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Towards climate resilient smallholder horticulture in Kiambu and Kajiado counties, Kenya

An explorative study on climate change adaptation in a horticultural market in transition from developmentally aided to sustainably, internationally trading



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WAGENINGEN UNIVERSITY & RESEARCH

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MSc thesis Climate Studies (Human Environment Interactions)

MSc thesis in the Water Systems and Global Change group, submitted as partial fulfilment of the degree Master of Science in Environmental Sciences at Wageningen University, the Netherlands.

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Abstract

Rising temperatures and changing rainfall patterns are expected to cause major losses in horticultural yields, while the sector is considered to be one of the main pillars of Kenyan development. Most of the agriculture is rainfed produced by smallholder farmers. This thesis presents adaptation strategies that can be implemented by smallholder horticulture farmers in two Kenyan counties to support or replace current agricultural practices with the aim to maintain or improve production under a changing climate.

Standardized, semi-structured interviews were conducted with smallholder farmers and local agricultural extension staff to assess their current practices and their objectives regarding horticulture. An explorative climate data analysis was performed for average daily temperature, precipitation, runoff and crop water requirements. Reference data was compared to mid and end century projections under RCP4.5 and RCP8.5, using data from four GCMs. A multi-criteria analysis was used to assess which measures could serve the identified objective in the local context. Location specific adaptation strategies were constructed that give room to progressive implementation under uncertainty.

Climate data analyses indicated that all areas are likely to receive more water through precipitation. However, crop water requirements will increase due to rising temperatures. Therefore, crops in most locations will experience enhanced water stress. These effects are more severe in areas that are already relatively dry. Moreover, farmers in areas with high agricultural potential are expected to have higher adaptation capacities than those farming in dry areas. To adapt to the identified changes, the projected increase in runoff plays a central role. The proposed adaptation strategies mainly consist of a series of small scale, cheap and on-farm soil and water conservation measures. It is argued that larger scaled, more robust water harvesting measures should be considered only in areas with the greatest agricultural potential. For these to be successfully implemented and operationalized, a strong organisation should be established that involves all stakeholders.

This thesis has shown that successfully constructing specific turning points is difficult (if not impossible) as production is determined by future non-linear trends of interacting climate variables. Moreover, dynamic socio-economic processes under rapid development are of high relevance to smallholder farmer decision making. It is argued that smallholder farmers mainly make day-to-day decisions to manage a wide range of risks, of which climatological circumstances are ‘only’ one of many stressors. Assessing which adaptation pathways would be most suitable to implement in a context like this might hence need a more holistic approach.

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Abbreviations

ATP	Adaptation Turning Point
CAS	Climate Adaptation Services foundation
CWR	Crop Water Requirement
ENSO	El Niño Southern Oscillation
ET_0	Reference evapotranspiration
ET_c	Crop evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
GCM	Global Circulation Model
IOD	Indian Oscillation Dipole
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KES	Kenyan Shillings
KMD	Kenyan Meteorological Department
P	Precipitation
PAW	Plant Available Water
R	Runoff
RCP	Representative Concentration Pathway
RH	Relative humidity
SACCO	Savings and Credit Co-Operative
SH	Sun hours
SSA	Sub-Saharan Africa
SWC	Soil and Water Conservation
T	Temperature
T_{max}	Maximum temperature
T_{min}	Minimum temperature
WARREC	Water Research and Resources Center
WRA	Water Resource Authority
WS	Wind speed

1. Introduction

1.1 Situation

Agriculture in Kenya is pressured by a changing climate: rising temperatures, higher occurrence of drought events and changing rainfall patterns are expected to cause major losses in agricultural yields (Bryan et al., 2012; Herrero et al., 2010). Financial and institutional limits, besides a low per capita gross domestic product (GDP), high poverty rates and an absence of well-established safety nets result in high levels of vulnerability and low adaptive capacity to climate change in African countries (Herrero et al., 2010; Kurukulasuriya et al., 2006; Thornton et al., 2006). Climatologically, sub-Saharan Africa (SSA) is expected to be impacted relatively heavily by climate change due to climatological conditions being quite extreme already (Kurukulasuriya et al., 2006). Economically, SSA is predicted to suffer greatly under climate change because country economies are highly dependent on agriculture. Agriculture accounts for about 34% of the Kenyan gross domestic product (GDP) (Worldbank, 2018). Most of it being performed under rainfed conditions, a change in precipitation and temperature patterns directly affect production of crops (Ngetich et al., 2014; Ochieng et al., 2016). This makes the Kenyan economy sensitive to variations in climatological conditions.

Since the end of Kenya's time as a British colony in 1963, the share of the horticulture sector has gained weight in the Kenyan export numbers (Minot & Ngigi, 2010). Due to this growth, the horticulture sector is by many Kenyan counties identified as one of the pillars of development (Wesonga et al., 2018). Smallholder farmers are estimated to have been responsible for around half of the horticultural export during the rapid sector growth. Contributing to the horticultural (export) market is stated to be the most lucrative option for smallholder farmers in Kenya (Minot & Ngigi, 2010).

After free trade was introduced in the early 90s, the international market demand shifted from the traditional retailers to supermarkets. This shift induced higher quality and quantity standards that smallholder farmers struggled to meet (Dolan & Humphrey, 2000; Minot & Ngigi, 2010). In particular, they face difficulties maintaining post-harvest crop quality and supplying consistent quantities of vegetables throughout the year (Dolan & Humpfrey, 2000). To be able to produce for own subsistence consistently, and potentially increase their production to profit from the growing international consumer market through supermarket trade, smallholder horticulture farmers cannot afford any setbacks in their yields. A changing climate however will further challenge smallholder farmers to maintain horticultural crop yields throughout the year (Wesonga et al., 2018). This hampers the potential development that a blooming horticulture sector could bring to smallholder livelihoods, and to the Kenyan economy.

To decrease the potential impact of climate change on Kenyan smallholder horticulture, livelihoods and food security, adaptation to climate change is key (Bryan et al., 2012). Moreover, adaptation will lead to a stabilization and strengthening of the position of smallholder horticulture farmers in Kenya. Without adaptation, the impact of climate change on the horticulture sector will indirectly reduce health and the development rate due to a likely increase in conflict and poverty (Orindi & Murray, 2005). Lacking knowledge on expected climate change obstructs insight in points of focus and adaptation investment opportunities (Wesonga et al., 2018). In addition to a lack of knowledge, the financial ability of smallholder farmers to adapt to changes in climate is limited in a low-middle income country like Kenya ((Bryan et al., 2012; Herrero et al., 2010; Kurukulasuriya et al., 2006; Thornton et al., 2006). As a result, vulnerability to the effects of climate change now remains significant.

1.2 3R Kenya and Climate Atlas

This thesis contributes to two projects of the Climate Adaptation Services foundation (CAS). This section briefly introduces both projects, and describes the contribution of this thesis to the project aim.

The 3R Kenya project aims to contribute to food and nutrition security and livelihoods in Kenya, by exploring the potential for sustainable and inclusive growth, trade and investments in the aquaculture, dairy and horticulture sectors (3R, 2019). CAS is part of the team focusing on climate change adaptation in Kenyan horticulture. Food safety and quality in a fragmented value chain are concerns and besides (or even exacerbating) these, there is the challenge of a changing climate. Farmers in Kenya commonly practice rain-fed agriculture, and are aware of dry periods in the normal agricultural cycle. However, transition to climate resilient agriculture is not widely evident in the country yet (Matui et al., 2016). The impact of different climate change scenarios on current horticultural practices needs to be identified, leaving the following question open to be answered by the 3R Kenya project (Matui et al., 2016):

> *What medium-term effects of climate change are expected in the horticulture sector, and how can they be addressed?*

To answer this question, the 3R Kenya project aims "to assess the sector's resilience against climate change related shocks, and to partner with other stakeholder to introduce and promote climate variability measures and practices" (Matui et al., 2016, p. 10).

The Climate Atlas Kenya is an interactive tool on climate change adaptation in Kenya. This tool is being developed by CAS, as part of the 3R project. It will give localized insight in how climate change is likely to affect crop growth in Kenya. Initially, the Climate Atlas is made for two counties in Kenya: Kiambu and Kajiado. In later phases of the project, the atlas will hopefully be made available for the rest of the country as well. This thesis will provide information on how farmers can deal with the climate change that is projected to impact them.

To fit the 3R project aim and add an extra dimension to the Climate Atlas, this case study will focus on climate change adaptation in the horticultural sector of Kiambu and Kajiado counties. These two neighbouring counties are located around the capital Nairobi, in the central Kenya (Figure 1). More elaborate information on these counties, and the difference between both is given in chapter 3.2.

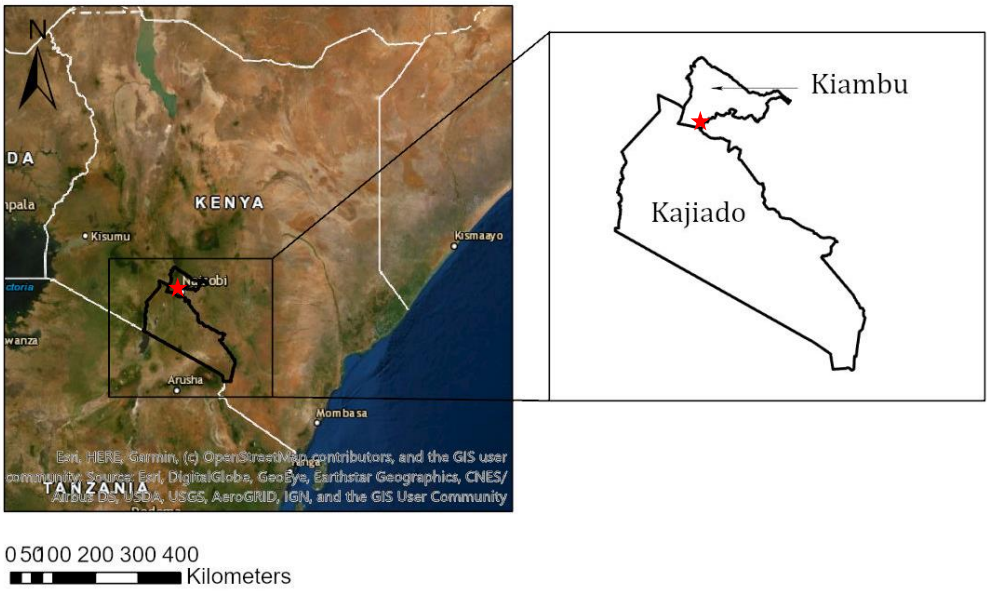


Figure 1 Physical map of Kenya, with the location of Kiambu and Kajiado counties indicated in the square. The capital (Nairobi) is indicated with the red stars.

1.3 Research context

1.3.1 Demography

The democratic republic of Kenya is located along the East coast of the African continent (Figure 1). After the British reign has been ended in 1963, the republic was officially founded one year later. In the republic as it functions nowadays, the president is the head of the state and the government while elected officials represent the people. Kenya is home to nearly 50 million inhabitants, while in 1950, this still was less than 6 million. The population growth has stabilized and then decreased to around 1.57 percent in 2018 (CIA, 2019). The population is centred around lake Victoria (Southwest), in the capital Nairobi and along the Indian Ocean coast (Southeast) (CIA, 2019).

In 2013, Kenya adopted a decentralised system in which the country is divided in 47 counties, each of which should be devolved state revenues and responsibilities to (Cheeseman et al., 2019). As mentioned, this research focuses on two of the established counties: Kiambu and Kajiado. Within counties, the governance is decentralised into sub-counties and wards (Cheeseman et al., 2019).

1.3.2 Economy

Kenya is one of the biggest African economies, with a stable growth in average GDP of around 5%. According to the World bank ranking, Kenya is a low to middle income country. The country's middle class is growing, but the economic development rate is impeded by weak governance in which corruption plays a big role. Besides, unemployment and underemployment rates are very high, estimated to be around 40% of the population (CIA, 2019).

The country's main sector is agriculture. Over 75% of the agriculture is smallholder rainfed farming or livestock production. The capital Nairobi serves as major regional market for agricultural production. The agricultural trade is not limited to the market of Nairobi. African and European markets are in also supplied with agricultural products from Kenya (Minot & Ngigi, 2010).

1.3.3 Climate

With a size of 580,367 square kilometres and altitudes ranging up to 5,199 meters, climates differ throughout Kenya. The coastal area has a tropical climate, while the inland areas are temperate. The north and north east areas are arid. Kenya experiences a biannual rainfall pattern. The *long rains* last from March to June. The *short rains* run through from October to November or December (Herrero et al., 2010). These rain seasons are the periods in which rainfed farming is practised.

In Figure 2, Kenya is divided into seven agro-climatic zones based on the moisture index by Sombroek et al. (1982). The moisture index expresses annual rainfall as a percentage of potential evaporation. If this moisture index is greater than 50%, the potential for cropping is considered high. These high potential zones for cropping (indicated I, II, III) cover about 18% of the Kenyan land area. Most of these zones are located around 1200 meters and higher, and experience temperatures of 18°C (Kabubo-Mariara & Karanja, 2007). Most of Kenyan land area is known as rangeland. These semi-humid to arid regions (IV, V, VI and VII) have moisture indexes of under 50% and receive a mean annual rainfall of under 1100 mm (Kabubo-Mariara & Karanja, 2007; Sombroek et al., 1982).

Overall, the Kenyan climate is greatly variable in terms of time and location. This specifically applies to precipitation patters (Ochieng et al., 2016). The long rains (March – June) are less variable than the short rains (Herrero et al., 2010). Moreover, intra-annual variability is high due to the systems sensitivity to atmosphere-ocean dynamics during the Indian Ocean Dipole (IOD) and the El Niño Southern Oscillation (ENSO) phenomena (Hulme et al., 2001; Marchant et al., 2007).

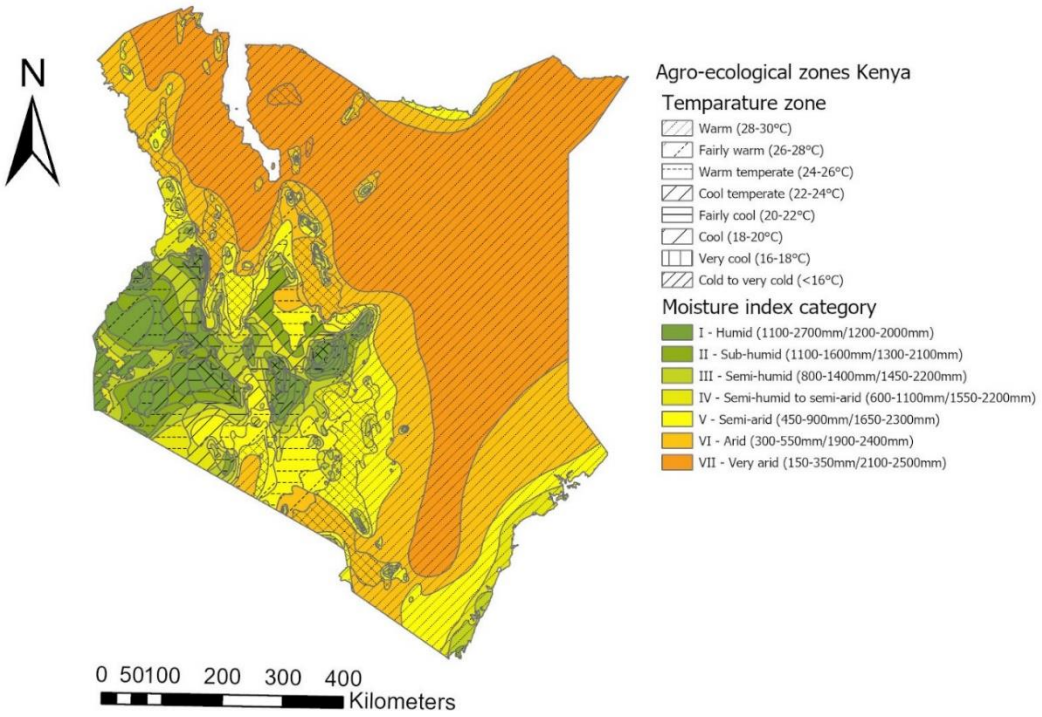


Figure 2 Agro-ecological zones in Kenya with an overlay showing temperature zones. Moisture index is shown according to Sombroek et al. (1982). The humidity label is followed by (average annual precipitation/average annual potential evaporation).

