letting the buyer pick up the crop, revenues per hectare triple.	Due to similar crop choices by farmers, and in order to still get a good price for their produce, farmers have to sell at larger markets. To that end, transportation is needed, which is a challenge. Most farmers only farm for self-sustenance. A clear, positive link is found between market-oriented farming and the cultivation of cash crops.
Irrigation systems	The Farm Incubator Model is built around the Barsha pump, a pump functioning solely on energy from the river flow. Therefore, no running costs are present. Also, training is supplied to enable participants to effectively operate this pump.	The type of irrigation system has a significant influence on the harvest amount. However, due to the small number of farmers using an irrigation system, no reliable observations can be done regarding the amount of influence of the type of irrigation system.	Smallholder irrigation is scarcely used in Sub-Saharan Africa. Only 3.53% of the cultivated land is equipped for irrigation. Even when irrigation systems are in place, they often ultimately fall apart due to a lack of maintenance services and a way of management not enabling farmers to take responsibility on their own.
Land tenure	The Farm Incubator Model knows two setups. The first one is the current setup, also known as a decentralised setup. In this setup, all participating farmers farm on their own plots. This generates a sense of ownership among participants. However, it also implies more operating costs, as all farms have to be visited separately. The second one is the centralised setup, in which all farmers farm on a large, centralised plot, owned by aQysta. This setup is present in other countries where aQysta is active and was previously also used in Malawi. Among the occurring challenges was a lack of responsibility by farmers. However, in this setup, operational costs were lower for aQysta.	Whether land is tenured in a statutory way or in a customary way has a significant influence on harvest amounts but not on used fertiliser amounts. However, due to the small number of entries for this variable in the data set, it was hard to draw conclusions. Furthermore, a relation was found between the way a plot is acquired and the time the plot is owned. This could either indicate a change over the course of time in the way plots are purchased from customary to statutory, or it shows that in the case of Malawi, land acquired in a customary way has more tenure security.	It was found that secure land tenure is very important for a smallholder farmer, amongst others to encourage long-term investments. However, whether land tenure security is achieved by customary or statutory tenure turns out to be very location-specific, and under the influence of a lot of additional external factors.
Farmer independence and ownership	Even though the participating farmers are currently farming on their own plot, they are lacking a sense of ownership. In the past growing season, participating farmers did receive a monthly allowance, regardless of performance. This resulted in farmers just being present at their plots to receive this allowance, and not putting in the effort to utilise the inputs and technology provided by aQysta. In the coming growing seasons, this will be changed to a milestone-based approach, in which farmers are only paid if they achieve a milestone. Furthermore, when comparing aQysta's Farm Incubator Model with other participatory learning programmes targeting smallholder farmers, it was found that the Farm Incubator Model seeks the middle ground between a traditional farm incubator and a farmer field school. While aiming at existing farmers like a farmer field school, the Farm Incubator Model provides all necessary agricultural inputs like a traditional farm incubator. Results from the interviews suggest that this unconditional input supply causes participating farmers to be unmotivated to participate in the rest of the model. Farmers become dependent on supplied inputs, only receiving what is given them and not taking initiative. This dependency is recognised as a danger by the creators of the farmer field school concept. It is concluded that this mixture between a FIM and an FFS puts aQysta in a complex position with regards to how to treat their participants.	-	Literature was analysed concerning the impact of external inputs influencing the independence of a farmer, such as input programmes and centralised irrigation scheme management. Findings show that, in Sub-Saharan Africa, a lot of government-managed irrigation schemes failed due to a lack of ownership of the participating farmers. This was in many cases caused by the government not involving farmers in constructing the system and managing it. The farmers then became dependent on the efforts of the government, leaving a dysfunctional irrigation system when these efforts eventually ceased. The same happened with input programmes. Often, overall productivity among beneficiaries increased for a while, but the supplied inputs did not reach their full potential on smallholder farms, due to other factors such as a lack of knowledge or manpower. Also, fear exists of farmers becoming dependent on input programmes and other forms of aid to operate. An example of a farmer aid programme with a high success rate is the farmer field school, which originated from the FAO. An FFS brings a group of farmers together and gives them a podium to exchange knowledge on actual relevant topics. The independence of participating farmers is highly valued in this participatory learning programme.

Literature review
The literature review on smallholder challenges was bounded by a framework based on the results of previous sub-questions. Despite this, still a sheer amount of literature falls within the scope of the performed literature review. This is a strength as well as a limitation. On the one hand, this allowed for a thorough literature review on all smallholder challenges. However, on the other hand, especially considering that the spatial scope is rather large, it is hard to present a concise overview of all challenges, since these challenges vary per country in many cases. Therefore, precaution had to be taken that the analysed literature reflected smallholder challenges and all its spatial nuances. For a spatial scope as big as Sub-Saharan Africa, this process is inherently flawed. Despite this drawback, the process of setting up a framework of smallholder challenges with a strong data foundation on a local scale, and consecutively comparing challenges within this framework with literature was a good way to make the most out of this approach.

Evaluation and recommendations for further research
The approach of this research consisted of three consecutive steps, with increasing spatial scope. This approach is positively evaluated because it combined the detail and small scale of a case study with the objectivity of a large data set and the inclusivity and the broad view of a literature review. Due to the multi-scope approach, local inconsistencies, if present, inevitably come to light, and the results could thus be generalised.

When a future quantitative analysis using Sentinel-2 data is performed in the wet season instead of the dry season, interference from clouds will most likely drastically reduce the number of usable images. Therefore it is recommended to reassess the usability of the Sentinel-2 mission for this purpose with regards to the temporal resolution. Also, it would be valuable to repeat the approach of the first research sub-question when some time has passed, allowing the Farm Incubator Model to expand, and get rid of the growing pains. This would increase the number of potential interviewees and their experience with the model. Additionally, since the model is rapidly expanding, more participating farms could then be used for the quantitative analysis using remote sensing data. This would increase the reliability of the harvest prediction model. Also, more data on harvests will be present then, since more growing cycles have passed. Lastly, inconsistencies in the plot data, which were encountered in this research, will most likely be filtered out by then.

5.2 Conclusion

In this final section, conclusions are drawn based on the gathered results and the discussion of these results earlier in this chapter. The main research question was as follows: 'How effective is the Farm Incubator Model as implemented by aQysta in Malawi as an approach to take smallholder farmers from self-subsistence to commercial farming?'. As described in Chapter 1, three research sub-questions were answered: 'What is the impact of the Farm Incubator Model on its participants?', 'To what extent does the Farm Incubator Model connect with challenges faced by smallholder farmers in Malawi?' and 'Is the Farm Incubator Model suitable for application in the context of Sub-Saharan Africa?'.

