Acknowledgements

First and foremost, I wish to thank my advisor, Professor Dr. Dr. Christian Ulrichs, for accepting me as a PhD student and for his support and supervision, since 2012. I am very grateful for his patience, trust and great knowledge that, taken together, made him a great mentor.

Many thanks also to Professor Dr. Wolfgang Bokelmann, for his valuable inputs and supervisory role. A special thank you to Dr. Christine Werthmann for her very comprehensive expert comments in the final stages of this thesis. I am further grateful to Dr. Susanne Huyskens-Keil and Dr. Cornellia Oschmann, for their support and advice.

Further thanks also to the supportive staff at the Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Kenya, notably Dr. Kenneth Ogila, Dr. Shadrack Muya and Professor Dr. John Wesonga. I was also very inspired by the great Professor Dr. Mary Abukutsa and her research on African Indigenous Vegetables and her dedication. A very special thank you also to all the farmers, experts and government staff that patiently answered my questions and gave me insights into agriculture and aquaculture sectors in Kenya.

Much of my research would not have been possible without the financial support from the DAAD, the Frauenförderung of the Faculty of Life Science, the Stiftung für Tropische Agrarforschung and the Böll-Stiftung, and the Deutsche Gesellschaft für Internationale Zusammenarbeit - German Federal Enterprise for International Cooperation for which I am very grateful.

A huge thank you to Rick Wheal his ever-constructive feedback and encouragement and for proof- reading this work. I am deeply indebted to my parents and grandparents for their moral and financial support. They have taught me about hard work and persistence. Especially my grandmother has always been a great role model of resilience, strength and character.

And last but not least thank you to all my friends in Kenya and in Europe. Special thanks to Ina Backasch, Mandana Mohit and Chris King for your encouragement, love and most of all, your humour.

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.

Abstract

This work offers a study on the adoption and diffusion of agricultural innovations in Kenya. Population growth and large agricultural challenges necessitate the adoption of intensive and resource efficient farming methods in the region. When exploring the historical context, it becomes clear that the adoption and diffusion of agricultural innovations, that revolutionised agriculture globally, has been limited in sub-Saharan Africa.

Following a case-study research approach, this work will focus on the technical and economic feasibility of whether aquaponics is a locally suitable innovation, and if mobile phone applications ("apps") are a suitable information diffusion tool.

Two case-studies were conducted in JKUAT Kenya and a field trial with farmers in Bungoma. The research proves that aquaponics systems can be built with locally available production materials; that its production outperforms in-soil production for the chosen crop, and that farmers can successfully operate such a system, given training and support. However, considerable practical challenges, important cultural factors and a missing Information and input network render it unlikely that this production method will be taken up by many farmers in Kenya within the next decade.

Mobile phone applications are a growing service sector, due to widespread mobile phone ownership and high cultural acceptance. In order to test if agricultural apps can be used as an information dissemination tool, an app for the aquaculture sector was built and tested with fish farmers in Kakamega County. The results show that while the farmers valued the information service provided, apps are not suitable to be used as a sole information medium, as direct contact and practical training are central to the African culture. However, apps and digital platforms are very likely to increase in relevance in the near future, as especially the younger generations in particular will use Information and Communication Technologies (ICT) and as ICT services will ease the bottlenecks in the various value chains.

Keywords: Agricultural innovation, Adaptation and Distribution, Aquaponics, Mobile Phone Application, Kenya

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.

Zusammenfassung

Diese Arbeit ist eine Studie zu Adaption und Diffusion von landwirtschaftlichen Innovationen in Kenia. Bevölkerungswachstum und große Herausforderungen in der Landwirtschaft erfordern die Einführung von intensiven und ressourcenschonenden Anbaumethoden in der Region. Der historische Kontext zeigt, dass viele revolutionäre landwirtschaftlichen Innovationen aber nur sehr eingeschränkt in Sub-Sahara Afrika eingeführt wurden.

Durch Fallstudien wird - mit dem Fokus auf technische und ökonomische Machbarkeit - ermittelt, ob Aquaponik eine lokal angemessene Innovation ist und ob Mobiltelefonapplikationen („Apps“) ein geeignetes Informations-Diffusionswerkzeug sind.

Es wurden zwei Studien an der JKUAT Universität und eine Feldstudie mit Farmern in Bungoma durchgeführt. Die gemachten Beobachtungen ergeben, dass es möglich ist, aquaponische Anlagen mit lokalen Baumaterialien zu fertigen. Es zeigt sich, dass diese Anlagen das Produktionsvolumen der getesteten Kulturpflanze im Vergleich zur Feldanzucht übertreffen und Bauern aquaponische Systeme mit Training und Unterstützung bewirtschaften können. Praktische Herausforderungen, wichtige kulturelle Faktoren und ein fehlendes Informations- und Zulieferungsnetzwerk machen eine breite Adoption dieser Produktionsmethode jedoch in den nächsten Jahren sehr unwahrscheinlich.