1.3.4 Projected climate change

Kenya might get wetter, and is very likely to become hotter. Global Circulation Model (GCM) simulations under multiple emissions scenarios unanimously project that for Africa, the median temperature increase lies between 3°C and 4°C in all seasons by the end of the 21st century (Christensen et al., 2007). This is roughly 1.5 times the global mean response (Herrero et al., 2010). Resulting in an increasing evapotranspiration, this increasing average maximum temperature can induce heat and water stress to horticultural crops (3R, 2019).

Changing precipitation trends are less certain due to its spatially and temporally variable character (IPCC, 2007). In East Africa, mean precipitation rates will only drop in a few areas (Thornton et al., 2006). The major part of East Africa will experience an increase in precipitation. In GCM simulations, 18 of 21 models projected this trend (Christensen et al., 2007; Doherty et al., 2010). The trend is especially strong for the core region of the Horn of Africa, which covers the Southwest of Kenya. Some uncertainty remains, as GCMs do not well cover the warming impacts of the IOD. Precipitation can be overestimated as a result (Herrero et al., 2010). Analysis of effective rainfall show that in both case study counties, already dry seasons will get slightly drier (Figure 3). The wet periods are projected to become wetter.

The impact of changes in climate on the horticulture sector in Kenya and the counties under research will vary per location. Ochieng et al. (2016) argue that increasing temperatures will have a positive impact on crop production in highland areas, while it will have a negative effect on crop production lowland areas. Logically, they also state that the impact of climate change depends on the crop cultivated. To identify the potential impact of changing precipitation and temperature trends on horticultural crop growth in different agro-ecological locations throughout Kiambu and Kajiado, further data analysis will be performed as part of this thesis (Chapter 5).

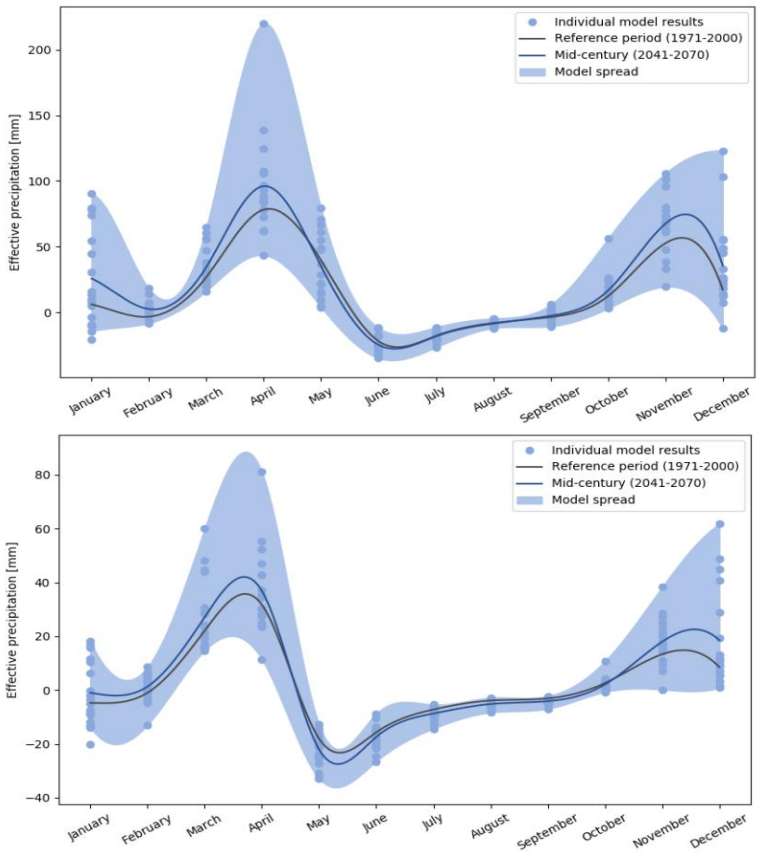


Figure 3 Indicative projections of future effective rainfall in Kiambu (upper) and Kajiado (lower) counties (Climate Atlas Kenya, 2019).

1.4 Problem statement and research objective

Smallholder farmers in Kiambu and Kajiado counties are aware of changes in climate (Koge & Ochola, 2018; Zwarts, 2018). Alternative climate resilient farming practices have been mentioned in stakeholder discussions. Most of these interventions however are not based on local data on expected climate change and are not specified according to different climatological scenarios.

To support Kenyan smallholder farmers in sector development towards climate resilient horticulture, the main objective of this research is:

> *To identify adaptation strategies that can be implemented by smallholder horticulture farmers in Kiambu and Kajiado to support or replace current agricultural practices in order to maintain or improve income, yield and/or environmental performance under a changing climate.*

In this light, it will be assessed when current horticultural practices cannot suffice anymore, and by what sequence of practices they should be replaced or supported. Under the uncertainty of a changing climate, such sequences of agricultural practices (strategies) can be implemented progressively, as time unfolds. The focus of this research is to develop such adaptation strategies. Bryan et al. (2012) argue that effective adaptation planning will require government "investments in drought and heat tolerant varieties, irrigation systems, disaster relief, insurance and social protection programs, and integrated strategies to reduce livelihood risks (p.27)". The results of this research could hence serve as input for (local) government programme content, investment decisions and policy plans.

2. Research design

This chapter presents the research design that follows from the problem statement and research objective introduced in the previous chapter.

2.1 Main research question

What adaptation strategies can be implemented by smallholder horticulture farmers in Kiambu and Kajiado to support or replace current agricultural practices in order to maintain or improve income, yield and/or environmental performance under a changing climate?

2.2 Sub research questions

1. What are current smallholder horticulture farming practices in Kiambu and Kajiado counties?
2. What are objectives of local institutions and stakeholders in the horticulture sector, determining investments in smallholder agriculture in Kiambu and Kajiado counties?
3. What changes in climate can be expected in Kiambu and Kajiado counties, influencing smallholder horticulture in terms of income, yield and/or environmental performance?
4. What adaptation measures can be implemented by smallholder horticulture farmers in Kiambu and Kajiado to support or replace current agricultural practices in order to maintain or improve income, yield and/or environmental performance?
5. What adaptation turning points occur in current smallholder horticulture practices in Kiambu and Kajiado, indicating a decrease in income, yield and/or environmental performance under the projected changes in climate?

3. Concepts and methods

The framework and concepts that are on the basis of the research are introduced in Section 3.1. The *adaptation turning point approach* was used, which consists of five steps that are each linked to one of the sub research questions. The selected study sites and their backgrounds are presented in Section 3.2 The methods used to answer each of those questions are elaborated on in Section 3.3. The last section reflects on the reliability and validity of this research.

3.1 Conceptual framework

The main approach used to identify adaptation strategies that can be implemented by smallholder farmers in Kiambu and Kajiado was the adaptation turning point approach (Figure 4). In this approach, the first three steps have set the scene, and assessed the objectives that are to be achieved by adaptation. The fourth and fifth step determined what adaptation measures are most suitable to adapt smallholder horticulture to climate change, and what strategy these measures should form in order to deal with the existing uncertainty. The turning point approach was expanded by the pathway approach in its last phase. This chapter will elaborate on all terms that give body to the research methodology.

3.1.1 Adaptation

According to Smit & Wandel (2006), "adaptation in the context of human dimensions of global change usually refers to a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity" (p. 282). Specifying this to adaptation to climate change, the Intergovernmental Panel on Climate Change (IPCC, 2014) uses the following definition: "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (p. 5). The IPCC (2014) definition of climate change adaptation was used in this research.

3.1.2 Adaptation turning point approach

The turning point approach is developed to support long term adaptation planning. Turning points are determined to indicate specific moments in the future at which current socio-political objectives or preferences cannot be met. Hence, turning points indicate when current management strategies may fail, and other management is needed (Werners, 2013). The adaptation turning point approach is often applied in technical systems, where thresholds are clearly identifiable. Identifying the timing of thresholds and attributive pathways can be more difficult for social–ecological systems. However, the turning point approach is proven to be successful as a communication tool in (water) related strategy development programmes (Werners et al., 2013).

Werners (2013) introduces a stepwise structure in which the assessment of adaptation turning points and adaptive responses can take place. This research was done according to these steps, illustrated in Figure 4. In step 1 to 3, the research target, the potential impact of climate changes and the socio-political objectives of concern were identified respectively. Step 1, 2 and 3 can be seen as preliminary research objectives in this case, since the focus was on step 4 and 5. In these last steps, the actual measures to increase climatological resilience in Kenyan smallholder horticulture were identified and translated into an action plan.

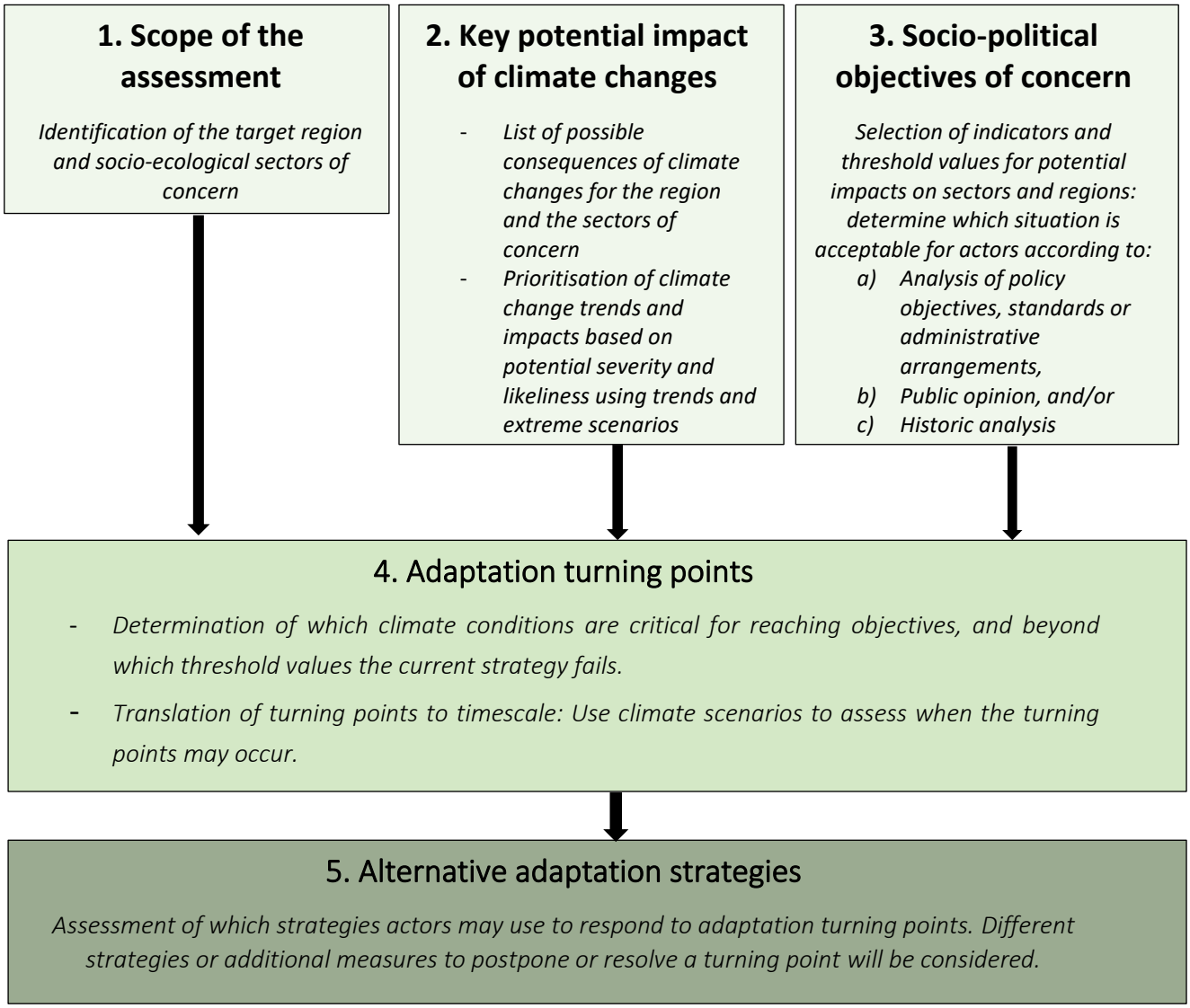


Figure 4 Stepwise structure for the assessment of adaptation turning points and adaptive responses based on Werners (2013)

3.1.3 Pathway approach

Climate change adaptation planning is inherently uncertain. This uncertainty will not diminish by gathering more information, but it will only reduce as time unfolds. In long term planning, large scale investments, it is therefore recommended to incorporate flexibility where possible. The pathway approach tackles part of the uncertainty by incorporating progressive implementation of adaptation measures in the adaptation strategy. The necessary short term actions are taken to sustain the current system, and options are kept open to plan longer term activities and more fundamental system changes later, if that appears to be needed (Werners et al., 2013). Besides uncertainty on the behaviour of the future climate, the pathway approach made it possible to deal with some uncertainties that were the result of generalization in this research.

3.2 Study region

This section elaborates on the study region that was already briefly introduced in the introduction. As mentioned, Kiambu and Kajiado counties experience quite different climates. Moreover, differences in climate are experienced within both counties. To generate spatial differentiation in the analysis and eventually in the advice, two different agro-ecological locations were selected within each county (Figure 5). These rather opposite agro-ecological locations were chosen to represent both ends of the spectrum regarding the climates present within both counties. 'Wet' and 'dry' in the names of the locations represent a relative humid, cool and an arid, hot area respectively. This section elaborates on the demographic differences between both counties, and on the climatic differences between the four selected locations.