The first research question was all about defining and analysing the Farm Incubator Model. The Farm Incubator Model is a model developed by aQysta, built around their core product, the hydro-powered Barsha pump. Currently, this model is still in its pilot phase. This model, in which selected smallholder farmers can participate, includes training of participants, the provision of the Barsha-pump for irrigation, and the provision of seeds for cash crops, fertiliser and pesticides. Furthermore, farmers are assisted in selling their produce. Each month, farmers get paid a monthly allowance. However, in coming growing seasons, this is changed into a milestone-based allowance. In return for this allowance and the supplied goods, aQysta keeps (a part of) the revenue from selling the harvest. Findings in literature on other participatory learning methods for farmers suggested that the Farm Incubator Model is a mixture between a traditional farm incubator and a farmer field school. Like farmer field schools, the FIM targets existing farmers, whereas a traditional farm incubator would target novice farmers. However, participants of the FIM are treated as novice farmers would be treated in a traditional farm incubator, being supplied inputs and receiving intense training. Several challenges occurring with the implementation of the FIM could be accredited to this fusion of participatory learning methods. First of all, the issue of the long-term feasibility of the FIM arises. Right now, the Farm Incubator Model is decentralised, meaning that all participating farmers farm on their own plots, which is common practice in farmer field schools. This would increase their sense of ownership and future sustainability. However, overhead costs for aQysta are way more in this decentralised approach than when all farmers would come together on a centralised plot owned by aQysta, like a traditional farm incubator. Therefore, this mixture of participatory learning methods causes a trade-off between the long-term feasibility of the model and the sustainability of the participating farmers' businesses. Secondly, challenges arise with regards to the payment of the monthly allowance and the distribution of inputs. This is approached by aQysta in a similar fashion as a traditional farm incubator would. Findings suggested that this approach caused some farmers that are participating in the FIM to just be present on their plots when the allowance is distributed, showing little responsibility with regards to being productive at other times. Since the participating farmers do not necessarily need the FIM to start farming, they need to be intrinsically motivated to perform and learn, and this intrinsic motivation is in some cases absent due to the unconditional payment of the monthly allowance. By analysis of the interviews, it became clear that aQysta is planning to change this monthly allowance to a milestone-based allowance, paying farmers for achieving milestones throughout the growing season. It will be interesting to see the effect of this promising measure.

Answering the second research question, defining smallholder farmers' challenges in Malawi, it was found that usage of agricultural inputs is a challenge in all districts of Malawi. Mainly the first application of inorganic fertiliser and the amount of seeds have a significant influence on the harvest amount. Also, it was found that the amount of used inorganic fertiliser is inversely proportional with the distance between the farm and an agricultural market, indicating that transportation of inputs from a selling point to their farm is an issue for smallholder farmers. The average distance to an agricultural market, and therewith the extent of this transportation challenge, did vary per district. Furthermore, findings suggested a positive influence of cash crops on revenue per hectare. At the same time, it was observed that cash crops are barely cultivated in any district. Another challenging factor in Malawian smallholder agriculture is the transportation of produce to a selling point. In all districts, a transportation mode yielding low returns per hectare was found to be predominant. Other identified factors that could pose challenges were the way in which land is tenured and what type of irrigation system is used. However, not enough data was available to analyse these variables properly. The main identified challenges are a shortage of agricultural inputs, lack of cash crop cultivation, lack of irrigation, lack of proper harvest transportation methods and oftentimes limited access to agricultural markets. Therefore, it is concluded that the components of the Farm Incubator Model as identified in the previous sub-question do connect well with the challenges for Malawian smallholder agriculture found in this data set.

Zooming in on the outcomes of the third research question, a two-way division exists. Firstly, the theoretical suitability of the Farm Incubator Model was addressed, strictly looking at the technical components of the model. Secondly, the practical suitability of the model, or the way in which the model is implemented, was assessed. Smallholder farmers having very limited access to agricultural markets and harvest transportation methods; farmers sticking to staple crops and farmers using limited amounts of fertiliser and other agricultural inputs. These challenges are to a large extent recognised in literature on smallholder challenges in Sub-Saharan Africa. In the previous sub-question, the influence of official land tenure security was hard to identify due to a lack of data entries. In literature, it turned out to be even harder to draw a coherent conclusion based on various (case) studies. In the end, findings in literature suggested that tenure security is an important factor in smallholder agriculture. At the same time it was found that a lot of variation is present in the way land is tenured for each country in Sub-Saharan Africa. Therefore, also the way in which tenure security is achieved is heterogeneous and cannot be accredited solely to either customary or statutory land tenure methods. Assessing the practical suitability of the FIM, a challenge identified in literature is the way in which external agricultural inputs influence the independence of a smallholder farmer. Many input programmes and management styles of i.e. irrigation systems in the end only achieve a short-term solution with regards to smallholder agricultural productivity. Despite the fact that the efficiency of a smallholder farmer is temporarily elevated, this goes at the cost of the farmer losing his independence, not being able to function without a form of aid. This was found to be an unfavourable situation.

Finally, answering the main research question, it was found that the Farm Incubator Model of aQysta in its current state is very effective in addressing challenges that are faced by smallholder farmers in Sub-Saharan Africa. The supplied goods and services do connect well with the farmers' needs as identified in this research. Despite these technical requirements being fulfilled, findings suggested that in order for smallholder farmers to thrive, independence is needed. It was found that when it comes to the management of irrigation schemes, ideally this is done by the participating farmers because this creates an incentive for farmers to invest and stay involved in the scheme. In cases when irrigation scheme management is done in a centralised fashion, participating farmers are not involved in the decision-making and are for their productivity therefore dependent on the institutions that manage the schemes. It was found that this dependence inevitably suppresses development, as it prevents farmers to actively invest and participate in economic activities. Findings suggested that this also applies to the way in which, in many cases, agricultural inputs are provided to smallholder farmers: as a form of aid, partly or entirely subsidised. Farmer Field School guides warn emphatically against this dependence on external agricultural inputs. It was concluded that, for a farmer to shift to market-oriented, commercial farming, independence is needed. However, findings in the context of the first research sub-question suggested that the way the FIM is set up, essentially being a mixture of components from a traditional farm incubator and a farmer field school, causes a trade-off that could potentially be a challenge to the future independence and sustainability of participating farmers. Furthermore, it was learned from the interviews that the way in which compensation and inputs are given to the farmers does not always induce the responsibility that the participating farmers need to learn and improve, and eventually become independent, commercial farmers.

It is concluded that the Farm Incubator Model, which at the time of this study is still in its pilot phase, is a very promising model, connecting well to the challenges encountered by smallholder farmers all over Sub-Saharan Africa. At the same time, several challenges are identified for the future sustainability of the model and its participants, The most urgent challenge is the danger for participating farmers to become dependent on aQysta's inputs, causing them after their incubating time to not be able to make the step to independent, commercial farming.