Mobiltelefonapplikationen sind durch die hohe Mobiltelefon-Nutzung und breite kulturelle Akzeptanz in Kenia ein stark wachsender Servicesektor. Um zu prüfen ob landwirtschaftliche Apps als Instrument zur Verbreitung von Informationen geeignet sind, wurde eine solche App für den Aquakultursektor gebaut und mit Fischfarmer in Kakamega County getestet. Es konnte nachgewiesen werden, dass Farmer den Service schätzten, aber eine App als alleiniges Informationsmittel weniger geeignet ist. Gründe hierfür sind in der traditionellen Kommunikationskultur Afrikas zu finden, bei dem der direkte Austausch und praktisches Training wichtig sind. Dennoch wird die Relevanz von digitalen Instrumenten zukünftig wachsen, da besonders die junge Generation Information und Communication Technologies (ICT) nutzen und ICTs bestehende Engpässe in Wertschöpfungsketten erleichtern werden.

Schlagwörter: Landwirtschaftliche Innovationen, Adaptation und Distribution, Aquaponiks, Mobiltelefon Applikation, Kenia

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.

1 Introduction

1.1 Research context and research objectives

"Land and water resources and the way they are used are central to the challenge of improving food security across the world. Demographic pressures, climate change, and the increased competition for land and water are likely to increase vulnerability to food insecurity, particularly in Africa and Asia. The challenge of providing sufficient food for everyone worldwide has never been greater."

The state of the World's land and water resources for food and agriculture

(FAO, 2011, p. 4)

The fight against hunger and poverty is one of the most serious challenges the global community is facing. According to the United Nation Food and Agriculture Organization (FAO), 815 million people, almost exclusively living in economically developing countries[1], were estimated to be chronically undernourished in 2016 (FAO, IFAD, UNICEF, WFP, & WHO, 2017). This is in addition to over two billion people, most of them women and children, who suffer from so-called "hidden hunger" i.e. an inadequate supply of vital micronutrients such as vitamins or minerals (Black et al., 2013; Kennedy, Nantel, & Shetty, 2003; Tulchinsky, 2010). Micronutrient deficiency is linked to many chronic diseases and also increases the severity of infectious diseases, including HIV/AIDS (Tulchinsky, 2010). Sub-Saharan Africa (SSA) is particularly affected by malnutrition, due to a complex mix of geographic, historic, political and cultural factors.

Over the next decades, globalisation will continue to expose the food system to more economic, environmental and political pressures. In the on-going process of globalisation -

[1] Countries will be referred to as 'economically less developed countries' or 'economically developed countries' throughout this thesis. This makes it explicit that other aspects of development, such as cultural richness or species diversity, should be included in a holistic understanding of development. This aims to counter the widely accepted understanding that defines development by focusing on the socioeconomic dimension only.

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.

defined by the Cambridge Dictionary ("Globalisation," n.d.[2]) as "the increase of trade around the world, especially by large companies producing and trading goods in many different countries"- the entire global food chain becomes affected. As the global population size is estimated to increase from over seven billion today to over nine billion by 2050 (UNDESA, 2019), competition for land, water and energy, to produce sufficient food for all, will intensify.

Many of the countries that are predicted to experience a large and fast growth in their populations are indeed those countries that are already struggling with adequate food supply and undernourishment. Up until recently, Africa was one of the least densely populated continents. Yet, during the last century, Africa's population increased nearly seven-fold from 120 million in 1900 to 817 million in 2000 (Goldewijk, 2005). Almost 50% of the projected global population growth of 2.3 billion between 2013 and 2050, is expected to occur in Sub-Saharan Africa alone (UNDESA, 2013). This trend is based on the fact that SSA has currently the highest reproduction rate with of 5.4 children per woman between 2000-2005 (UNDESA, 2013). As access to education - especially for females improves - average fertility rate is likely to decrease, yet the absolute numbers will overwhelm this effect for the coming decades.

Providing sufficient food for current and future generations presents a critical challenge in the region. Past efforts to establish a sustainable food system have been challenged by climate shocks, epidemics and military conflicts, often affected by a combination of political, geographical and historical causes. In addition, the growing demand for food must be met against a backdrop of rising global temperatures, extreme weather events, shifting patterns in precipitation and phenology, as well as spreading habitats of pests and plant diseases (IPCC, 2007; Walther et al., 2002). For the past two decades, unprecedented temperature records have been documented globally. Their effects are increasingly felt and well-documented in most countries, as "the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen" (IPCC, 2014, p.2). The aftermaths are very likely to intensify as global greenhouse gas emissions - the very likely cause of global warming – are still increasing despite multilateral agreements to curb their emission. Climate change dramatically affects agricultural productivity and food systems, including crop yields, livestock performance, tree growth as well as food prices and availability (Adams, Hurd, Lenhart, &

[2] Publications without a date are abbreviated to n.d

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.