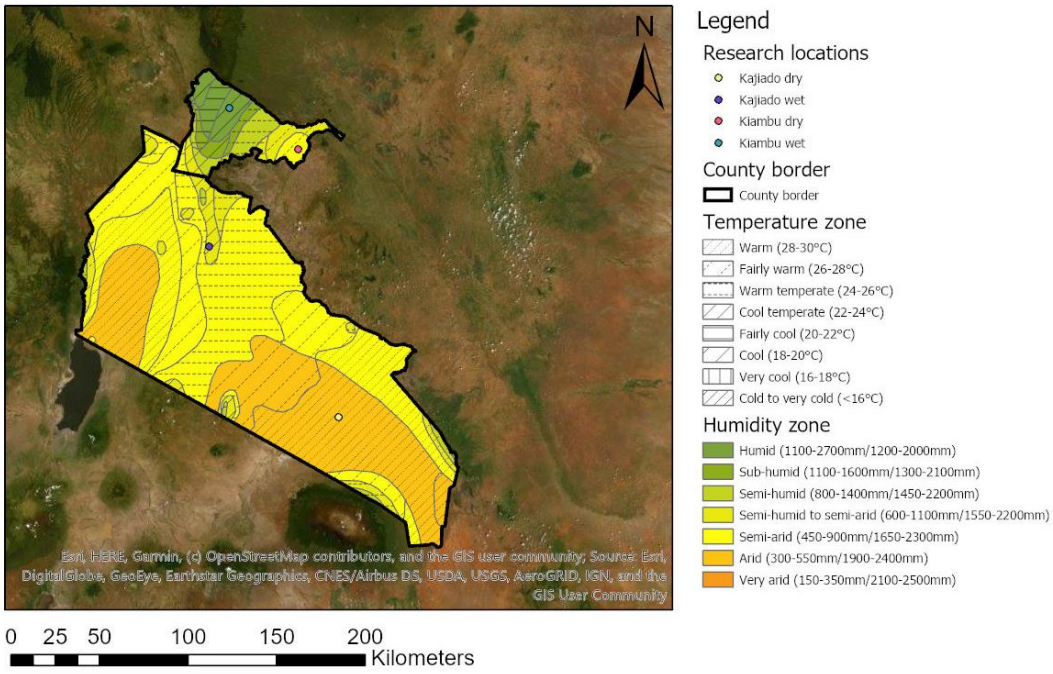


Figure 5 Agro-climatic zones in Kiambu and Kajiado counties

3.2.1 Kiambu

Kiambu county is located in the centre of Kenya. With an area of 2,543 km^2, it is a lot smaller than its Southern neighbour Kajiado. Housing 2,676,945 people in 2017, its population density was 1052 heads per square kilometre. Topographically, Kiambu county can roughly be divided in the Upper Highlands, Lower Highlands, Upper Midlands and Lower Midlands. (County Government of Kiambu, 2019a)

Kiambu wet is located in the Upper Highlands in the Northeast of Kiambu county. This area is relatively wet and mountainous and is therefore considered as an important catchment area for water provision. Kiambu dry is located in the Upper Midland. Compared to the fertile volcanic soils in the Upper Highlands, the Upper Midlands have to deal with lower soil fertility. The shallow sand and clay soils are prone to erosion, and do not hold a lot of water. (County Government of Kiambu, 2019a)

3.2.2 Kajiado

Kajiado is a large county stretching from the South border of Kiambu to the Tanzanian border. It covers 21,901 km^2 and has been home to about one million people in the year 2017. This means that at that time, the population density of Kajiado county could be estimated at around 46 heads per square kilometre. (County Government of Kajiado, 2019a)

The main physical features of Kajiado are wide plains, valleys and volcanic hills. Overall, Kajiado county is water stressed. The herding Maasai community is native to the Kajiado plains, living from extensive dairy and beef production. Economic development takes place by investments in agriculture, horticulture, livestock production, poultry farming and other commercial exploits. (County Government of Kajiado, 2019a) Kajiado dry is located at a lower altitude compared to Kajiado wet, where it is dryer, warmer and vegetation cover is limited. Table 1 presents the main climatological features of the four selected locations.

Table 1 A comparison of annual mean precipitation (P), potential evapotranspiration (ET_{pot}) and temperature (T) in the four research locations

	Latitude	Longitude	Elevation (m.a.s.l.)	Humidity zone	*P (mm/year)*	*ET_{pot} (mm/year)*	*T (°C)*
Kiambu wet	0° 57′ S	36° 46′ E	2117	Humid	1100-2700	1200-2000	22-24
Kiambu dry	1° 09′ S	37° 07′ E	1488	Semi-arid	450-900	1650-2300	26-28
Kajiado wet	1° 39′ S	36° 40′ E	1713	Semi-humid/semi-arid	600-1100	1550-2200	22-24
Kajiado dry	2° 31′ S	37° 20′ E	1129	Arid	300-550	1900-2400	28-30

3.3 Methods

3.3.1 Interviews

A three week field visit was conducted in September 2019. Smallholder farmers in Kiambu and Kajiado were interviewed during multiple farm visits (Table 2). Besides, interviews with agricultural extension officers and experts from different fields relevant to agriculture were conducted. All interviews were qualitative, with the aim to draft a general insight in the status of (climate change adaptation in) smallholder horticulture in both counties researched.

Interviews during initial farm visits were informal and conversational, focusing around their current agricultural practices and their perception of climate change. According to Gall et al. (2003), these interviews build "…entirely on the spontaneous generation of questions in a natural interaction, typically one that occurs as part of ongoing participant observation fieldwork" (p. 293).

Later, in-depth, standardized, semi-structured interviews were conducted with a selected group of farmers. These interviews were based on observations made during the initial farm visits. These interviews were focused on climate change adaptation potential and willingness to adapt. Standardized, semi-structured here implied that all respondents were asked exactly the same questions, but they were free to provide as much information to those questions as they personally preferred (Gall et al., 2003). Optional follow-up questions were asked if the respondent touched upon relevant issues that needed further explanation. These semi-structured interviews were recorded for further analysis.

Table 2 Overview of farm visits and extension officer interviews per county

	Farmer		**Extension officer**
	Orientational farm visit	Of which in depth interview	
Kiambu	8	4	1
Kajiado	5	2	2

All farmers were selected by the local extension officers. This might have influenced the representation of the farmer community in both counties. However, it was assumed that farmers represent 'average' farmers from their county. The farmer interviews can be found in Appendix 1.

In both Kiambu and Kajiado, agricultural extension officers were interviewed with the aim to validate the outcomes of the farmer interviews. These extension workers were selected within the 3R project because of their personal interest in the topic of climate change adaptation in horticulture. Since they are supervising a large farmer community, they were able to provide a broader insight in the status and opportunities in horticulture farming in their respective counties. The semi-structured interviews questions discussed can be found in Appendix 1.

Semi-structured interviews were conducted with experts from different disciplines including soil and water engineering, water resource management and water research (Table 3). The interview outlines can be found in Appendix 1.

Table 3 Overview of experts interviewed, and their respective institutes

Name	Institution
Mr. Nyangua	Water Research and Resource Center (WARREC) at Jomo Kenyatta University of Agriculture (JKUAT)
Prof. Gathenya	Department of Soil and Water Engineering at Jomo Kenyatta University of Agriculture (JKUAT)
Mr. Mwaniki	Water Resource Authority Kenya (WRA)

The information gained during the field visit was supported by the analysis of previous field visit reports by CAS, and by scientific literature.

3.3.2 Literature analysis

An analysis of the scientific literature was the main source of information for results on three topics in this research. First, it was used to create an initial list of potential climate change adaptation measures to take into the multi-criteria analysis. In this literature research, focus was on obtaining a list of adaptation measures that have proven to work in comparable circumstances. Case studies from scientific literature are selected based on socio-economic context (developing country), climatological circumstances (semi-humid, semi-arid, arid) and current agricultural practices (open field agriculture and horticulture, mainly for subsistence). Second, scientific literature was used to validate interview results on crop information. Third, information on crop development and its boundary conditions was gathered from scientific literature. This information was used to give insight in the effect of climate change on crop growth, and to eventually identify turning points.

3.3.3 Multi-criteria analysis

All selected potential adaptation measures were used in a Multi Criteria Analysis (MCA), to assess the relative suitability of each measure within the local context. An MCA helps decision-making by including a full range of environmental, economic, technical and social criteria that cannot be easily quantified (Gamper & Turcanu, 2007). The relative measurement of criteria took place based on quantitative analyses where each measure was scored according to its functioning on different criteria. Effectiveness, side-effects, economic efficiency and level of organisation were selected based on Mendizabal et al. (2015) to develop the concept version of the MCA framework. Each of these criteria consists of several sub-criteria. The concept set of (sub-)criteria is at the basis of the MCA scoring, but was first discussed, expanded and validated by local (horticultural) experts in a group discussion. The final full MCA framework resulting from the group discussion can be found in Appendix 2.

Scoring of the MCA, as well as the weighting of the four main criteria in the final outcome of the MCA was determined based on expert knowledge, and results of the interviews. Since agricultural extension workers have on-the-ground knowledge on horticultural performance and farmer decision making, they were involved in scoring of potential measures in terms of their co-benefit, time horizon and executive party. Farmers, just as the agricultural extension officers, were invited to give their individual weighting to the listed criteria. The final MCA scoring was validated by an expert on climate change and horticulture in Kenya.

The weighting and scoring applied by researchers will have an impact on the final outcome of the MCA. To deal with the impact of uncertainty in the MCA scoring and weighting, a sensitivity analysis was executed in DEFINITE (version 3.1.17; Janssen et al., 2006). When slight variations of the initial measure scoring or criteria weighting result in considerable changes in the MCA ranking, it is stated that scoring and/or weighting are sensitive to the examined parameter. In order to deal with this

influence, the sensitive parameter should be determined very accurately or the scoring or weighting should be altered to reach lower sensitivity (Simanaviciene & Ustinovichius, 2010).

The scoring that results from the MCA gave insight in which measures are more suitable to enlarge climatological resilience of Kenyan smallholder horticulture than others. Taking the result of the sensitivity analysis into account, the top measures were taken into further consideration in the research.

3.3.4 Climate data analysis

To assess the impact of climate change on horticultural crop growth conditions, data were analysed for crop water requirement (CWR), temperature (T), precipitation (P) and runoff (R) using Excel. All analyses were done for two representative concentration pathway (RCP) projections that represent two levels of future climate change. Emissions in both scenarios are based on radiative forcing values of 4.5 and 8.5 W/m2 to be reached by the end of this century (van Vuuren et al., 2011). RCP4.5 and RCP8.5 were chosen to represent the impact of climate change in the least extreme scenario (achievable) and the most extreme scenario. It is very likely that the actual impact of climate change is within these two boundaries. The models used in all analyses are IPSL-CM5A-MR, HadGEM2-ES, MPI-ESM-LR. In a preliminary study in the 3R project, these models were found to be most accurate for the region of interest. For all analyses, the upcoming century was divided into three time periods being early century (2011-2040), mid-century (2041-2070) and the end of the century (2071-2100). Historical data on all parameters between 1981-2011 were used as reference data. Sources used to extract data from are presented per variable in Table 4.

To all variables applies that interannual trends were studied. Monthly data was analysed in most cases because the trends were applied to the crop growing seasons that do not cover more than 6 months. Only for the temperature analysis, daily data was used to assess the number of days per growing season on which the temperature is unsuitable for crop growth.

Monthly CWR was calculated according to guidelines by the Food and Agriculture Organisation of the United Nations (FAO) (Allen et al., 1998). In these calculations, CWR is calculated on the basis of two factors. The climate variable *potential evapotranspiration* (ET_0) depends on minimum temperature (T_{min}), maximum temperature (T_{max}), relative humidity (RH), sun hours (SH) and windspeed (WS) on the research location. Crop factor K_c depends on the crop type and the development stage it is in the moment of interest. In establishing K_c, it is assumed that crops are not irrigated. To analyse future CWR, future projections of the parameters were used that construct the climatic variable. The analyses of the other variables (T, P and R) were based on direct data from various sources.

Table 4 Overview of the data sources used in data analyses

Climate variable	Time scale	Data source
Crop Water Requirement	Monthly	
Maximum temperature (T_{max})		SMHI Hypeweb
Minimum temperature (T_{min})		SMHI Hypeweb
Relative humidity (RH)		NASA POWER Data Access Viewer (hist), SMHI Climate Data Interface (proj)
Windspeed (WS)		NASA POWER (hist), SMHI Climate Data Interface (proj)
Sun hours (SH)		NASA POWER (hist), SMHI Climate Data Interface (proj)
Temperature	Daily	
T_{mean}		Copernicus Data Store, era5 (hist), ISIMIP (proj)
Precipitation	Monthly	SMHI Hypeweb
Runoff	Monthly	SMHI Hypeweb

3.3.5 Validity and reliability

This section describes the methods used to assess upon the validity and reliability of the methods used in this study.

According to Scott & Morrison (2005), "A measure is reliable if it provides the same results on two or more separate occasions when the assumption is made that the object being measures has not changed" (p. 208). For the more qualitative part of this research (being the interviews and the MCA), reliability is likely to be low. Interview responses were especially expected to be depending on the weather of that particular day and season. This effect was minimalized by having farmer responses cross-checked by extension officers. They were assumed to have a more objective view on what plays in their counties, and to less subjectively connect climatic observations to their income and yields. Also, a sensitivity analysis was incorporated into the MCA. This increased reliability. The data analysis part of the research was more reliable, as it is less subjective. If the same data would be used to run these analysis again, outcomes are likely to be the same.

Validity is often split into two categories: internal validity and external validity. Internal validity is described as "The accuracy or authenticity of the description being made … a measure of accuracy and whether it matches reality (p. 253)" (Scott & Morrison, 2005). By having the farmer interviews cross-checked by extension workers and experts, internal validity for the qualitative part of this research is considered to be high. The data analysis part however should be executed with localized reference data to safeguard internal validity. However, doing so would not diminish the uncertainty in climate projections.

External validity according to Scott & Morrison (2005) is "a measure of generalisability (p. 253)". External validity of this assessment is low, but generalization to other parts of the country, continent or world is by any means not the objective of this case study. The methods used are however highly location specific, those can be used in other case studies on this topic.

Both reliability and validity can be enhanced by triangulation (Bush, 2012). In this research, findings are cross-checked with scientific literature where possible.

4. Current farming practices

This chapter provides a concise description of the current horticultural practices in Kiambu and Kajiado counties. These current practices can be seen as the basis from which adaptation to a changing climate should take place. All information presented in this section is based on interview results (Appendix 3) and observations made in the field.

4.1 Current horticultural practices

4.1.1 Land tenure

According to extension workers, a smallholder farmer possesses less than two acres of agricultural land. In Kajiado, it is estimated that the average smallholder plot size is less than one acre. An estimated 8% of all Kajiado's smallholders in that county leases his/her land, while the rest of the farmers privately owns it. No farmers lease land in Kiambu.

4.1.2 Cropping patterns and inputs

Common annual crops cultivated in both Kiambu and Kajiado counties are maize, beans, tomatoes, spinach, kales, cabbage, onion and potato. These crops are mainly cultivated in diversified systems in open fields. Most smallholder farmers in both Kiambu and Kajiado depend solely on rainfall to meet crop water requirements. Therefore, the cropping season starts slightly before or at the onset of the rain season. Both counties have a biannual rainfall regime, giving farmers the opportunity to harvest twice a year. The growing seasons of annual crops cultivated in the counties are displayed in Figure 6. The dark green colour indicates the start of the wet season. This start can fluctuate over the years, potentially starting several weeks earlier or later than indicated below.