5.3 Recommendations

According to this research, to make the Farm Incubator Model both lucrative for aQysta and helpful to the participating farmers, two goals need to be achieved. Firstly, farmers need to retain their independence throughout the course of the incubator programme, to be able to farm commercially when their incubating time is finished. Secondly, they need to be willing to accept and implement advice, agricultural inputs and novel technologies, in order to increase their productivity and level of advancement. In this section, recommendations are given to achieve both goals.

The first recommendation is to connect the distribution of the monthly allowance and the agricultural inputs to the efforts and achievement of the farmer. For the monthly allowance, this is already being implemented. The advantage of this approach is that the ultimate responsibility for acquiring agricultural inputs rests with the farmers. It is important that this conditional distribution not only happens with the monthly allowance, but also for the agricultural inputs. The reason for this is that, for farmers to be independent, they not only need to be responsible for their own livelihood (monthly allowance), but also for their business (agricultural inputs). Findings from this research clearly emphasize the importance of independence being a prerequisite for a farmer to be commercially oriented.

A second recommendation is to increase farmer engagement. Whilst it remained unclear from the interviews whether this is already happening to some extent, it would be valuable to involve farmers in backstage processes of the Farm Incubator Model. This could for example mean that a farmer not only receives inputs and learn how to use them, but also helps selecting and acquiring them. Another example of this would be to make farmers responsible for transportation of inputs and harvest, or for maintenance of the pumps. Engaging farmers in this way increases their involvement in and ownership of the model. Case studies on Farmer Field Schools showed that smallholder farmers who felt responsible and involved often were able to develop and increase their revenue. Lastly, involving farmers in the background processes of the Farm Incubator Model is an excellent preparation for when they eventually will become independent commercial farmers.

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A
Interview guide

A.1 Interview guide - extension officers

Table A.1: Semi-structured interview questions - Extension officers

#	Question	Priority	Remarks
	Introductory part		
1	What is your name?	5	Anonimize
2	Where do you live?	5	Anonimize
3	Since when are you an extension officer?	5	
4	What are the specifics of this role?	5	
5	In which area are you operating?	5	
	General part		
6	How did you get to know aQysta?	4	
7	How would you describe the purpose of aQysta?	5	
8	How does a typical day as an extension officer look like?	5	
9	What would you name as your most important tasks as extension officer?	4	
10	How would you describe the role of extension officers in the agricultural sector of Malawi?	5	
11	Are you involved with any other parties like aQysta?	5	
12	Can you describe the type of relationship you have with aQysta?	4	
13	What do you particularly like about your job?	4	
	Specific part: general info about FIM		
14	How would you describe the Farm Incubator model	5	
15	On how many farms is the FIM currently deployed?	4	
16	How much of these do you serve personally?	5	
17	Can you describe the procedure you followed when introducing the FIM?	3	
18	Can you describe your activities on these farms where the FIM is running?	3	
	Specific part: practical info about FIM		
19	On the farms that you serve personally, since when is the FIM in use there?	5	
20	On the farms that you serve personally, has the FIM been in continuous use since the implementation?	5	
21	On the farms that you serve personally, what are challenges you encountered during implementation of the model?	4	
22	On the farms that you serve personally, what are challenges you encounter now that the model is running?	4	
23	How do you evaluate the use of the Barsha-pump?	3	
24	How do you evaluate the use of cash crops garlic and ginger?	3	
25	How would you describe the eagerness of farmers to adopt the FIM?	3	
26	Can you please elaborate on how the FIM changed the agricultural practice on farms where it is applied?	5	
	Validation Data		
27	On the plots that you personally manage, which crops are grown on which plot?	5	
28	On the plots that you manage, did farmers report increased yields?	5	
29	On the plot that you manage, is there a fixed irrigation planning?	5	
30	On the plots that you manage, are you aware of any interruptions of that planning?	5	
31	In your experience, during the running time of the FIM, were there any external factors (i.e. droughts) that did influence crop growth?	5	
	Evaluating part: opinion about the FIM		
33	What is your personal opinion about the FIM?	5	
34	In your opinion, what is the strongest aspect of the FIM?	5	
35	If it was up to you, what part of the FIM would you improve?	5	

A.2 Interview guide - aQysta office staff

Table A.2: Semi-structured interview questions - aQysta

#	Question	Priority	Remarks
	Introductory part		
1	What is your name?	5	Anonimize
2	Since when are you involved with aQysta?	5	
3	What is your role within aQysta?	5	
4	What are the specifics of this role?	5	
5	How long have you been in this position?	5	
	General part		
6	How would you describe the core business of aQysta?	5	
7	How did this core business develop over time?	2	
8	What is, in your opinion, the main purpose of the products (e.g. Barsha-pump) of aQysta?	4	
9	Which aspect of the operation of aQysta does appeal to yourself most?	2	
	Specific part: general info about FIM		
10	How would you describe the Farm Incubator model	5	
11	When did the first idea for the FIM pop up?	1	
12	What were reasons to develop the FIM?	3	
13	How has the FIM developed since the initial idea?	3	
14	What has been your role in the proces of the development of the FIM?	5	
15	Are there any plans for this model to be developed further in the near future?	5	
	Specific part: practical info about FIM		
Implementation and maintenance of the model			
16	In which countries is the FIM implemented?	5	
17	Since when is the FIM implemented in these countries?	5	
18	Can you elaborate on the choice of countries?	3	
19	How would you evaluate the implementation in these countries?	5	
20	Did you encounter any particular challenges during the implementation of the model?	5	
FIM in Malawi			
21	Can you describe the steps that were taken to implement the FIM in Malawi?	5	
22	Did this approach differ from the implementation of FIM in other places?	4	
23	What is the role of extension officers in this implementation proces?	5	
24	Can you describe the way in which the FIM is maintained?	4	
25	What is the role of extension officers in this?	5	
26	Can you describe the relationship between aQysta and these extension officers?	3	
27	How many individual farms are participating in the FIM in Malawi?	5	
28	How does this number compare with other countries?	4	
29	How has this number developed since the first implementation in Malawi?	4	
30	How would you envision this number developing in the future?	3	
Farmers response			
31	Can you say something about the openness of the participating farmers to the FIM?	3	
32	What kind of feedback from farmers does aQysta receive, if any?	3	
33	What kind of feedback from extension officers does aQysta receive, if any?	4	
	Evaluating part: opinion about the FIM		
34	What is your personal opinion about the FIM?	4	
35	If you had to name one strong point of the model, what would you name?	4	
36	If you had to choose one aspect you would like to further develop in the future, what would you choose?	4	

B
Interview Transcripts

This data can be requested by contacting the thesis supervisor on `M.W.Ertsen@tudelft.nl`.