Leary, 1998). This implies that future production increases must be met through climate-smart methods and inputs.

Kenya, the geographical focus of this thesis, like many countries in SSA, is unable to feed its population sufficiently. As a result, malnutrition is a chronic and severe problem. Despite many efforts to improve food security, the 2012 Global Hunger Index (International Food Policy Research Institute, Welthungerhilfe, & Concern, 2012, p. 55) shows that between 2006-2008, 33% of the population in Kenya were undernourished and that the level of hunger remains 'serious' for many Kenyans. Prolonged insufficient supply of micronutrients can lead to an increase in cardiovascular disease, diabetes and a general decrease in productivity of adults and impaired development of children (Abukutsa Onyango, 2010). The effects of prolonged malnutrition are often long-term, as malnourishment directly affects people's physical and mental health, reducing the capacity of young people to learn, or the ability of adults to work productively. Nutrition is especially relevant during the first 1000 days of life - starting at conception - which form the base for optimum health, growth, and neurodevelopment later in in life (Cusick & Georgieff, 2016).

In 2013, Kenya's entire agriculture sector, which includes arable farming, livestock, fisheries, forestry and hunting, contributed 20.7% to the GDP and supports an estimated 75% of the population (African Development Bank Group, 2014, p. 2). Yet, while a third of Kenyans are undernourished, significant potential to increase production, for example through better irrigation systems, remains largely unexploited. The current state of the agriculture sector in Kenya will be described in Chapter 2.3, thereby highlighting the largest challenges and needs of farmers in the country.

Currently 95% of the food grown in Sub-Saharan Africa is produced by rain-fed agriculture (Wani, Sreedevi, Rockström, & Ramakrishna, 2009). This makes production vulnerable to adverse weather conditions, which are highly likely to increase and intensify in the future. With Africa's demographic and the nutrition crisis intensifying, the region urgently needs to adapt their agriculture production systems to an increasingly warming world. New strategies and approaches for resilient farming systems are needed to meet the rapidly increasing food demand triggered by rural and urban population growth. Innovative agricultural practices,

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.

tools and technologies that promote climate-smart agriculture (CSA) should be part of the solution.

Innovations, defined by Sunding & Zilberman (2000, p. 2) as “new methods, customs, or devices used to perform new tasks” have transformed agriculture since its beginning. These include the use of animals in land preparation and harvest from 4000-3000 BC onwards to steady mechanisation of farming activities between 1700-1850. This was followed by the Green Revolution in the 1950-70s when newly developed cultivars, fertilisers, pesticides and mechanical tools, such as tractors, were adopted in many countries and led to large increases in crop production. While this development was particular successful in the so-called Western countries and Asia, adoption was limited in Africa (as summarised in Chapter 3.5).

A new set of modern agricultural innovations has been advanced in the last decades, including drip irrigation, hydroponics as well as an increased utilisation of Information and Communication Technologies (ICT) in agriculture.

One such innovative agricultural practice is aquaponics, which combines the production of vegetables and fish. Aquaponics (AP) is a relatively new horticultural production method, where aquaculture and hydroponics (soil-less plant production) are combined in a recirculating, closed-loop nutrient system. This method holds many advantages, as it does not require costly fertiliser and makes very efficient use of water resources, while providing farmers with an additional protein source and a potential double-income stream. Thus, this system has a high production output per land area, allowing smallholder farmers to generate higher returns by growing vegetables, compared to land intensive staples foods, such as rice or maize, that reap smaller profits by volume. Aquaponics has the potential to increase the supply of highly nutritional and affordable vegetables by producing them close to the increasingly urban and peri-urban consumer population. In addition, aquaponics systems do well in the local tropical and arid climate zones, where water is the main limiting factor for food production, thus strongly limiting food security.

New technological advances and innovations increasingly cross over into the agriculture sector, such as mobile phone applications, sensors and drones. In many countries, the ICT revolution has transformed the public, private and business sectors, while mobile phones, personal computers (PCs), and a diverse number of technical gadgets have become an

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.

integrated part in people's everyday lives. These technological advances have also started to transform the agriculture sector. An innovative tool that is increasingly used to provide a constantly increasing set of services to farmers and the agriculture sector are mobile phone applications. A range of such applications – often shortened to "apps" - has been established to supply farmers with information on weather predictions, market prices or services that support the implementation of new practices. Additionally, they can provide institutions and governments with a tool to monitor production rates and farmers' needs. They also offer data to support evidence-based policies and targeted initiatives.