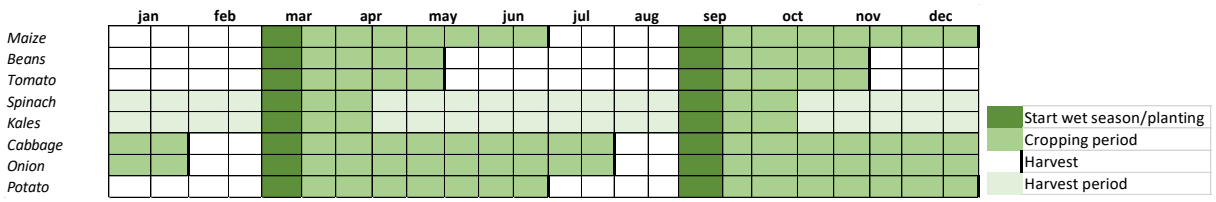


Figure 6 Cropping calendar of main annual crops grown in Kiambu and Kajiado according to smallholder farmers and extension officers. Most crops have a harvest date, after which the field is bare. Some crops have a harvest period, in which the crop remains on the field and only the eatable parts are removed on a regular basis. This is indicated as a harvest period.

In addition to annual crops, banana is also cultivated in both counties. In Kiambu, coffee is another perennial that is widely cultivated, either in large scale monocultures or in mixed agroforestry systems with other tree species like macadamia, avocado, mango and orange.

Farmers who do irrigate their crops, use their extended cropping season to meet high market demand in specific times of the year. Irrigation water is applied to the field either manually, or using a drip irrigation system. Almost all farmers use fertilizers, either organic or inorganic.

4.1.3 Market

In both Kiambu and Kajiado, smallholder farmers cultivate their crops for household consumption. If any, the surplus production of crops (outside the maize and beans production) is sold at the local market. Farmer access to the local market is well established, and farmers have not faced major problems selling their produce. One of the extension officers however mentioned the issue of low quality production, that hampers the farmers from selling their produce to supermarkets instead of local markets. Selling to supermarkets could ensure a higher revenue.

Among the products of the interviewed farmers, organic macadamia and chili are the only ones exported to international markets from middle to large scale farms. At this point, many smallholder farmers are not able to meet export market demands.

4.1.4 Sources of income

Horticulture is often not the only (or main) source of income for smallholder farmers. Especially in Kajiado, farming is often seen as a side-business in combination with fulltime jobs. Domestic horticulture then is strongly focused on household provision. In both Kiambu and Kajiado, a lot of farmers keep cattle for dairy farming on a small scale. Cow manure is used as farm input, and surplus milk is sold on the local market. Other income generators are found in for example running businesses, self-hiring labour or catfish farming.

4.1.5 Main causes of yield gap

The interviewed farmers were asked to select the main constraints leading to a yield gap that apply to their farm. Many selected constraints are of technical nature, like *declining soil fertility* (in erosion prone zones), *pests and diseases* and the *use of low yielding varieties*. *Inappropriate practices under the current climate* was selected as a constraint to optimal yield by all interviewed farmers and extension workers.

In terms of climatological pressures, water shortage in critical times of the year is the main shared burden among all farmers from both counties. More than half of the interviewed farmers also mention high temperatures as a major stress to their crops. Focus however remains on precipitation and its patterns: erratic rainfall, less rainfall, a late onset of the season, and badly distributed rainfall were mentioned to be of main burden to horticulture by the interviewed farmers (Figure 7). This is mainly explained by the farmers' dependence on the wet season. The start of the seasons is highly unpredictable. This has regularly led to failed yields in the past.

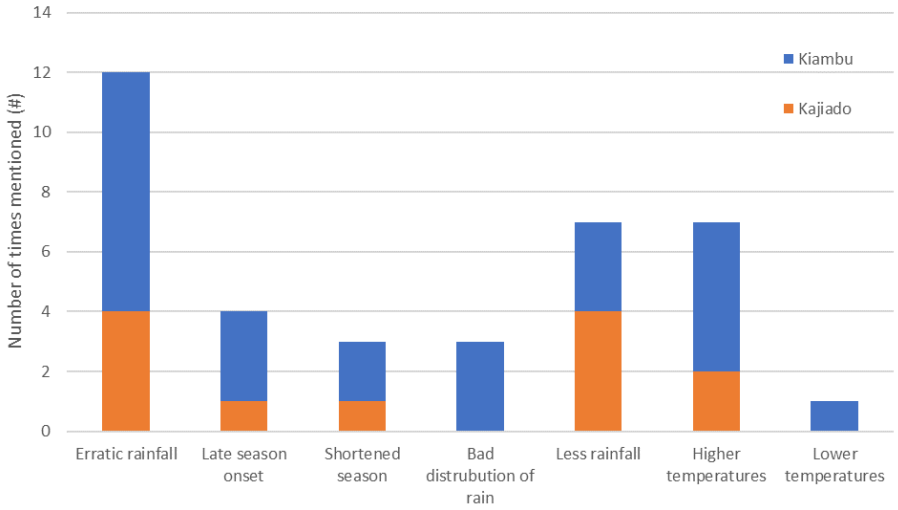


Figure 7 Main climatological constraints to optimal yields in smallholder horticulture according to thirteen interviewed farmers from Kiambu and Kajiado counties

Limited access to credit is mentioned to be a major socio-economic constraint to optimal yield. Also, *formal farmer collectives are not present* in both areas as a result of which farmers miss out on cooperative market opportunities. Both constraints were also pointed out by extension officers.

Only in Kajiado, *inadequate institutions and policies* were mentioned to be a main constraint to optimal yield. In tackling this, farmers and extension workers mention that the focus should be on enforcement of current policies, especially on land use.

4.1.6 Climate change perception

In line with previous assessment on farmer perception on climate changes in Kiambu and Kajiado counties, most farmers interviewed in this study point out a growing water scarcity in critical moments in the season as major environmental struggle (Zwarts, 2018). The timing of rains is crucial in rainfed agriculture, but continues to become harder to predict. Besides, the overall amount of rainfall seems to have decreased. Higher temperatures were perceived by more than half of the farmers. Together with decreasing amounts of rainfall and rainfall being increasingly erratic, it has created farmer awareness of the need to adapt to climatological circumstances.

4.1.7 Soil and water conservation measures adopted

As mentioned above, Kiambu county is relatively wet compared to Kajiado. However, farmers in Kiambu appear to have adopted more, and a more varied package of soil and water conservation (SWC) measures compared to those in Kajiado. This section describes the results of interviews with extension workers. They were asked to make an estimation of the adoption of SWC measures in their counties.

Common practices seen in Kiambu besides crop diversification and the cultivation of climate tolerant varieties are rainwater harvesting and storage for irrigation, mulching, pit cultivation, terracing and agroforestry. In Kajiado, most smallholder farmers have diversified their crop production and cultivate climate tolerant varieties, but only harvest and store rainwater for domestic use. Only mid-scale farmers (> 10 acres) use deep boreholes to provide water for irrigation.

Education on the use of on-farm measures like pond excavation, mulching and pit cultivation has enabled an approximate 25% of the horticulture farmers to adapt their farms to climatic extremes. Another 37,5% is in the process of implementing a few measures, while the last 37,5% (according to the extension worker in charge in Gatondo sub-county (Kiambu)) does not act to deal with climatological stresses at all. The relative large share of estimated non-actors can mainly be attributed to ignorance.

Around 15 years ago, agroforestry has been actively promoted as means to deal with smaller plot sizes and degradation of agricultural soils. Main incentive of adoption of agroforestry could hence be assigned to its potential to increase farm productivity. Although this increase in farm productivity as well might be induced by the newly created micro-climate in which favourable conditions are created for crop growth, farmers did not consciously increase farming resilience to climatic stresses. However, climate variability is a relevant issue for farmers to deal with in both counties, and SWC (including agroforestry) is experienced as a successful way to deal with extremes and climate variability. Farmers that adopted a series of SWC measures feel confident about their yields not being affected by climate change in the future. The local extension worker knows that farmers will continue to adapt if it turns out to be needed.

In Kajiado (Kitengela ward), extension officers estimate around 10% of the horticulture farmers to have adopted SWC measures. According to local extension workers, this relatively low number can best be explained lack of financial resources, fear of the future (for example, irrigation is not adopted because people are afraid to exhaust water available for domestic use) and lack of knowledge. Besides, horticulture is not main income generating activity in most livelihoods, resulting in lower investments and efforts.

Farmers that implement measures on their farm did so to i) reach bigger markets, or at most to ii) manage current climatological circumstances, being highly variable temperatures and water availabilities. Some however did not even realize that these measures could induce climate proofing of their farm. Long term climate planning is not incorporated in their practices.

4.1.8 Access to credit

This section treats the smallholder farmer's view on access to credit. All information is based on their personal knowledge. They base their decisions on this information. Therefore, the economic systems mentioned by smallholder farmers are taken into account in this research.

Credit for farm investments mostly comes from farmers' personal savings. Often, these savings are not big. In that case, farmers can try to get a loan at different institutions or organisations. Commercial banks provide loans, but the application process is tough and the interest is high. Locally, Savings and Credit Co-Operative (SACCO) societies are active and provide loans against the relative low interest of 1% a month.

A more informal way of gaining access to credit, used by farmers is the so called *table banking*, managed by an informal farmer group. Farmer's in Kiambu are able to lend up to 50,000 KES that should be paid back within 18 months. Under certain conditions, this amount can be raised after 3 months of paying back. A local women's group in Kajiado also provides loans on this similar informal level. Farmers however struggle to pay back their loan in the set time frame. In that timeframe, it is impossible for them to get a second loan. Since loans are mainly used to overcome tough times (for example to buy cattle feed during drought), it is difficult to find ways of getting an extra loan to invest in future proofing the farm. One of the interviewed farmers also mentions to have never tried getting a loan, because it is assumed to be too difficult.

By five out of eight interviewed farmers, limited access to credit is felt to be one of the main constraints in achieving optimal yields. However, all interviewed extension officers mention that farm investments (in climate change adaptation and beyond) do not require a lot of resources. Only for 15-20% of the farmers in their counties, it is argued to be a matter of lack of financial resources. Most farmers seem to have formed the (false) preconception of not being able to pay for SWC measures. This misunderstanding results in farmers sticking to their traditional practices. Education on affordable opportunities would enable them to act.

4.1.9 Farmer organisations

In both counties, farmers have not established themselves in formal farmer collectives. Instead, farmer collectives are present in the area in the form of informal groups. According to one of the farmers from Kiambu, previous attempts to set up a formal farmer collective failed due to mistrust among farmers – especially regarding finances. However, being part of a farmer group could help farmers gaining easier access to funding, higher quality farm inputs and reaching a bigger market. The Kiambu extension officer supports this by stating that being part of a farmer group could help farmers reaching a bigger market by providing a collective yield that is stable in terms of quantity and quality. Moreover, their collective negotiation power would be stronger compared to that of a single farmer, enabling farmers in a formal collective to receive a higher price for the products sold. Besides, a formal farmer collective would enable farmers to eliminate the 'middle man' (broker), thereby saving extra money. This would also apply to farmers in Kajiado county. There, one of the farmers mentioned lack of common objectives as a reason for the absence of formal farmer collectives. Smallholder horticulture in Kajiado is not as widely spread compared to Kiambu because of relative unfavourable climate conditions. This could explain the lack of community co-support in for example setting up a formal farmer collective.

For extension officers, the existence of (semi-)formal farmer groups in their counties would bring them easier access to the farmers in the distribution of information from the government.

4.1.10 Government support

As mentioned, Kenyan governance has been decentralised to county level since 2013. The lowest level of governance is the ward level. The Ministry of Agriculture enforces regulations and implements programmes through these three levels.

In Kiambu county, governmental support to the horticulture sector is provided in the form of programmes and installation of technologies. To qualify for receiving a programme that involves new technologies like the excavation of a water pan, sub-counties or wards identify and nominate the location in their area that is likely to be most vulnerable to drought. The county government then selects a pre-set amount of locations, depending on their budget. Agricultural extension services are offered in a demand driven manner on ward level.

The two agricultural training centres in Kiambu county are under the responsibility of the county government. Demonstrations and trainings on sustainable farming practices ought to be planned regularly. However, poor management led to minimal use of the centres. Kajiado county has a demonstration farm for trainings. However, these are mainly targeting the livestock keeping community from pastoralist areas. The functioning of the crop section of the demonstration farm has deteriorated.

The Kenyan Meteorological Department (KMD) provides seasonal forecasts at county level. These seasonal forecasts are distributed via agricultural extension officers in the counties. Besides directly used for season planning by farmers, the KMD seasonal forecasts are also used by the Agrovet. Based on this forecast, the seed supplier distributes particular seeds that are well adapted to the locally projected circumstances each season.

4.2 Synthesis

Smallholder farmers in both counties farm mainly for their own consumption. Only surpluses are sold on the local market and provide an income. Horticulture is rarely prioritized as main or only source of income for smallholder households. This might partially explain (low) smallholder investments in their horticulture.

Comparing the two counties, what stands out are the estimated percentages of farmers working on farm level SWC. Based on current climatological pressures, Kajiado seems to be in biggest need of climate adaptation since the climate is dryer and warmer compared to Kiambu, making it less suitable for the majority of horticultural crop cultivation. However, 25 percent of the farmers in the relative wet Kiambu practice a wide range of SWC measures on their farms, while in Kajiado only approximately 8 percent of the farmers does so. According to the Kajiado extension worker, this difference could be explained by the lower dependence on horticulture as (secondary) source of income in Kajiado. Extension workers have explained that since it is relatively hard to farm under the current climate in Kajiado, a lot of people either do not farm at all or only manage a small domestic garden. Managing a domestic farm, inputs and farmer efforts to achieve optimal yields are assumed to be low compared to small or medium scaled farms that sell large parts of their produce on the market.

Farmers that are implementing SWC measures on their farms in Kiambu and Kajiado seem to do so in order to manage current climatological circumstances that they experience to be most pressing, being variable water availabilities. Both the demand from farmers as well as the services provided by the extension office centre around seasonal forecasting. Long term planning around the expected changes in climate does not yet happen. In the future however, the measures currently implemented by the active farmers might not suffice to adapt horticulture to changes in climate. Instead, multiple farmers think to be well equipped to a changing climate. This could be attributed to the tendency of farmers to confuse long term climate change with climate variability. Being dependent on rainfall for their crop growth, their main focus seems to be on timing and duration of the rains, which both are highly variable. Possibly, farmers reflect on the circumstances during the last five to ten years in describing climate change encountered. In these last five to ten years, a lot of other factors could have played parts in determining water availability that are not taken into account (Gathenya, J. personal communication, September 18, 2019). Water availability on farm level might have changed because of other external factors than climate change only. Interview results on farmer's perceptions of climate change should

therefore be validated by a climate data analysis. The rising temperatures noticed by farmers are less directly dependent on external factors.