C
Interview Analysis

This data can be requested by contacting the thesis supervisor on `M.W.Ertsen@tudelft.nl`.

D

Overview of quantitative data on the Farm Incubator Model

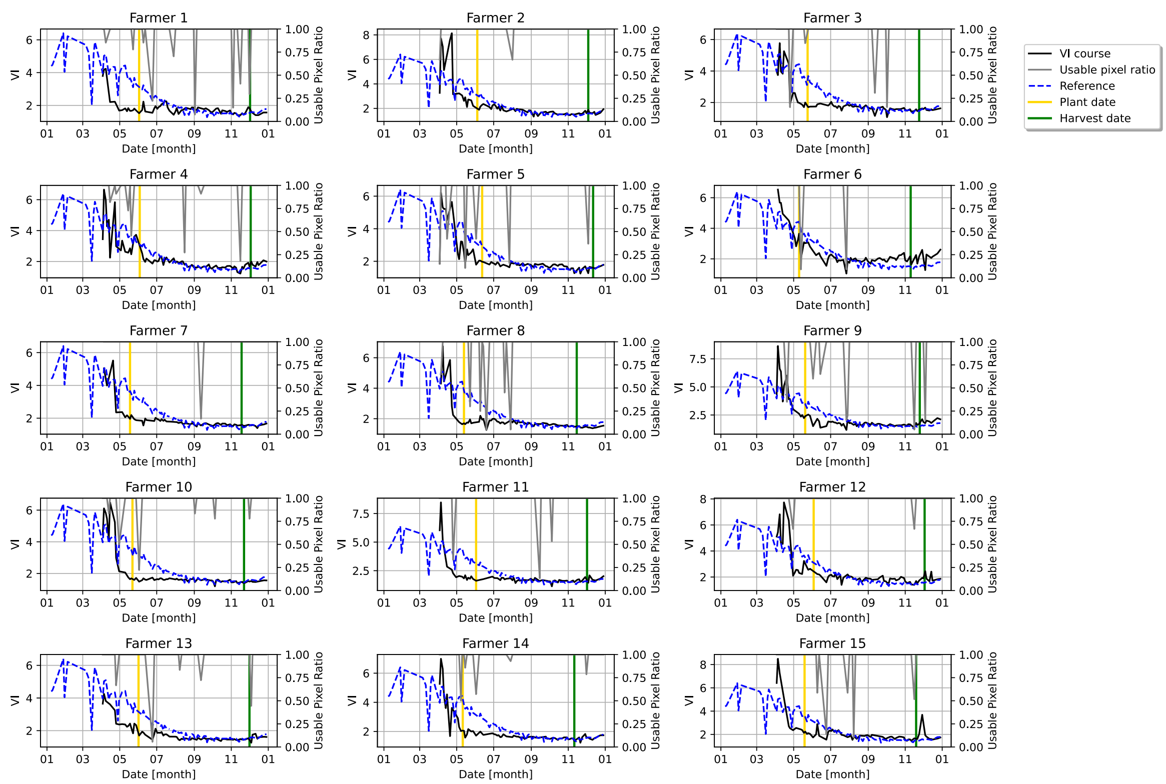

Figure D.1: Course of SR over the growing season

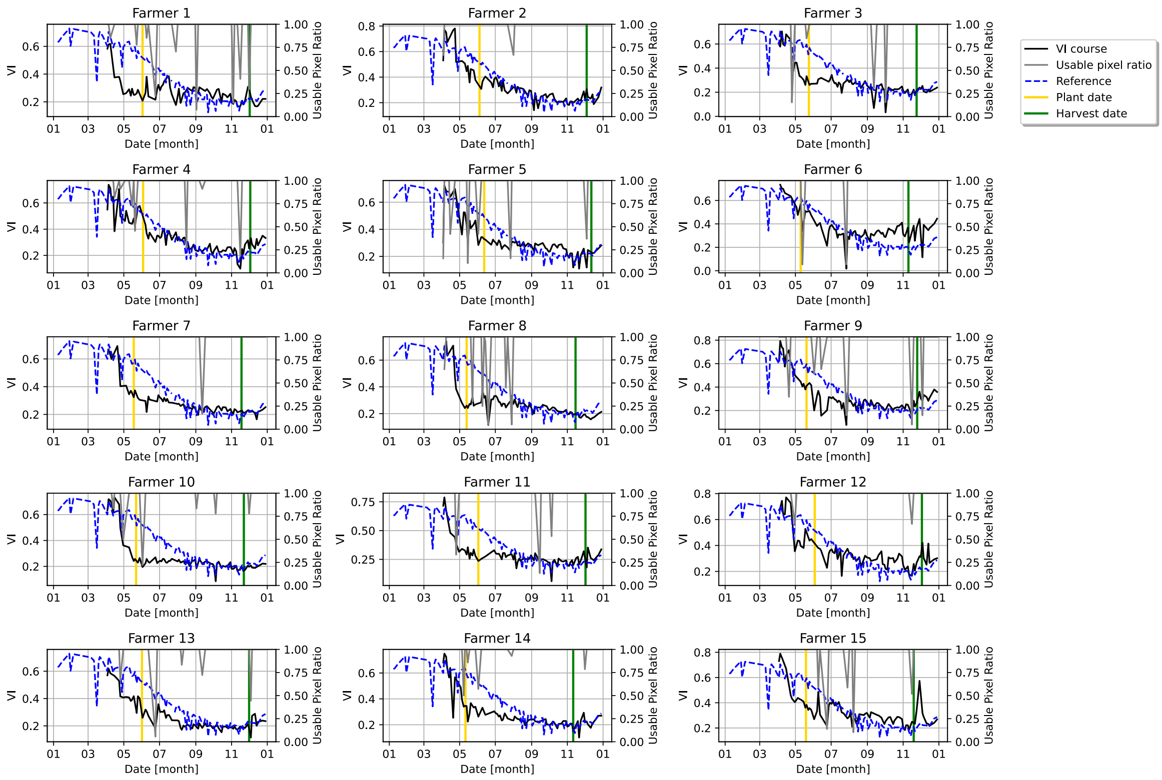

Figure D.2: Course of NDVI over the growing season

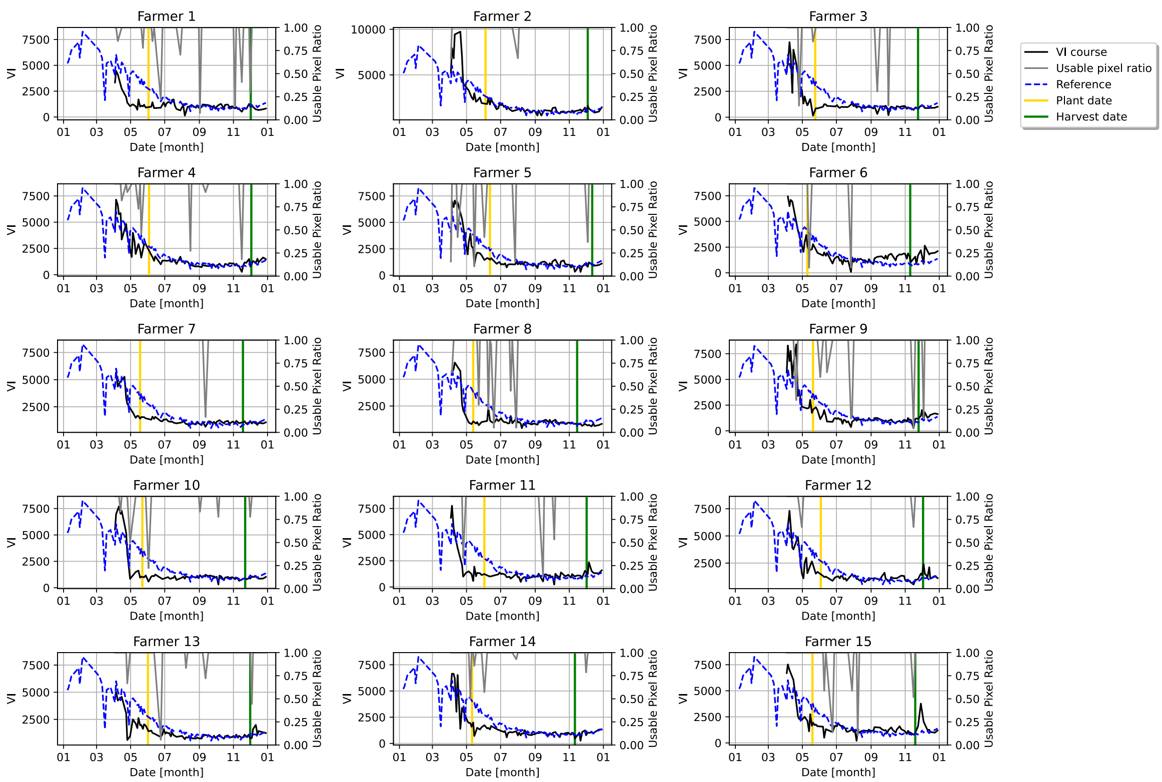

Figure D.3: Course of IRECI over the growing season

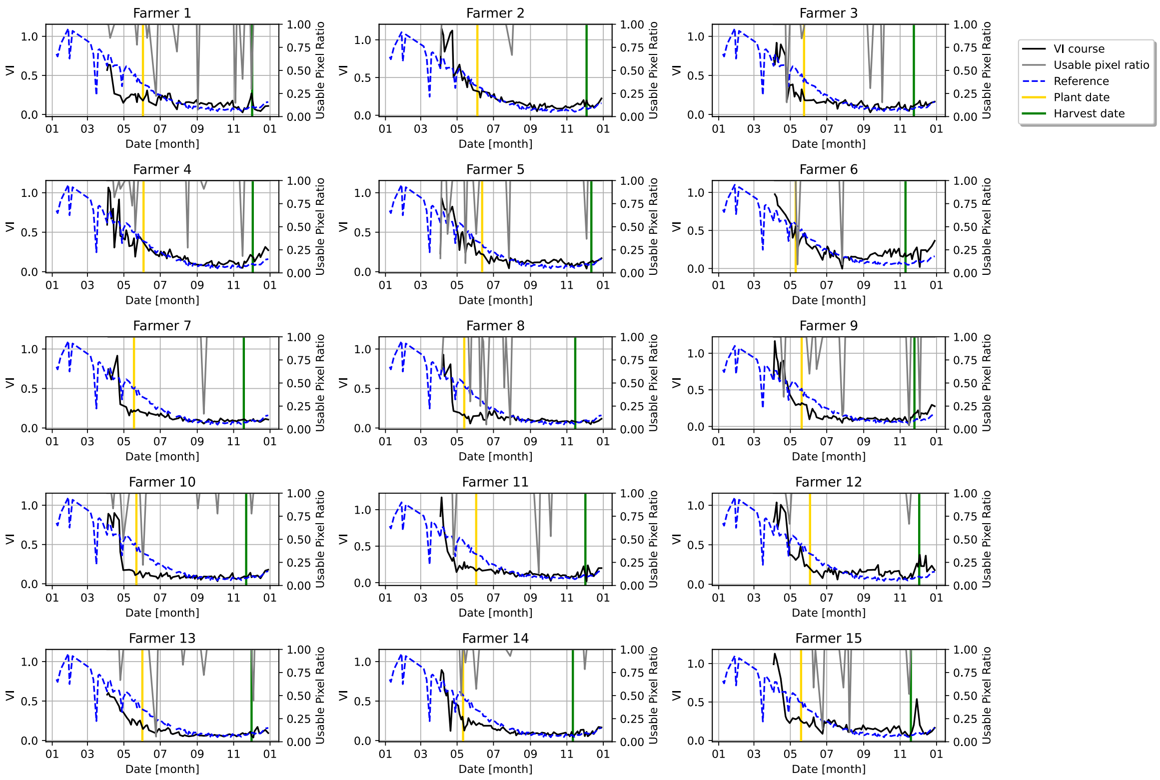

Figure D.4: Course of MTCI over the growing season

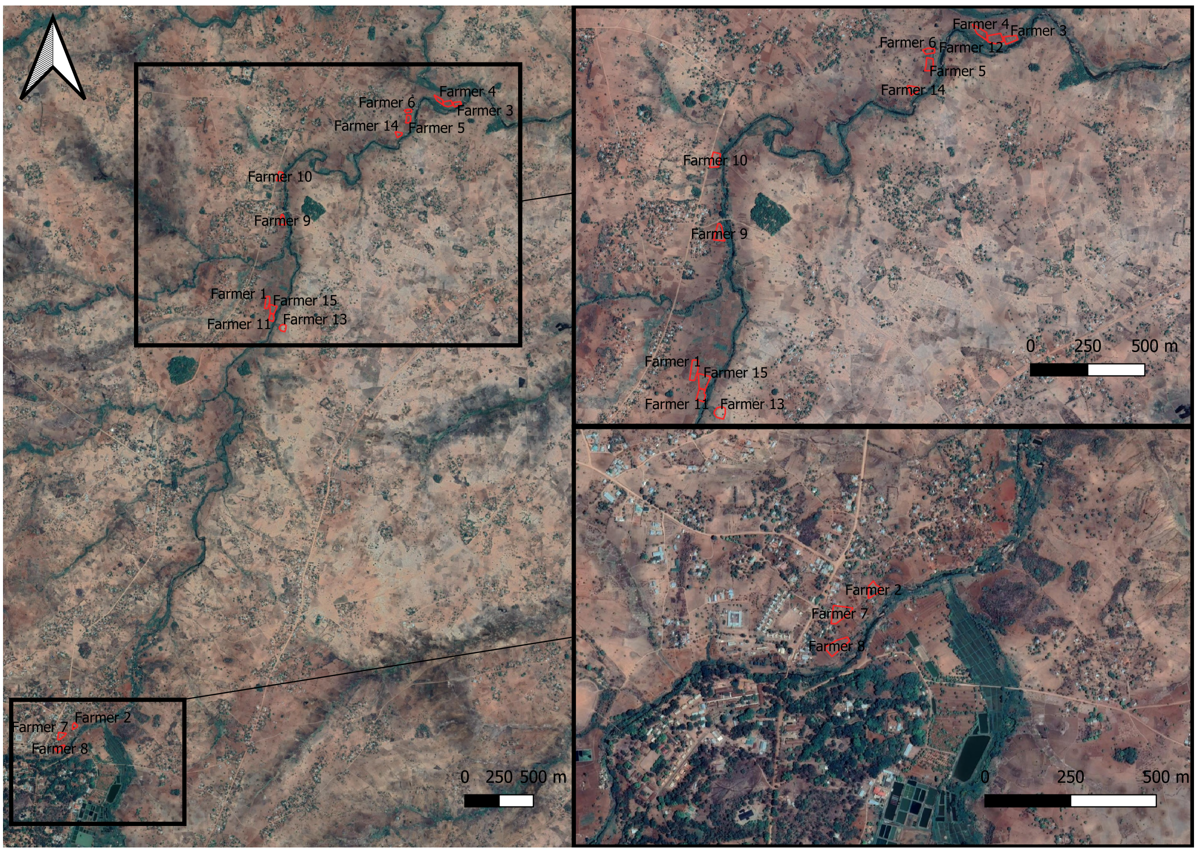

Figure D.5: Map with aQysta plots. Basemap: Google Earth (2021)

Table D.1: Details on participating plots

	Gender	Location	plot_x	plot_y	Size (acres)	Land clearing	Land prep	First Irrigation	Plant Date	Harvest Date	Planted (kg)	Harvested [kg]	Bags manure [#]	NPK applied	NPK type	NPK quantity	Irrigation	Fertilized #2	Fungicide
Farmer 1	m	Mtwiche	-15.25	35.42	0.42	yes	yes	yes	2021-06-02	2021-12-02	126.0	207	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	yes, chlorpyrifos