1.2 Problem statement and research question

Many agricultural innovations have not been widely implemented in Sub-Saharan Africa (SSA). Illustrating this point is the limited adoption of mechanisation (such as tractors) and fertiliser in SSA, as highlighted in Chapter 3.5. While some of these where not adopted due to the diverging local conditions, more sustainable production approaches are urgently needed. To **understand why previous agricultural revolutions experienced little uptake in SSA**, this work briefly explores **adoption and diffusion barriers of these innovations**. This background is essential to evaluate if the modern agricultural innovations considered in this thesis - aquaponics and mobile phone apps – are likely to reach adoption and distribution, or if they will experience the same, or other challenges as the agricultural revolutions before.

While aquaponics systems have shown great results in terms of both high-density fish production and vegetable cultivation, they are only slowly moving from being essentially a cultivation practice for self-sufficient "backyard" farmers to a commercially viable production system. Commercial systems are still very limited. Most aquaponics systems are based in economically developed countries, in particular the United States of America, with some in Europe and Australia (Lennard, 2004; Savidov, 2004; Villarroel et al., 2016). Consequently, most literature focuses on examples of aquaponics in those industrialised countries, where prospective farmers have easy access to adequate technical equipment, building material, seeds, feeds and state of the art know-how. Australia aside, they are also mostly based in temperate climate zones, which have specific requirements and implications for farming in aquaponics systems. What potential aquaponics has in less economically developed countries (LEDC) settings, in particular in Africa, is still relatively unknown, due to the lack of documented operating systems.

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.

Furthermore, most literature on aquaponics focuses on the technological and ecological aspects and benefits (Blidariu & Grozea, 2011; Frankic & Hershner, 2003; Lennard & Leonard, 2006; Quagrainie, Flores, Kim, & McClain, 2018; Rakocy, Bailey, Shultz, & Danaher, 2011; Tokunaga, Tamaru, Ako, & Leung, 2015), yet there is a lack of analyses of the social and cultural aspects.

This work seeks to address this gap and conduct a thorough research into the **potential of aquaponics to be adopted in Kenya** to improve food security.

Additionally, this work seeks to **define the potential and barriers of agricultural ICT solutions in Kenya**. The focus thereby is brought to the expanding sub-section of mobile phone applications, reviewing their capacity and key challenges, both as an information diffusion tool and an agricultural service tool. As a very recent addition to the toolbox, so far only limited research has been conducted to establish their potential in the agriculture sector. Chapter 6 first outlines the types of services that mobile phone applications provide in Kenya, followed by an assessment of a mobile app for fish farmers designed in the context of this thesis.

The geographic focus is Kenya; which is a comparatively stable country, both politically and economically. Kenya's aquaculture sector employs 70% of the population directly or indirectly (Kenya National Bureau of Statistics, 2014). In 2016, Kenya ranked at position 146 out of 187 countries in the Human Development Index (UNDP, 2016), which lists countries based on the health, education and economic prospects of it citizens, therefore Kenya is a prime candidate to benefit from this research.

Main research question:

What potential do agricultural innovations such as aquaponics and mobile phone application - as an information diffusion tool- have to be adopted in Kenya and what are the main challenges?

From this main research question, three specific research questions can be derived based on a) current need and past-performance, b) feasibility and suitability and c) local adaptation and diffusion of new methods, tools and systems.

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.

Research question 1: What are the biggest agricultural challenges and why have other agricultural revolutions struggled with implementation and distribution in the past?

Method: Comprehensive diffusion analysis of past agricultural innovation and review of current issues.

The principal purpose is to establish a thorough picture of the past and current status and the challenges of the agriculture sector in Kenya.

Research question 2: Proof of concept - Is aquaponics a feasible farming practice for Kenya? Could aquaponics be a sustainable method that can be widely adopted and assist in tackling food insecurity locally?

Given the urgency to implement highly productive farming methods that will be able to feed more people whilst using fewer resources, aquaponics appears to be a promising method with much potential. To evaluate its potential and limitations is the aim of this section of the thesis.

Method: Case-study research through construction of three prototype systems in Kenya for proof of concept

Based on fieldwork conducted in Kenya from March 2014 until March 2016, this work will evaluate how aquaponic systems can be set up and operated efficiently under local conditions at Jomo Kenyatta University of Agriculture and Technology (JKUAT) University in Juja, Central Kenya and in a rural setting. The following criteria will be assessed:

Design and construction

1. Adapting an AP system design that is most suitable for the local conditions
2. Establishing the decisive factors which determine a suitable location
3. Constructing a simple, yet functional AP system that is cost-effective
4. Sourcing all required building materials locally
5. Finding the optimal source to power the aquaponics system
6. Establishing the biggest challenges during construction

Dieses Werk ist copyrightgeschützt und darf in keiner Form vervielfältigt werden noch an Dritte weitergegeben werden.
Es gilt nur für den persönlichen Gebrauch.