Farmers are demotivated to invest in climate change (or variability) adaptation due to limited access to credit, weak farmer organisations and low governmental policy enforcement. Although farmers do not seem to consciously adapt to a changing climate, some farmers in Kiambu are well on their way to become resilient to climate variability – which can be seen as a first step towards resilience to climate change.

5. Key potential impact of climate change

This chapter summarizes the results of an explorative climate data analysis on the impact of climatic changes on future crop growth in the four defined agroecological locations. Climate indicators researched are interannual temperature (T), and interannual crop water requirements (CWR) in relation to plant available water (PAW). These latter analyses are executed for all main annual horticulture crops currently grown. Each analysis is run twice to distinguish between the effects of climate change under the RCP4.5 scenario and the RCP8.5 scenario. The future is separated into 3 parts, being early century (2011 to 2040), mid-century (2041 to 2070) and late century (2071 – 2100).

5.1 Average daily temperature

Future trends in average daily temperature are analysed to assess whether current crops can still be grown under a changing climate. As displayed in Figure 8, daily average temperature during the reference period was lowest in Kiambu wet. Temperatures in Kiambu dry and Kajiado wet are the same in the used dataset. Highest temperatures are found in Kajiado dry. The seasonal pattern is the same in all locations. July, August and September are the coldest months, while February, March and April are hottest. A second warm period occurs from October to December.

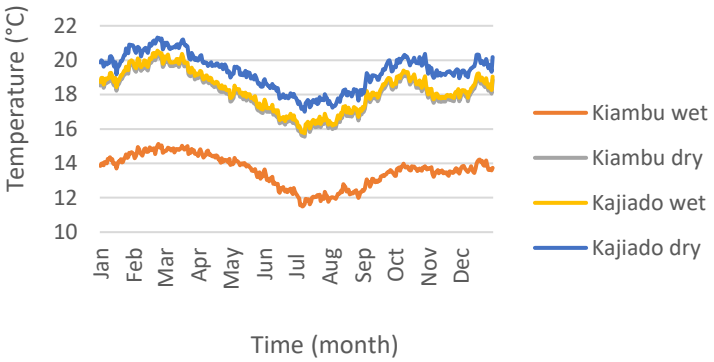


Figure 8 Average daily reference period temperature per research location

According to Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) projections, daily average temperature in all four locations will increase throughout the year (Figure 9). The temperature increase is positively correlated to the reference temperature per season. This means that the higher the current average temperature, the higher the temperature increase. In all locations, the biggest increase in average temperature will occur around April and May, and around November and December. Kiambu



Figure 9 Change in average daily temperature for four research locations according to RCP8.5 compared to the reference period (2001 - 2011)

wet and Kajiado wet will experience the most moderate temperature increases. There, the minimal increase in average temperature during the cooler months is at least 2°C, to be reached by the end of the century. The maximum increase in average temperature in these areas is 6°C. In Kiambu dry and Kajiado dry, the average temperature during the cooler months increases by at least 3°C. During the warmer months, this increase is around 6°C (Kajiado dry) to 7°C (Kiambu dry).

5.2 Plant available water

To analyse whether the crop water requirements are (and will be) met under rising temperatures, a simplified rule to assess plant available water (PAW) is used. It is assumed that all precipitation that is not surficially discharged through runoff, is available for crop evapotranspiration (function 1).

$$PAW_{ET} = P - R \quad (1)$$

In this section, the results of analyses on future precipitation, runoff and PAW are presented.

5.2.1 Precipitation

Projected interannual trends for monthly averages of daily precipitation are shown in Figure 10**Fout! Verwijzingsbron niet gevonden.**. These projections are presented for RCP4.5 and RCP8.5, relative to the reference values. Trends for all four locations are similar, although actual precipitation differs per area.

According to both scenarios, the months October to April will get wetter. This means that both rain seasons will get wetter, including the short intermediate period from December to March. For the March season, the biggest increase is projected to be reached by the end of the century under both RCP4.5 and RCP8.5. At the peak in the September season, RCP4.5 shows a smaller increase than RCP8.5. However, both RCPs project an increase in daily precipitation. Precipitation is highest at the end of the century. During the dry period from January to March, an increase in precipitation is projected by both RCP4.5 and RCP8.5. Again, the biggest increase is projected by RCP8.5, to be reached during the end of the century. The long dry period from June to September does not show consistent trends according to the scenario projections. Only in Kiambu wet, June is likely to receive less rain as compared to the reference period.

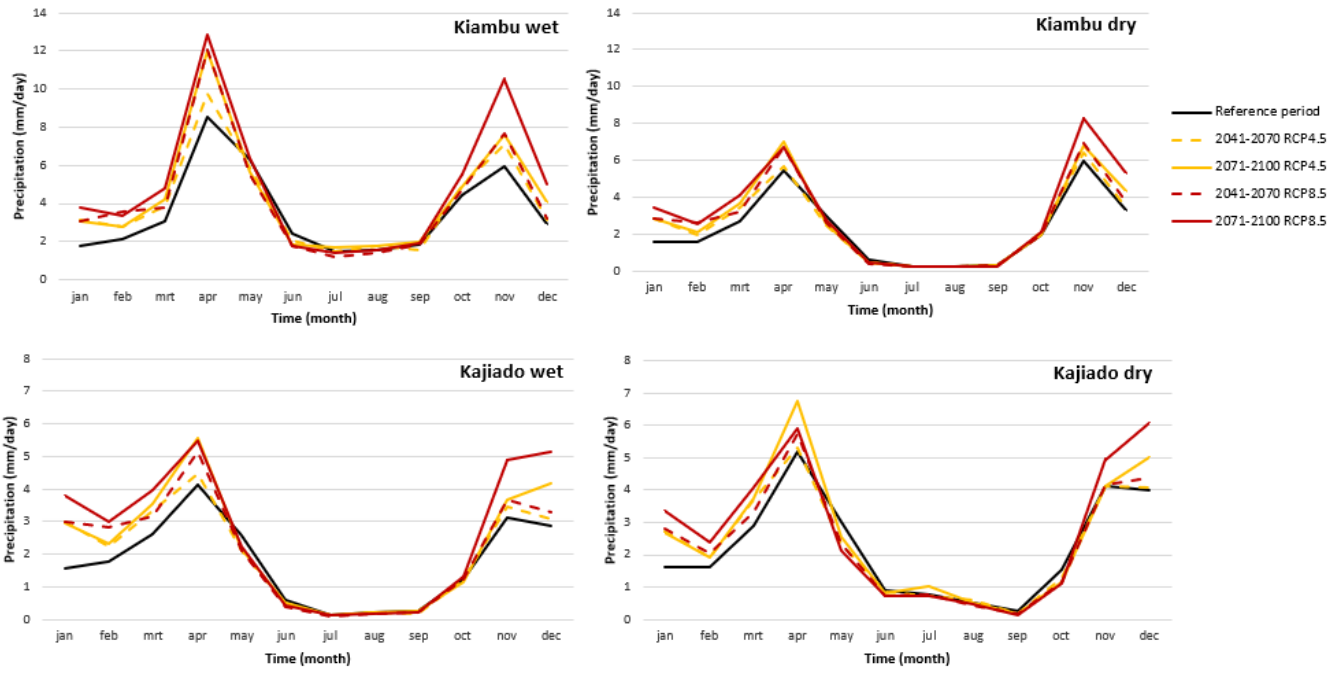


Figure 10 Daily precipitation under RCP4.5 and RCP8.5 for mid and end century as compared to reference period. Note the scale difference between Kiambu and Kajiado areas.

5.2.2 Runoff

As presented in Figure 11, runoff patterns will change similarly for all four locations. Both RCP4.5 and RCP8.5 project an increasing runoff rate in the wetter months. The greatest increase in runoff will take place under RCP8.5, to be reached by the end of the century. Runoff rates will hardly or not change in the long dry period (June to September) in Kiambu dry, Kajiado wet and Kajiado dry. In Kiambu wet, runoff is projected to slightly decrease in June. Runoff during the dry period from January to March increases in all scenarios. This increase is most evident for the RCP8.5, end of the century projection in all four locations. These trends are very similar to those described for precipitation. However, runoff rates increase out of proportion compared to the increase in precipitation.

The runoff peaks starting around April and December increase in size. The April peak doubles (Kiambu wet), or almost triples (Kiambu dry, Kajiado wet, Kajiado dry) in size in the most extreme scenario. The other scenarios also predict an increase in this period. The biggest increase is projected to occur at the end of the century, under RCP8.5 for Kiambu wet, Kiambu dry and Kajiado wet. For Kajiado dry, it occurs at the end of the century under RCP4.5. Similar trends are projected for the December runoff peak.

The April peak does not only increase in size, it also shows steeper slopes that create a sharper peak. Where in the reference period the peak is spread over two months (April and May), projected runoff peaks shows its increase in size mainly (if not only) in April. The May level is close or equal to the reference values. All areas can hence expect more runoff water in less time.

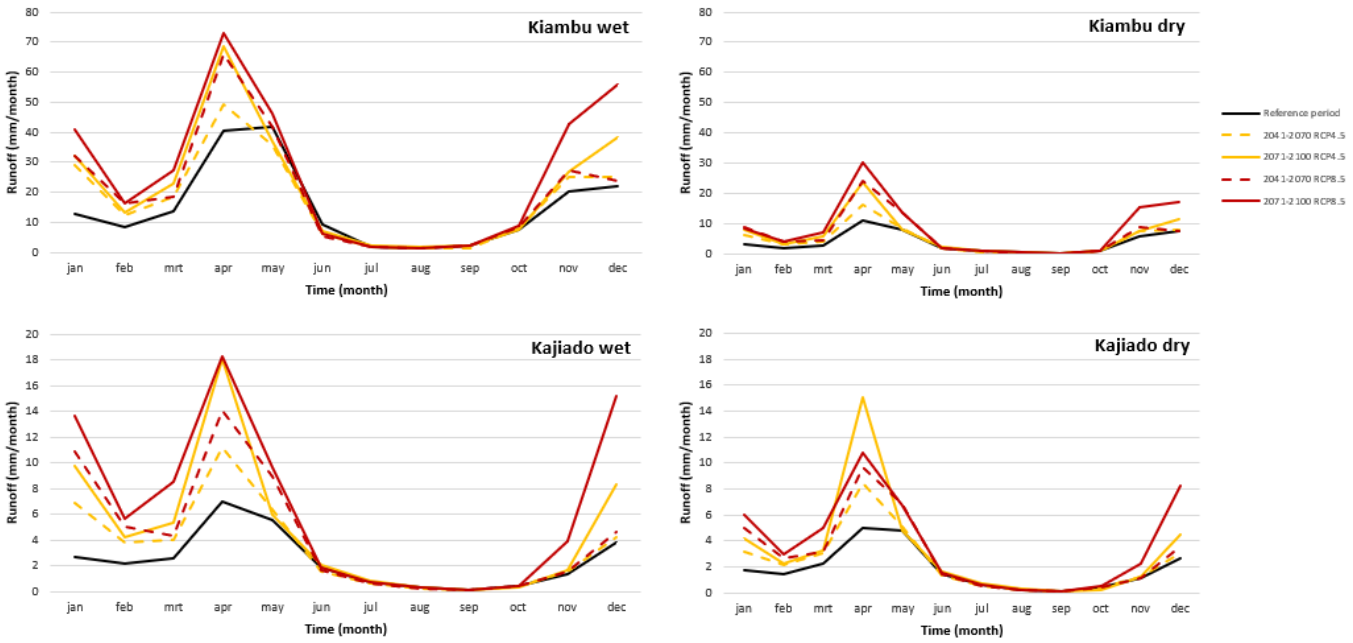


Figure 11 Monthly runoff under RCP4.5 and RCP8.5 for mid and end century as compared to reference period. Note the scale difference between Kiambu and Kajiado areas.

5.2.3 Plant available water (P-R)

Combining the trends for precipitation and runoff results in what is assumed to be the PAW, Figure 12 shows that results are very similar to those shown in the assessment of future precipitation: The long dry period (June to September) does hardly show any trend in PAW. Only in June, slightly less water seems to become available in all areas. This decrease is most evident in Kiambu wet, where absolute PAW values are highest. PAW increases in the period from October to April/May. This means that water available to plant to be used to fulfil crop water requirements will be higher in both rain seasons (cropping seasons) and the short intermediate dry period from December to March. From the second half of April until July, PAW slightly decreases as compared to the reference period. Despite this slight decrease, accumulated PAW increases in both rain seasons.

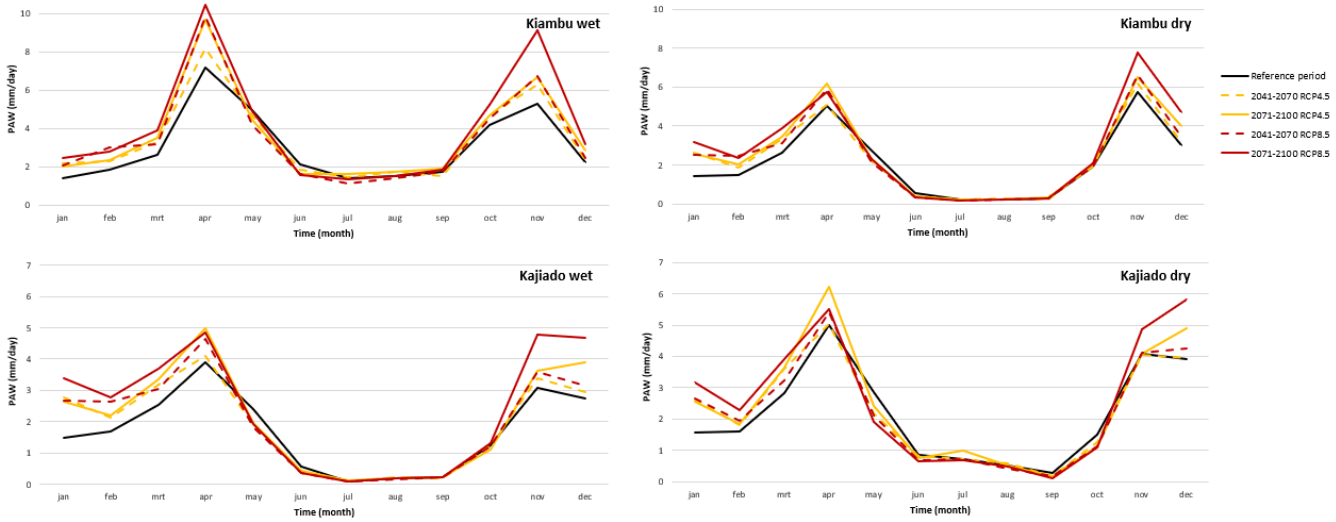


Figure 12 Daily plant available water (PAW) under RCP4.5 and RCP8.5 for mid and end century as compared to reference period. Note the scale difference between Kiambu and Kajiado areas. PAW is defined as P-R.

To all observations described above applies that the trends are most extreme under RCP8.5, reaching their maximum at the end of this century. RCP4.5 projects similar, but more nuanced trends. The difference between different scenarios is most evident when absolute PAW levels are relatively high.