Farmer 2	m	Machinjiri	-15.28	35.40	0.35	yes	yes	yes	2021-06-04	2021-12-04	105.0	29	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	NaN
Farmer 3	m	Bakali	-15.23	35.43	0.32	yes	yes	yes	2021-05-24	2021-11-24	96.0	145	20.0	yes	D-compound	12.5 grams per station	twice/week	Yes, 1,4kg/200l	yes, copper oxy
Farmer 4	f	Bakali	-15.23	35.43	0.33	yes	yes	yes	2021-06-03	2021-12-03	99.0	97	20.0	yes	D-compound	12.5 grams per station	twice/week	Yes, 1,4kg/200l	yes, copper oxy
Farmer 5	m	Bakali	-15.24	35.43	0.39	yes	yes	yes	2021-06-12	2021-12-12	117.0	?	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	NaN
Farmer 6	f	Bakali	NaN	NaN	0.38	yes	yes	yes	2021-05-10	2021-11-10	114.0	81	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	NaN
Farmer 7	m	Msangeni	-15.28	35.40	0.44	yes	yes	yes	2021-05-18	2021-11-18	132.0	96	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	yes, mancozeb
Farmer 8	f	Msangeni	-15.28	35.40	0.36	yes	yes	yes	2021-05-13	2021-11-15	108.0	18	30.0	yes	D-compound	12.5 grams per station	twice/week	NaN	NaN
Farmer 9	f	Chibwana	-15.24	35.43	0.50	yes	yes	yes	2021-05-20	2021-11-25	150.0	33	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	NaN
Farmer 10	f	Chibwana	-15.24	35.42	0.61	yes	yes	yes	2021-05-22	2021-11-22	183.0	64	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	NaN
Farmer 11	f	Mtwiche	-15.25	35.42	0.30	yes	yes	yes	2021-06-02	2021-12-02	90.0	105	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	yes, chlorpyrifos
Farmer 12	m	Bakali	NaN	NaN	0.39	yes	yes	yes	2021-06-03	2021-12-03	117.0	222	20.0	yes	D-compound	12.5 grams per station	twice/week	Yes, 1,4kg/200l	yes, copper oxy
Farmer 13	m	Machinjiri	NaN	NaN	0.64	yes	yes	yes	2021-06-01	2021-12-01	192.0	0	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	NaN
Farmer 14	m	Bakali	-15.23	35.43	0.34	yes	yes	yes	2021-05-11	2021-11-11	102.0	0	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	NaN
Farmer 15	f	Mtwiche	-15.25	35.42	0.30	yes	yes	yes	2021-05-19	2021-11-19	90.0	65	20.0	yes	D-compound	12.5 grams per station	twice/week	NaN	yes, chlorpyrifos