5.3 Crop water requirements

In this section, the future trends in crop water requirements are assessed. Crop evapotranspiration (ET_c) is dependent on temperature. Despite more water becoming available for crop use, water sufficiency is not guaranteed under a rising temperature. Comparing ET_c with the plant available water trends that are presented in the previous section, gives insight in the extent to which crops experience a growing or shrinking water buffer (or deficit).

5.3.1 Principles

ET_c curves are constructed on the basis of the climatic factor daily potential evapotranspiration (ET_0) and a crop factor (K_c) (function 2). The potential evapotranspiration is dependent on the climatic variables minimum temperature T_{min}, maximum temperature T_{max}, wind speed (WS), relative humidity (RH) and the amount of sun hours (SH). The crop factor is depending on the developmental stage of the crop, and provided per decad (10-day period) by Allen et al. (1998). This factor is adjusted to the crop's water reception which in this case study is assumed to be rainfed only in all four locations.

$$ET_c = ET_0 * K_C \quad (2)$$

5.3.2 Projections

In this analysis, ET_0 changes over time according to changes in the climatic variables listed above. K_c stays constant, which results in a similar pattern in ET_c for all different crops. Per location however, slight differences can be observed. In Figure 14, ET_c is displayed per research location for all main horticulture crops cultivated in the research areas. The white areas in the graphs indicate the periods in which the soil is bare.

To all crops in all four locations applies that reference evapotranspiration of annual crops is lowest in the initial growing stage. ET_c peaks during the middle developmental stage and then settles slightly under its maximum in the end stage. ET_c middle and final are higher during the September season, compared to the March season. Patterns of ET_c remain the same in different agro-climatic locations. However, ET_c in Kiambu wet is considerably lower than in the other areas. Crops in Kajiado wet experience the highest ET_c.

The daily ET_c lies within the range of 2 to 8 mm/day for all crops included in this analysis. The length of growth seasons varies among crops. Season length mainly determines the differences in yearly accumulated ET_c (Figure 13). In ETc in the initial growth stage is equal for all crops, because the impact of the crop factor in that period is almost negligible. The soil surface is barely covered by crop canopy, and ET_c hence mainly consists of soil evaporation. Only the climate factor (ET_0) in ETc remains.

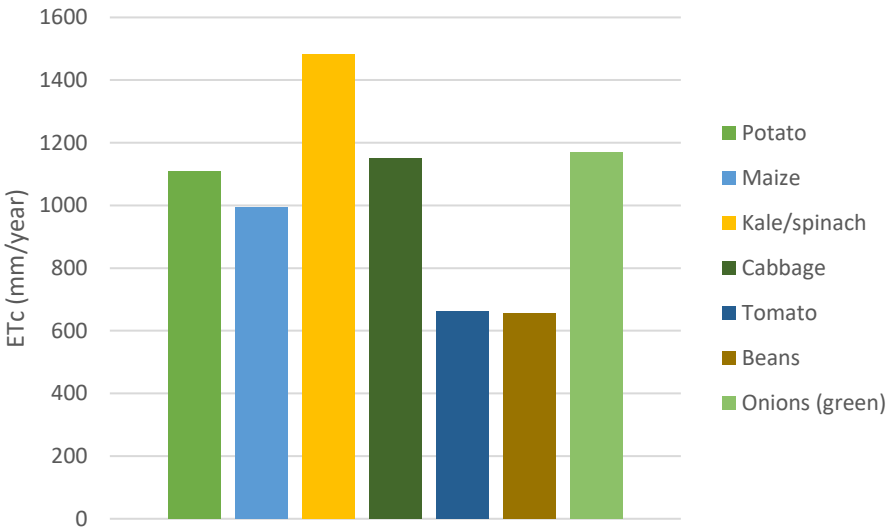


Figure 13 Yearly accumulated water requirement per crop during the reference period in Kiambu wet. The same pattern is observed in other areas

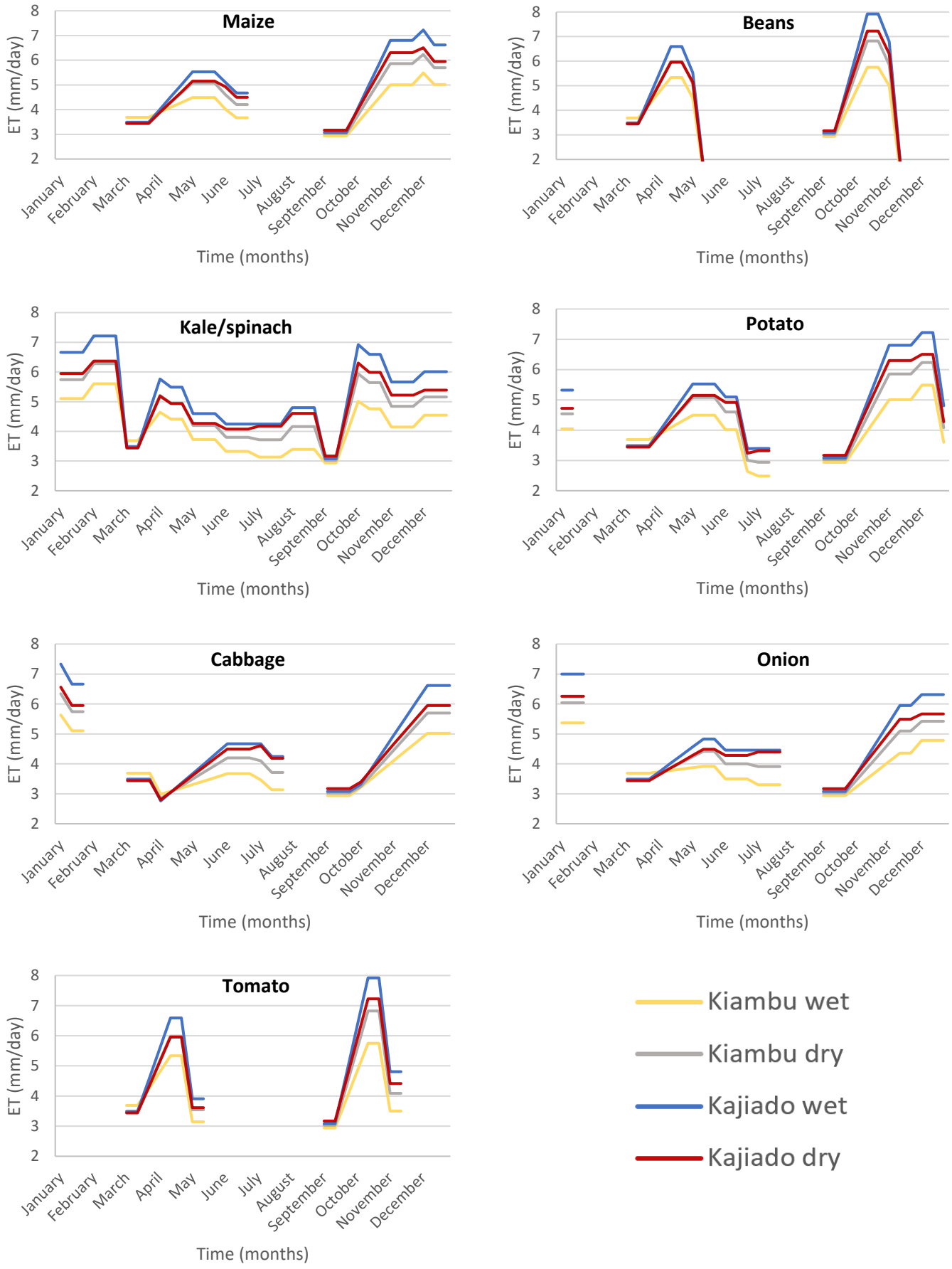


Figure 14 Reference evapotranspiration of all main horticultural crops for the four research locations

Future projections of $ET_{kale/spinach}$ and ET_{maize} are presented in Figure 15. These crops serve as an example, since trends are similar for all annual crops. The earlier described general trend in ET_c remains present in the future projections for all time frames, under both RCPs. The two RCPs however show contradicting projections during the initial growing stage. According to RCP4.5, ET_c is increasing with time. ET_c decreases until mid-century under RCP8.5, to increase to the reference level by the end of the century. In the middle crop development stage, both scenarios project an increasing ET_c over time. For RCP8.5, this increase is greater than the increase under RCP4.5. This trend is also visible in the end stage of crop development.

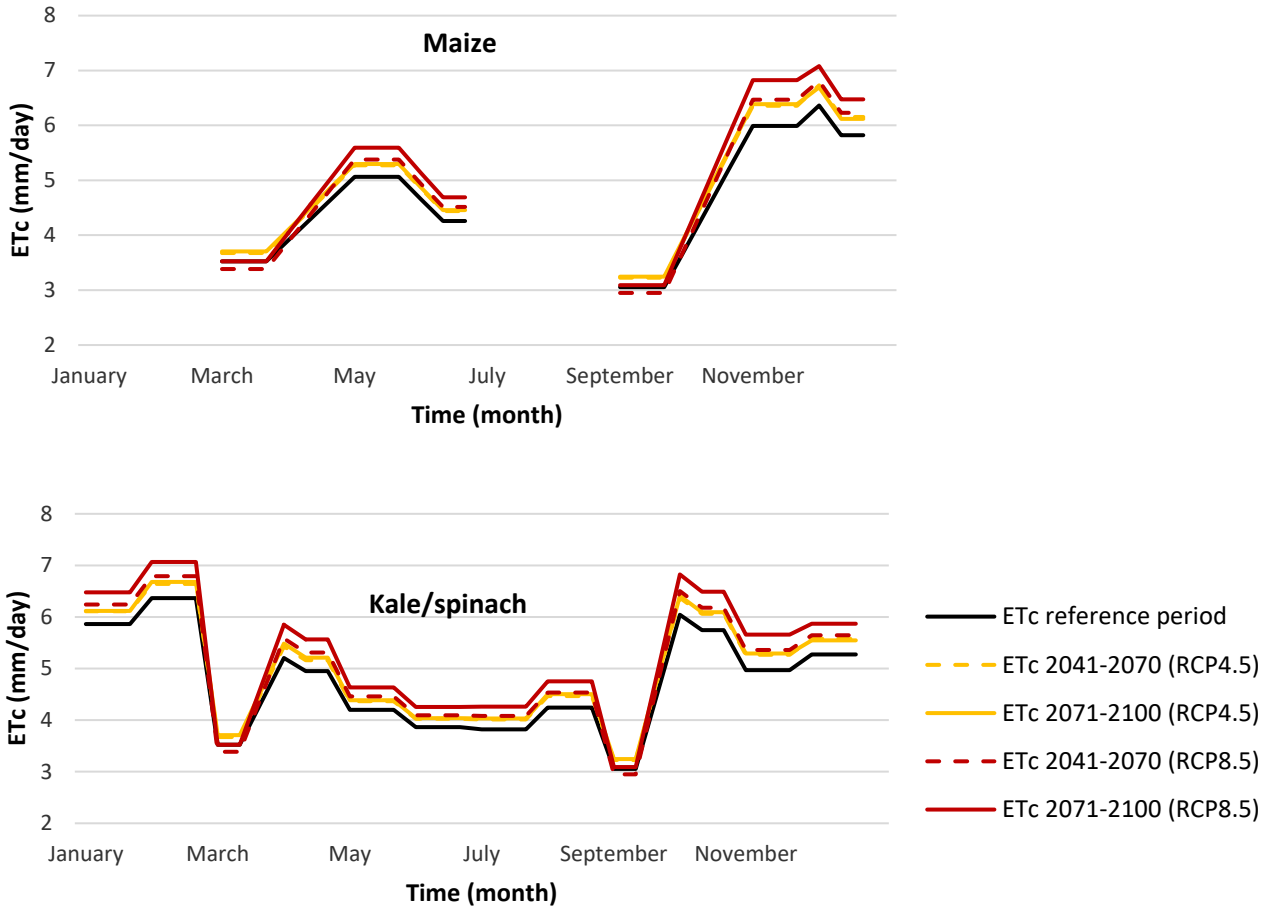


Figure 15 Current and projected ET_{maize} and $ET_{kale/spinach}$ for mid and end century under RCP4.5 and RCP8.5 as compared to reference period. Trends are the same for all four locations. This figure shows the location average.

5.4 Water available for plant growth

Whether the projected PAW will better or worse be able to serve projected ET_c is assessed in this section. Plotting the difference between the two variables, Figure 16 presents the example result for kale. Where results are higher than zero, the water availability after ET_c increases. This implies that the water buffer increases. If the reference situation is that the crop suffers from a water deficit, a value greater than zero means that this deficit shrinks. Where the results are below zero, buffers shrink (or deficits increase).

Results show similar trends for all crops (during their growing seasons) per county (Appendix 4). Comparing the results from different counties, Kiambu dry, Kajiado wet and Kajiado dry show similar trends. There, the water buffer is likely to shrink from January to June, while it is likely to grow from July to December. This is projected by both RCP4.5 and RCP8.5, although RCP8.5 projects more extreme decreases and increases. The biggest changes are projected to occur at the end of the century. In

Kiambu wet, water available to crops after ET_c is increasing in both wet seasons and in the short dry season (January to March). Water buffers are only shrinking in the long dry season (May to September). Again, both RCPs project the same trends, but RCP8.5 shows more extreme results. These are projected to occur at the end of the century.