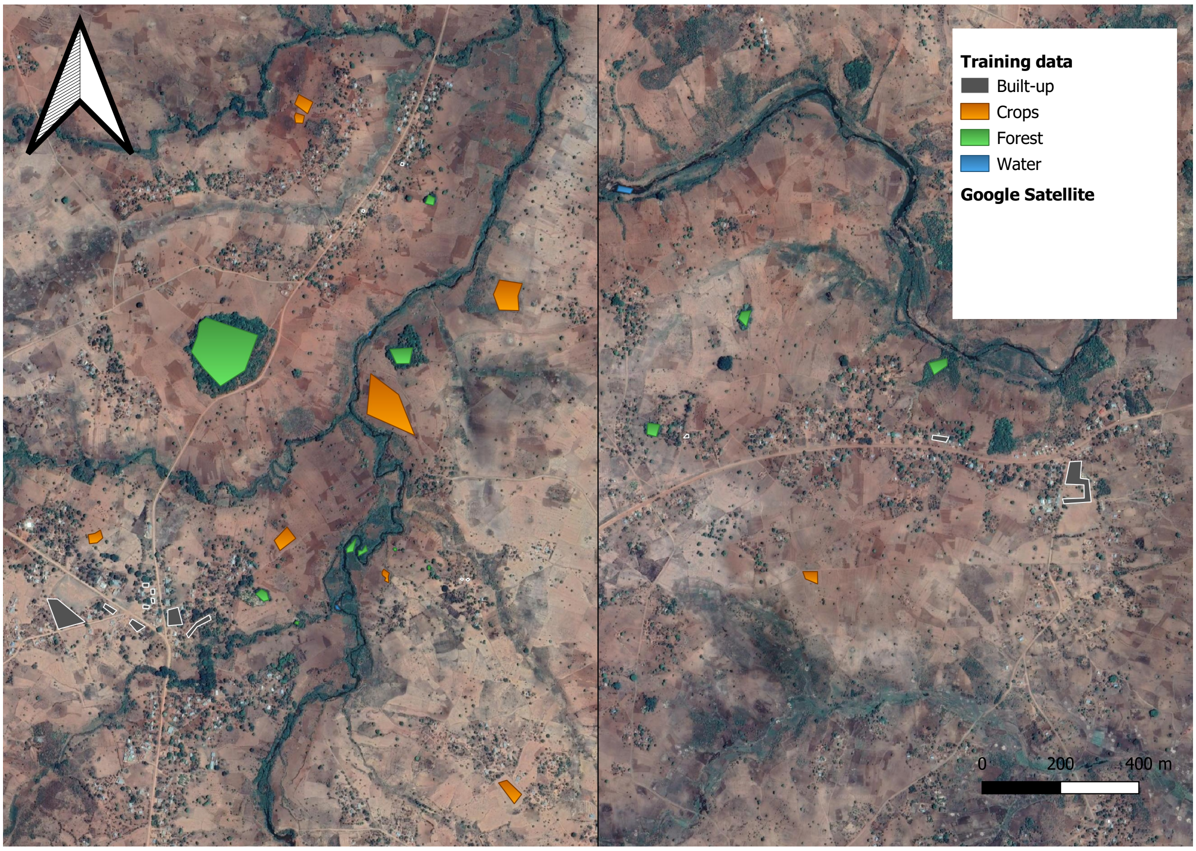

Figure D.6: Machine Learning: examples of training data. Basemap: Google Earth (2021)

E

IHS4-data pre-processing

E.1 Data filtering

In the proces of analysing the IHS4-data set, outliers must be detected and filtered out. Besides from applying a filter removing entries where the z-score is higher than 3, also, several filters are applied, based on the assumption that the data set mainly includes smallholder farms. In figure E.1, the plot size distribution is shown. It is observed that plot sizes are very small. Since smallholder farms are typically defined as smaller than 2 ha of arable land (Wiggins, 2009, Livingston et al., 2011, Nakawuka et al., 2018), it can be seen that this is a valid assumption. The following values were considered outliers and therefore neglected (Garrity et al., 2010, Nakawuka et al., 2018, Tchale, 2009):

- Harvest amount ≥ 3 t/ha
- Inorganic fertilizer (1st/2nd) ≥ 0.5 t/ha
- Organic fertilizer ≥ 6 t/ha
- Seeds ≥ 0.25 t/ha

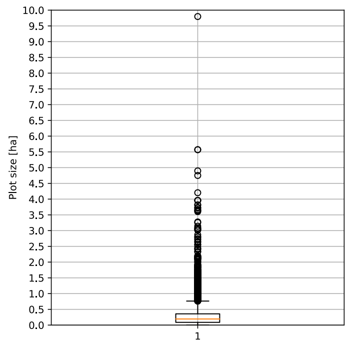

Figure E.1: Plot size distribution

E.2 Used variables

In table E.2, the used variables from the IHS4 data set are listed, as well as the processing steps that were taken to use the data. These steps are described in the form of a calculation, sometimes involving a function. Such a function takes the value of a variable, and translates it into a relevant value for this research. These functions are described in table E.1

Table E.1: IHS4 data - Used functions

Function:	F_{irr}		F_{mult}		$area$		F_{seed}		F_{unit}	
	Value	Translation	Value	Translation	Value	Translation	Value	Translation	Value	Translation
	Bucket	100	1/2	0.5	ACRE	4046.856	10 KG BAG	10	10 KG BAG	10
	Divert stream	100	1/4	0.25	HECTARE	10000	2 KG BAG	2	2 KG BAG	2
	Gravity	100	3/4	0.75	SQUARE METERS	1	3 KG BAG	3	3 KG BAG	3
	Motor pump	100	Less than 1/4	0.125			3.7 KG BAG	3.7	5 KG BAG	5
	Other (specify)	100	More than 3/4	0.875			5 KG BAG	5	Other (Specify)	nan
	Rainfed/no irrigation	0	None	1			50 KG BAG	50	50 KG BAG	50
	Treadle pump	100					GRAM	0.001	GRAM	0.001
							KILOGRAM	1	KILOGRAM	1
							OTHER (SPECIFY)	nan	LITER	1
									MILLILITER	0.001
									BALE	nan
									PAIL (LARGE)	25
									PAIL (SMALL)	10
									PIECE	nan
									OX CART	100
									WHEELBARROW	50
									BUCKET	8
									NO 10 PLATE	nan
									NO 12 PLATE	nan
									BUNCH	nan

Table E.2: IHS4 data - Used variables and preprocessing

Variable		Used variables			Operation
Module	*Variable*	*Module*	*Variable*		
Plot specs.	Self-Rep. Area [m2]	C C	1:Self Reported Area of Plot 2:Units of Area Reported	A B	$A * F_{area}(B)$
Plot specs.	Area Meas. [m2]	C	3:Area of Plot Measured with GPS	A	$A * 4046.856$
Plot specs.	ratio	Plot specs. Plot specs.	Self-Rep. Area [m2] Area Meas. [m2]	A B	A/B
Plot specs.	Area Multiplier	G	4:Approximately, how much of the [PLOT] is under [CROP]?	A	$F_{multiplier}(A)$
Plot specs.	Adjusted Area Meas. [m2]	Plot specs. Plot specs.	Area Multiplier Area Meas. [m2]	A B	$A * B$
Harvest	Reported yield [kg]	G G	12:How much [CROP] did you harvest from this [PLOT] during the [RS]? (QUANT) 13:How much [CROP] did you harvest from this [PLOT] during the [RS]? (UNIT)	A B	$A * F_{unit}(B)
Harvest	Reported yield [t/ha]	Harvest Plot specs.	Reported yield [kg] Area Meas. [m2]	A B	$(A/1000)/(B/10000)$
Harvest	Adjusted Reported yield [t/ha]	Harvest Plot specs.	Reported yield [kg] Adjusted Area Meas. [m2]	A B	$(A/1000)/(B/10000)$
Harvest	Crop Type	G	2:Collapsed CC maize,gn,tob,rice		
Irrigation	Irrigation presence	D D	1:What systems of irrigation, if any, are on this plot [PLOT](1ST)? 2:What systems of irrigation, if any, are on this plot [PLOT](2ND)?	A B	$F_{Irr}(A) + F_{Irr}(B)$
Irrigation	Irrigation method 1	D	1:What systems of irrigation, if any, are on this plot [PLOT](1ST)?		
Irrigation	Irrigation method 2	D	2:What systems of irrigation, if any, are on this plot [PLOT](2ND)?		
Irrigation	Water Source	D	6:What is the source of water on this[PLOT]?		
Inputs	Seeds [kg]	G G	5:How much seed did you plant for the [CROP] on this [PLOT] during the[RS]?(QUANT) 6:How much seed did you plant for the [CROP] on this [PLOT] during the[RS]?(UNIT)	A B	$A * F_{seed}(B)$
Inputs	Seeds [t/ha]	Inputs Plot specs.	Seeds [kg] Adjusted Area Meas. [m2]	A B	$(A/1000)/(B/10000)$
Inputs	Inorganic fertilizer use	D	12:Did you use any inorganic fertilizer on this [PLOT] during the [RS]		
Inputs	Organic fertilizer use	D	9:Did you use any organic fertilizer on this [PLOT] during the [RS]		
Inputs	Inorganic fertilizer use (2x)	D	18:Did you apply a second application of inorganic fertilizer to this p		
Inputs	Pesticide use	D	23:Did you use any pesticides/ herbicides on this [PLOT] during the [RS]		
Inputs	Inorganic fertilizer (1st) [kg]	D D Plot specs.	15:FIRST APPLICATION QUANTITY 16:FIRST APPLICATION UNIT Area Multiplier	A B C	$A * F_{unit}(B) * C$
Inputs	Inorganic fertilizer (1st) [t/ha]	Inputs Plot specs.	Inorganic fertilizer (1st) [kg] Adjusted Area Meas. [m2]]	A B	(A/1000) / (B/10000)
Inputs	Inorganic fertilizer (2nd) [kg]	D D Plot specs.	19:SECOND APPLICATION QUANTITY 20:SECOND APPLICATION UNIT Area Multiplier	A B C	$A * F_{unit}(B) * C$
Inputs	Inorganic fertilizer (2nd) [t/ha]	Inputs Plot specs.	Inorganic fertilizer (2nd) [kg] Adjusted Area Meas. [m2]	A B	$(A/1000)/(B/10000)$
Inputs	Organic fertilizer [kg]	D D Plot specs.	10:How much organic fertilizer did you apply to this [PLOT](QUANTITY)? 11:UNIT Area Multiplier	A B C	$A * F_{unit}(B) * C$
Inputs	Organic fertilizer [t/ha]	Inputs Plot specs.	Organic fertilizer [kg] Adjusted Area Meas. [m2]	A B	$(A/1000)/(B/10000)$
Inputs	Total Inorganic Fertilizer [t/ha]	Inputs Inputs	Inorganic fertilizer (1st) [t/ha] Inorganic fertilizer (2nd) [t/ha]	A B	$A + B$
Inputs	Total Fertilizer [t/ha]	Inputs Inputs Inputs	Inorganic fertilizer (1st) [t/ha] Inorganic fertilizer (2nd) [t/ha] Organic fertilizer [t/ha]	A B C	$A + B + C$
Inputs	Pesticides [kg]	D D D D Plot specs.	25:QUANTITY 26:UNIT 27:How much pesticides/herbicides did you apply to this [PLOT]?SECOND TYPE 28:UNIT Area Multiplier	A B C D E	$(A * F_{unit}(B) + C * F_{unit}(D)) * E$
Inputs	Pesticides [t/ha]	Inputs Inputs	Pesticides [kg] Adjusted Area Meas. [m2]	A B	$(A/1000)/(B/10000)$
Planning	Fertilizer application date	Planning D	Planting Date 17:How many weeks after planting did you finish the 1st fertilizer application	A B	$A + B$
Planning	Planting Date	G G	7:When did you plant the seeds for the [CROP] on this [PLOT]during the[RS]?(MONTH) 8:When did you plant the seeds for the [CROP] on this [PLOT]during the[RS]?(YEAR)	A B	$A\&B$
Planning	Growing Season Duration [month]	G G	10:What months did the harvest start? 7:When did you plant the seeds for the [CROP] on this [PLOT]during the[RS]?(MONTH)	A B	$A - B$
Planning	Harvest Start Date	Planning Planning	Planting Date Growing Season Duration [month]	A B	$A + B$
Market	Sold Crop Amount [kg]	I I	3:How much of the harvested[CROP] was sold in total ? 4:UNIT	A B	$A * F_{unit}(B)$
Market	Sold Crop Value [MWK]	I	7:What was the total value of all [CROP] sales?		
Market	Sold Crop Value/Tonne [MWK/ton]	Market Market	Sold Crop Value [MWK] Sold Crop Amount [kg]	A B	$A/(B/1000)$
Market	Sold Crop Value/ha [MWK/ha]	Market Plot specs.	Sold Crop Value [MWK] Adjusted Area Meas. [m2]	A B	$A/(B/10000)$
Storage	Main Transportation	I	10:What was the main mode of transportation associated with all [CROP] sales?		
Storage	Stored crop amount [kg]	I I	32:Amt of harvested[CROP]being stored by HH?(QUANT) 33:UNIT	A B	$A * units(B)$
Storage	Stored crop amount [t]	Storage	Stored crop amount [kg]	A	$A/1000$
Geography	Latitude	HH Geovars.	1:GPS Latitude Modified		
Geography	Longitude	HH Geovars.	2:GPS Longitude Modified		
Geography	Distance to city (>20,000p)	HH Geovars.	3:HH Distance in (KMs) to Nearest Population Center with +20,000		
Geography	Distance to nearest agricultural market	HH Geovars.	4:HH Distance in (KMs) to Nearest Agricultural Market		
Geography	Annual Precipitation [mm]	HH Geovars.	5:Annual Precipitation (mm)		
Geography	Elevation [m]	HH Geovars.	6:Elevation (m)		
Geography	Slope [%]	Plot Geovariables	2:Plot Slope (percent)		
Tenure	Ownership	B2	1:How did your household acquire this garden ([GARDEN])?		
Tenure	Ownership Document	B2	3:Does your HH currently have a title or ownership document for this [GARDEN]?		
Tenure	Ownership duration	Meta B2	moduleB_start_date 3:In which year was this [GARDEN] acquired?	A B	A - B