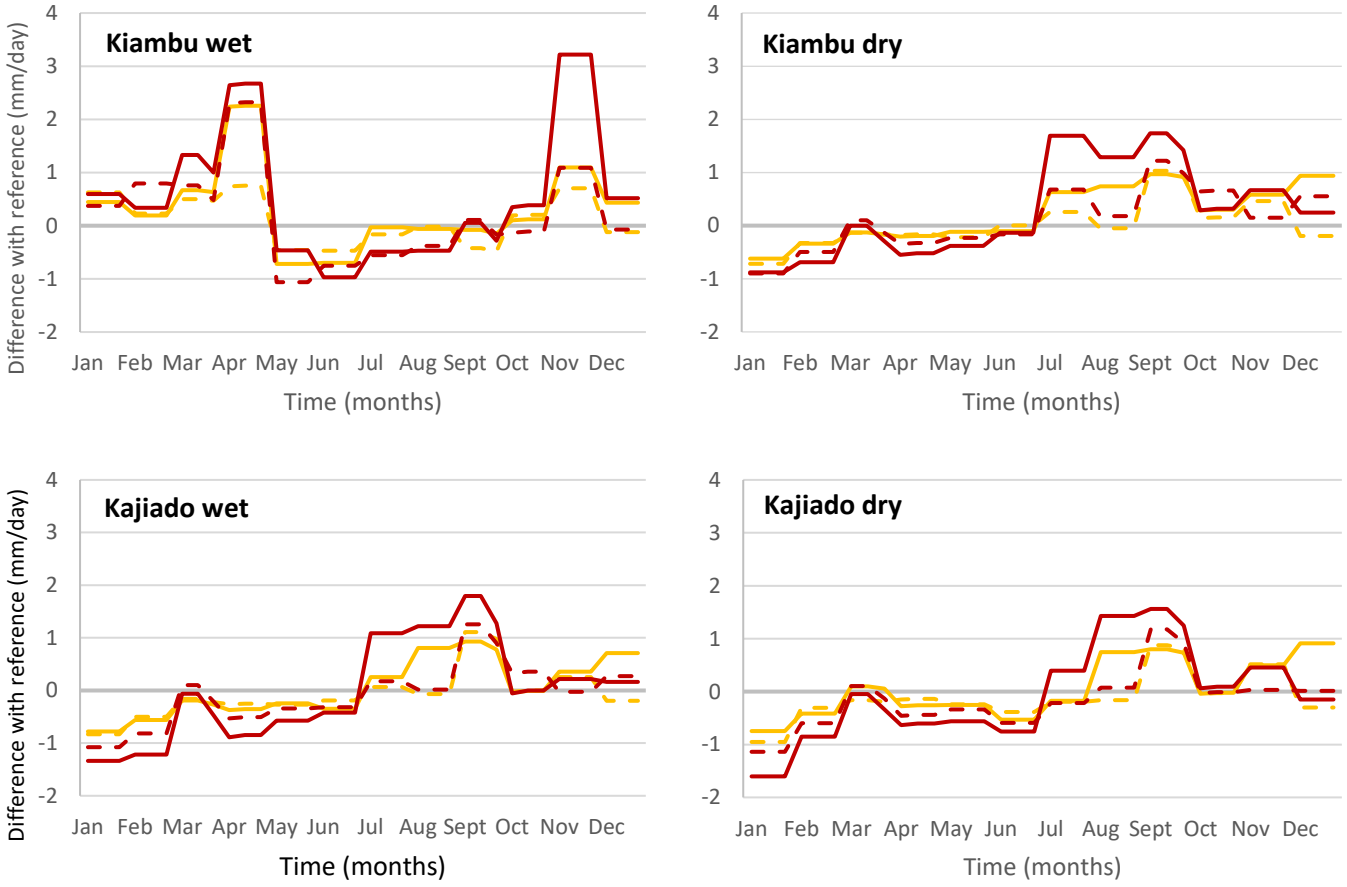


Figure 16 PAW – $ET_{kale/spinach}$ for RCP4.5 and RCP8.5 during mid and end century, relative to reference period. A value > 0 indicates a growing water availability, whereas a value < 0 indicates a declining water availability.

5.5 Synthesis

Precipitation and runoff are projected to increase in the wet seasons and the short dry period (January to March). The increase in runoff is remarkably high, compared to the increase in precipitation. Due to the increase in precipitation, the water that is assumed to be available to crops (P – R) also increases during the wet seasons. Due to higher temperatures projected in mid and end century however, crop water requirements also increase during the entire growing season. During the January to June, these trends result in decreasing water buffers for all crops in Kiambu dry, Kajiado wet and Kajiado dry. From July to December, crops in these areas will experience an increasing water buffer (or a shrinking water deficit). Crops in Kiambu wet experience shrinking water buffers (or growing water deficits) between May and September. Water buffers grow during the rest of the year in Kiambu wet.

6. Socio-political objectives

Adaptation to climate change could support achieving the objectives set in the horticulture sector in Kenya, and in Kiambu and Kajiado counties. Therefore, this chapter briefly treats the objectives set by national and county governments, and moreover the objectives of local small holder farmers mentioned in the interviews. In the last paragraph, a common objective for this research is distilled from all different objectives encountered in policy documents and interviews.

6.1 Governmental policy objectives

The information in this section is largely based on a review of policy documents. The objectives set by the lower level governments (sub-county and ward) are mentioned in extension worker interviews.

6.1.1 National government Kenya

The ministry of Agriculture, Livestock, Fisheries and Irrigation is responsible for Kenyan agriculture, and thus horticulture within the Kenyan government. Their vision is as follows (Ministry of Agriculture, Livestock, Fisheries And Irrigation, 2019):

> "*A secure and wealthy nation anchored by an innovative, commercially oriented and competitive agricultural sector*."

With a slightly different nuance, their mission is stated below (Ministry of Agriculture, Livestock, Fisheries And Irrigation, 2019).

> "*To improve the livelihood of Kenyans and ensure **food security** through creation of an enabling environment and ensuring sustainable natural resource management*."

6.1.2 Kiambu county

The Kiambu county department of Agriculture, Livestock & Irrigation has set their vision and respective mission as follows (County Government of Kiambu, 2019b).

> "*A Healthy, **Food secure** and Prosperous County.*"
>
> "*Promoting sustainable agriculture through capacity building on agricultural productivity, **food and nutrition security**, value addition, marketing, extension and infrastructural development*."

In Gatondo sub-county, where the head of the crop department was interviewed, the vision and mission are is translated into one objective for horticulture:

> "*To increase **food security** at household level in order to increase household income and reduce poverty, and to create employment (for youth)*."

6.1.3 Kajiado county

The vision and respective mission of the Kajiado county Agriculture, Livestock Veterinary Services & Fisheries department are the following:

> "*An innovative and commercially oriented modern agriculture.*"
>
> "*To increase productivity and management by promoting competitive agriculture through improved extension advisory support services, appropriate technology transfer, while ensuring sustainable natural resource management for agricultural development*" (County Government of Kajiado, 2019b).

The main objective of the ward of Kitengela (where crop extension officers were interviewed) on agriculture is stated below.

> "*To make room for commercial income generation, growth of farms into market oriented businesses in which people are empowered.*"

In almost every governmental objective, there is a slight reference to the aim of sector commercialization. These references are underscored in the objectives. However, food security is also high on the agendas of different levels of governance. References to food security are bolded.

6.2 Farmer objectives

This section presents the objectives held by smallholder farmers in Kiambu and Kajiado counties. The information comes solely from interviews.

6.2.1 Kiambu

Smallholder farmers in Kiambu share the general objective of maintaining or expanding current yields. Among the six interviewed farmers, some mention to prefer expanding their dairy business rather than their horticulture. One of the farmers wishes to be able to supply schools and supermarkets with vegetable crops in five years from now. Most farmers however, as confirmed by the interviewed extension officer, have an objective similar to that of the sub-county government of Gatondo. They are first and foremost farming for subsistence, only their surpluses are sold on the market and provide an income. Increasing production would safeguard domestic production and would raise their income from horticulture. Most farmers have additional sources of income that are mostly their main source, so increasing their horticultural production is often not prioritized.

6.2.2 Kajiado

One of the interviewed smallholder farmer, fully reliant on rainfall for farm water supply states that within 5 years from now, he/she will still grow the same amount of food as his/her current produce. He/she believes that his/her land is producing its potential yield under the current climate already. Another farmer wishes to diversify his/her crop supply in the near future. In reaching these objectives, water availability is the main climatological issue encountered.

Most farmers do not share the objective of Kajiado county and Kitengela ward to commercialize their farms, according to both extension officers interviewed. They argue that in farming for domestic use and (if possible) the local market, smallholder farmers fear competition by commercial farms when they would grow their production. Supplying a bigger market comes with a lot more policies and regulations to be met. Commercial farmers already struggle with these regulations, so smallholder farmers remain discouraged and passive. To an even larger extent than farmers in Kiambu, farmers in Kajiado have additional sources of income besides their home garden style of agriculture, so increasing their horticultural production is not prioritized.

6.3 Potential supportive legislation

Smallholder farmers and extension officers are asked to share their vision on what additional government support they need to reach the objectives they mentioned before. The sections below summarize their answers.

6.3.1 Kiambu

According to Kiambu farmers, the price for tank water for the purpose of irrigation should go down (like the water price for domestic use). Another form of government support mentioned is a ban on the cultivation of trees like Eucalyptus, that withdraw water in large quantities. Water availability according to these respondents is the main (if not only) climatological hazard preventing their yields from being optimal.

According to the crop extension officer interviewed, policy and governmental support that could contribute to reaching the county objective could be proper land use planning to prevent natural resources from degrading. Key aspect is the actual enforcement of existing policies. For example, riparian land should not be used for agricultural purposes. Another example is the ban on Eucalyptus

plantations, also mentioned by the farmer. Rules on these examples exist, but are not enforced and thus not complied with.

6.3.2 Kajiado

According to interviewed farmers, the organisation of seminars and trainings is an opportunity for the government to support to the horticulture sector in Kajiado. One farmer observed that government support (in the form of relief aid) has disappeared from the area. In the eyes of this farmer, this could be explained by most government support in Kajiado targeting the Maasai and their cattle farming, since they are the original inhabitants of the area.

The extension officers stationed in Kitengela ward (Kajiado county) mention the high price of inputs for commercial farming as another issue that keeps smallholder farmers from investing in production expansion. The government in the past tried to overcome this by subsidizing fertilizers. However, this offer was not widely used. One of the interviewed crop extension officer thinks that investments need to be made in research to pest resistant crops, since drought resistant crops are widely available and used already. Both extension officers agree on the need for a land use planning policy and its proper enforcement.

6.4 Synthesis

The objectives set by the national and county governments seem to deviate slightly from the objectives of smallholder farmers that are targeted in this research. Where the national mission focuses on nationwide commercializing of the agricultural sector, their vision is focused on improving food security and the livelihoods of all Kenyans. In county visions and missions, main focus is on strengthening the position of agriculture on the market. Even on the lowest level of governance, the objective of Kitengela ward (Kajiado county) is focused on commercialization of agriculture. From information gained during the field visits however, it has become clear that smallholder farmers will very likely not contribute to reaching objectives on commercialization and market strength of Kenyan agriculture. Striving to grow the horticulture sector towards a commercial level in Kiambu and Kajiado seems to be too big of a step at this point.

In the objective of Gatondo sub-county, there is a clear focus on providing food security and improve household income. This objective seems to suit the smallholder farmers in both Kiambu and Kajiado counties best, considering their current practices and challenges. Slightly adapted to the focus of this thesis, the following objective is chosen to serve as general objective in the rest of this research.

"*To increase food security at household level, increase household income and reduce poverty.*"

7. Adaptation measures: Multi-criteria analysis

The establishment of the multi-criteria analysis (MCA) framework is partly done on the basis of observations and expert insight. This chapter therefore starts by introducing the final MCA framework. The measures assessed in this MCA are introduced in Section 7.2. A more elaborate description of adaptation measures that are subjected to this analysis is given in Appendix 5. The scoring and weighting that were applied to this MCA are the results of interviews. Those are elaborated on in Section 7.3. Results follow in Section 7.4, and the chapter will be closed with a brief synthesis.

7.1 Framework

As introduced in Section 3.3.3, the concept version of the MCA scoring framework has four main criteria to which the adaptation measures should be assessed: effectiveness, side-effects, economic efficiency and level of organisation. These criteria are selected from the collective of criteria to assess climate adaptation options presented by Mendizabal et al. (2015). The four main criteria are represented in the scoring framework of this MCA. Each of these consist of several sub-criteria. Part of the mentioned sub-criteria is selected with regard to the socio-economic context of the research target group and the research aims (long term adaptation under uncertainty). This concept set of (sub-)criteria of the MCA scoring is discussed, expanded and validated by local (horticultural) experts in a group discussion at the start of the research. The final version of the framework is presented in Table 5. The matrix used for scoring the criteria can be found in Appendix 6. The following sections will elaborate on the criteria used.

Table 5 Framework of criteria used to score potential adaptation measures

Criteria	*Sub-criteria*	
Cost-efficiency	Return on investment	Short term returns
		Long term returns
	Maintenance costs	
Organisation	Responsible party (level)	
Effectiveness	Time horizon	
	Robustness	
	Flexibility	
	Reducing sensitivity	P decrease (drought)
		P increase intensity (extreme rainfall events)
		T increase (heat stress)
		Erratic rainfall (predictability)
Co-benefits	Environmental co-benefit	
	Economic co-benefit	
	Social co-benefit	

7.1.1 Cost-efficiency

This variable gives insight in the economic viability of adaptation options in terms of their costs and benefits ratio. It is selected to take into account the low adaptive capacity of the target group of this research, and their incentive to invest in climate change adaptation. The lower the costs of achieving

the desired outcome, the higher the cost-benefit. Costs on operationalization and maintenance are also taken into account.

Short term returns (<2 y)

Return of costs refers to the time it takes for the implementor to earn back his investment and operating costs. This could be in the form of income, or other benefits regarding social or environmental capital. Short term returns in this thesis reflect on the profitability of a measure 2 years after implementation.

Long term returns (>5 y)

Long term returns in this thesis reflect on the profitability of a measure 5 years after implementation.

Operating and maintenance costs

Operating and maintenance costs are made to operate a measure after implementation. Costs could for example be related to energy use, service costs or material costs.

7.1.2 Organisation

The organisation indicator gives insight in the processes of organisation and implementation of the adaptation measure. It could for example address the potential feasibility of measures in terms of implementation requirements, implementation responsibility and financing, or the cultural acceptability of newly introduced technologies. This information is mostly interesting in the implementation phase of adaptation, and will determine the success of a measure. Therefore, it is taken into account in this MCA.

Executive party

The executive party – the one responsible for implementation – can range from the smallholder farmer to the national government. It indicates the institutional, or collective efforts needed in successful implementation and operationalization of adaptation measures. Again, this sub-criterion is selected to take the socio-economic background of the research target group into account. Since the aim of this research is to mobilize smallholder farmers, it is considered most optimal if the individual household can implement and operate a measure without external support or approval. Scoring is based on this prerequisite.

7.1.3 Effectiveness

The effectiveness variable describes the extent to which the measure actually contributes to climate change adaptation after its implementation. The sub-criteria chosen reflect the time horizon of the measure becoming effective, its functioning in adapting the current situation to future climate change, and its functioning under different climatological scenarios. The first two sub-criteria are selected to assess the actual performance of the adaptation options in realizing adaptation of the horticultural practices to a changing climate. The latter two sub-criteria are accounting for uncertainty in climate scenarios and socio-economic developments.

Time horizon

Time horizon refers to the time it takes for a measure to start being effective. The chance of a measure to be successfully implemented and operated by a smallholder farmer is expected to increase with shorter time horizons. Short time horizons hence score high in this MCA.

Reducing sensitivity

Sensitivity assesses the nature and degree to which a system is adversely affected by climatic variations. Climate change adaptation aims to reduce this sensitivity. The sensitivity of the horticultural system to the most important climatic pressures to horticulture was assessed in this MCA. These pressures are formulated by the 3R team as listed below.

- Heat stress

- Drought
- Extreme rainfall events
- Erratic rainfall (lower predictability in terms of timing)

Robustness

The robustness of a measure reflects on the extent to which a measure achieves its objectives under different climate scenarios. A no-regret measure is most optimal, since their (indirect) consequences are cost effectively achieving objectives under current climate conditions. Moreover, no-regret measures achieve their objectives in situations in which uncertainty surrounding future impact does not allow for improving policy responses.

Flexibility

The flexibility of a measure indicates whether a measure could be easily adapted to different scenarios (climatic or socio/economic). Adapting in this sense would imply that the measure could be adjusted, or implementation could be incremented in terms of magnitude if conditions change of if changes appear different from those we expect today.

7.1.4 Co-benefits

This variable refers to effects of the measure outside of its main target domain. These effects can be positive, being beneficial to other objectives which were not targeted in the first place. However, they can also be negative. The criterion is regarded in this MCA to include a measure of increased (smallholder farmer) incentives to adopt the proposed adaptation measure, outside the on-farm climate change adaptation domain. Besides, it is used to assess potential harmful implications of using the adaptation options that could outdo the positive effect of the adaptation on the long term. This MCA regards the social, economic and environmental policy domains.

7.2 Measures assessed

A list of potential climate change adaptation measures (Appendix 5: Folder with potential adaptation measures) to take into the multi-criteria analysis is established on the basis of a literature study. Focus was on adaptation measures that have proven to work in comparable circumstances. Case studies from scientific literature are selected based on socio-economic context (developing country), climatological circumstances (semi-humid, semi-arid, arid) and current agricultural practices (open field agriculture and horticulture, mainly for subsistence).

All selected measures belong to one of the categories listed below. Most measures directly target water retention. Moreover, most measures under soil conservation are selected because of their water retaining side-effects. Only a few measures directly target heat stress. However, a lot of selected measures potentially create a micro-climate in which (soil) temperatures are reduced. All measures are scored individually.

- Water retention
- Soil conservation
- Cropping practices
- Temperature control
- Irrigation
- Post-harvest quality conservation

7.3 Weighting and scoring

Giving different weights to variables in the MCA prioritizes specific criteria in the final ranking of potential adaptation measures. Stakeholders can hence influence the outcome of the MCA according to their priorities. This section discusses the weighting applied by the smallholder farmers and the weighting applied by a horticultural expert. These weightings are distilled from interviews with

smallholder farmers and extension workers from Kiambu and Kajiado counties, and from the interview with a horticultural expert.

Figure 17a visualises the weightings by the smallholder farmers as compared to that of the horticultural expert. What is immediately clear, is that both weightings are the exact opposite. Smallholder farmers prioritize co-benefits and economic efficiency, while the expert prioritizes the level of organisation and the effectiveness of the measure.

Both the interviewed farmers and the horticulture expert ranked the climatological variables that they expect to have the biggest negative impact on horticulture from most to least relevant. Results are visualized in Figure 17b. Again, these rankings show major differences. Where the horticulture expert prioritizes heat stress, farmers mainly see harm in changing precipitation patterns in terms of timing and quantity.

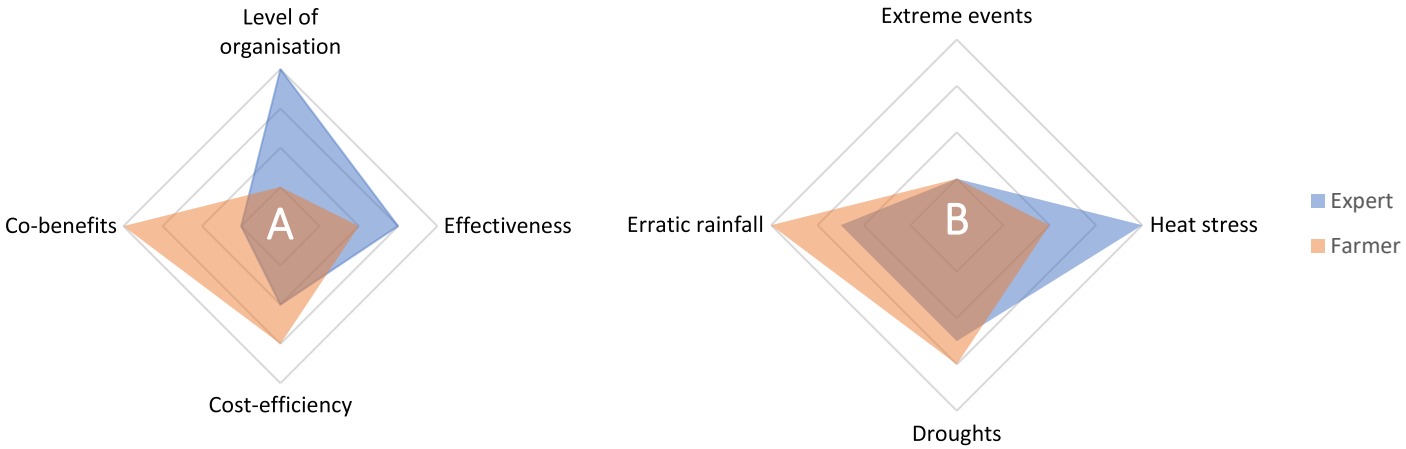


Figure 17 Visual presentation of priorities in adaptation to climate change (A) and relevance of climatological impact on horticulture (B) by different stakeholders by different stakeholders

Based on the priorities identified in the interviews, the weightings that are applied in the MCA are shown in Table 6 (farmers) and Table 7 (expert).

Table 6 Weighting applied to MCA according to farmer perspective

	Weight level 1	Weight level 2	Weight level 3	Total
Cost efficiency	0.333			
Short term return on investment		0.4		0.133
Long term return on investments		0.2		0.067
Maintenance costs		0.4		0.133
Executive level	0.083			
Implementing party		1		0.083
Effectiveness	0.25			
Time horizon		0.176		0.044
Robustness		0.176		0.044
Flexibility		0.176		0.044
Reducing sensitivity to		0.471		
Drought (water availability decrease)			0.333	0.039
Extreme rainfall events			0.083	0.01
Heat stress (T increase)			0.25	0.029
Erratic rainfall (predictability)			0.333	0.039
Co-benefits	0.333			
Environmental		0.231		0.077
Economic		0.615		0.205
Social		0.154		0.051

Table 7 Weighting applied to MCA by expert judgement

	Weight level 1	Weight level 2	Weight level 3	Total
Cost efficiency	0,174			
Short term return on investment		0,2		0,035
Long term return on investments		0,4		0,070
Maintenance costs		0,4		0,070
Executive level	0,391			
Implementing party			1	0,391
Effectiveness	0,348			
Time horizon		0,133		0,046
Robustness		0,267		0,093
Flexibility		0,267		0,093
Reducing sensitivity to		0,333		
- Drought (water availability decrease)			0,25	0,029
- Extreme rainfall events			0,167	0,019
- Heat stress (T increase)			0,333	0,039
- Erratic rainfall (predictability)			0,25	0,029
Co-benefits	0,087			
Environmental		0,5		0,043
Economic		0,25		0,022
Social		0,25		0,022

7.4 Results

This chapter presents the results of the MCA using three different weightings. Besides the farmer and expert weighting presented in the previous section, a neutral weighting is applied to serve as a reference. In this neutral weighting, all (sub)criteria are weighted equally. The results for all weightings are presented in Table 8. The different outcomes are discussed below.

7.4.1 Neutral weighting

The results of the MCA for a neutral weighting are given in Table 8. Except for a few measures on the bottom of the list, all measures included in the assessment score relatively high (> 0.70). The measures that score low (≤ 0.70) are expensive, and larger scaled compared to measures that score high. The top scoring measures are small, cheap, and overall on-farm adjustments to current practices. The outcome seems mainly dependent on the implementation costs and operationalization costs of the adaptation measure or the level of organisation.

7.4.2 Farmer weighting

Table 8 also shows the results of the MCA with a weighting applied from the farmer perspective. This result is subjected to a sensitivity analysis to correct for potential sensitivities and errors in the scoring and weighting process. Scores assigned to the measures after the applying different weights and including the sensitivity analysis are not in the same scale as the original scores. Therefore, only the ranking resulting from these analyses is shown.

Overall, the outcome of the farmer weighting is similar to the neutral outcome. On-farm, cheap and low level adaptation measures are in the top 15 top ranked measures, while expensive, large scale measures remain in the bottom positions. After applying the sensitivity analysis to the farmer weighting, some measures change their position in the ranking. However, a similar distinction remains present between the top ranked half of the measures and the lower ranked half of the measures. There slight difference with the neutral weighting is the focus on water retaining measures. The lower half of the farmer ranking consists of measures that either are expensive and/or large scaled, or measures that do not directly target adaptation to water shortages. These lower ranked measures are also score rather low on (social and environmental) co-benefits.

7.4.3 Expert weighting

As compared to the neutral and farmer weightings, the expert weighting is similar in the distinction between cheaper, on-farm and more expensive, large scale adaptation measures. Peculiarly, measures that (in)directly target heat stress are not ranked higher than in the farmer weighting.

Table 8 Outcome of multi-criteria analysis for the neutral weighting, the farmer weighting, the farmer weighting with score sensitivity analysis applied and the expert weighting. Weight uncertainty is accounted for in all outcomes in which a weighting is applied.

	Total score	Ranking			
Alternatives	Neutral	Neutral	Farmer	Farmer (sensitivity)	Expert
Contour cultivation	0,96	1	1	5	7
Mulching	0,94	2	2	2	1
Conservation tillage	0,94	3	3	3	2
On-farm runoff water diversion and harvesting	0,93	4	4	6	3
Pit cultivation	0,92	5	6	7	6
Green manure in crop rotation	0,92	6	5	1	5
Bottle irrigation	0,92	7	7	4	4
Woollen water retention	0,89	8	8	9	8
Terrace structures	0,86	9	11	8	15
Plastic sheet under root zone	0,85	10	14	12	9
Bucket cultivation	0,85	11	13	14	11
Raised beddings	0,83	12	15	22	18
Agroforestry	0,81	13	9	10	12
Shade netting	0,80	14	16	27	16
Plastic shelter	0,80	15	18	25	17
Drip irrigation	0,79	16	17	26	14
Pond lining	0,78	17	21	15	13
Sprinkler irrigation	0,78	18	20	21	10
Runoff water harvesting from external catchment	0,74	19	10	11	20
Rainwater harvesting (above/below ground)	0,72	20	12	13	23
Solar dryer	0,70	21	22	20	21
Improved storage	0,68	22	24	18	22
Hydroponic agriculture	0,64	23	19	16	25
Greenhouse farming	0,64	24	25	17	19
Cistern	0,60	25	23	19	26
Tube well for irrigation	0,43	26	27	24	24
Rock catchment	0,34	27	26	23	27

7.5 Synthesis

Expensive measures that require high levels of organisation in implementation and operationalization tend to score low. That is independent of the weighting applied. High costs in this list of measures coincide with high levels of organisation. Low final scores for expensive measures can therefore partly be attributed to the higher level of organisation. The farmers put the most weight on (economic) co-benefits and cost-efficiency, while the expert put most weights on level of organisation. Measures that score low on one of these criteria also score low on the other (for this list of measures). As a result, those measures end up at the bottom of the list for both the farmer and the expert weighting. The top 7 measures has the same composition in all different weightings. Although arguing from completely

different values, these stakeholders considered in this MCA would easily agree. This could be beneficial in implementation of the adaptation measures.

In terms of climatological pressures, measures that directly deal with water scarcity score the highest. According to farmers, water scarcity is the main challenge in horticulture. In the expert weighting, the effect of temperature changes is prioritized over water scarcity. Measures that reduce heat stress however are not ranked much higher compared to the farmer ranking: water retention measures still score higher. This can be attributed to the fact that these water retention measures often target more than one of the climatological impacts assessed: drought and unpredictability of precipitation. Besides, having more water available also indirectly reduces heat stress to crops (Cavero et al., 2009; Dubuc et al., 2008).

8. Adaptation strategies

The main stakeholders in this research are Kenyan smallholder horticulture farmers. The general objective they have is *to increase food security at household level, increase household income and reduce poverty* (Chapter 6.4). If they can reach consistent self-sufficiency, there might be room for them to grow towards a more market oriented production and increase their farm income. Climatologically, this remains possible until weather conditions are no longer favourable for crop growth. Boundary conditions for crop growth in terms of crop water requirement and optimal growth temperature could serve as thresholds to identify turning points. Continuously adapting growing circumstances to most favourable growing conditions possible, will serve the goal of being able to produce for domestic use by smallholder farmers. At what point in the future this adaptation should take place, depends on how (fast) the climate changes and on the reaction of crops grown to changes in climate.

With the available information, it is not possible to identify specific turning points in smallholder horticulture. Information on the performance of local crop varieties under changing conditions is missing, and the climate data analysis is too coarse. Moreover, uncertainties in climate projections are too big to connect turning points to specific moments in the future. The climate system behaves according to very non-linear patterns like the Indian Oscillation Dipole (IOD) on which too little knowledge is available. However, based on vulnerable periods in crop growth, this section will indicate in which parts of the season crops will experience enhanced stress due to changes in climate – and where adaptation likely is most effective.

8.1 Sensitive periods in crop growth

Special attention in adaptation planning should go to sensitive phases in crop development, and the changes in climate in those phases that are likely to influence yields. The following sections identify periods during the main crop growing seasons that are most sensitive to changes in water availability and temperature stress. In addition, trends in plant available water and temperature in these periods are discussed.

8.1.1 Temperature sensitivity

Generally, crops are most sensitive to high temperatures in their reproductive development phase. Excessive heat in this phase results in early maturity and low biomass production (Challinor et al., 2005; Teixeira et al., 2013; Wheeler et al., 2000; Zinn et al., 2010). Crop specific literature on some crops however suggests differently. Beans are most sensitive to high temperatures in the pre-fertilization stage (Konsens et al., 1994). Potato crops are most sensitive to high temperatures around the tuber formation (Ingram & McCloud, 1984). The earlier high temperatures occur in the growing season, the higher the negative impact on total yields (Rykaczewska, 2015). Tomatoes are most sensitive to high temperatures at the end of the growing season (Adams et al., 2001). Sensitivity of tomato fruit growth is highest midway between anthesis and full ripening, while sensitivity to tomato fruit development is highest close to maturity (Heuvelink, 2005). Figure 18 visualizes the months in which these mentioned sensitive growing stages occur for the main crops grown in Kiambu and Kajiado.

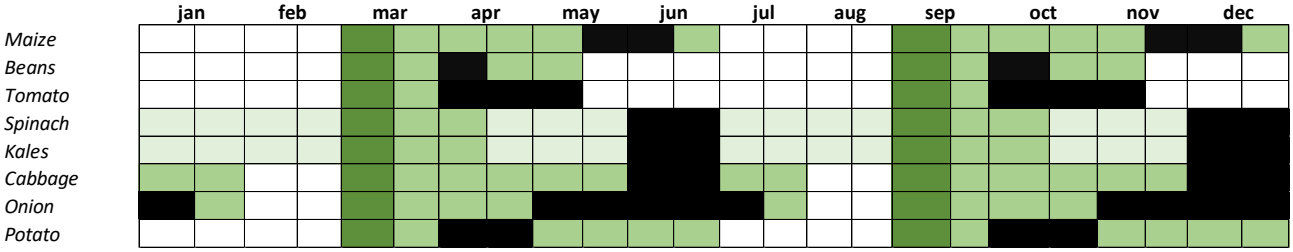


Figure 18 Cropping calendar as identified by interviewed farmers and extension workers. Black areas in the calendar indicate periods in which crop is most sensitive to high temperatures.

8.1.2 Future temperature in sensitive periods

The increase in temperature is consistent throughout the year, but is highest in the months that are already warmer (Figure 19). The growing seasons coincide with these warm months. Increased heat stress will be the result for all crops, during both growing seasons in all research locations. The increase is especially large during April, May and June. All annual crops assessed in this research are most sensitive to increased average temperatures during (part of) these months.

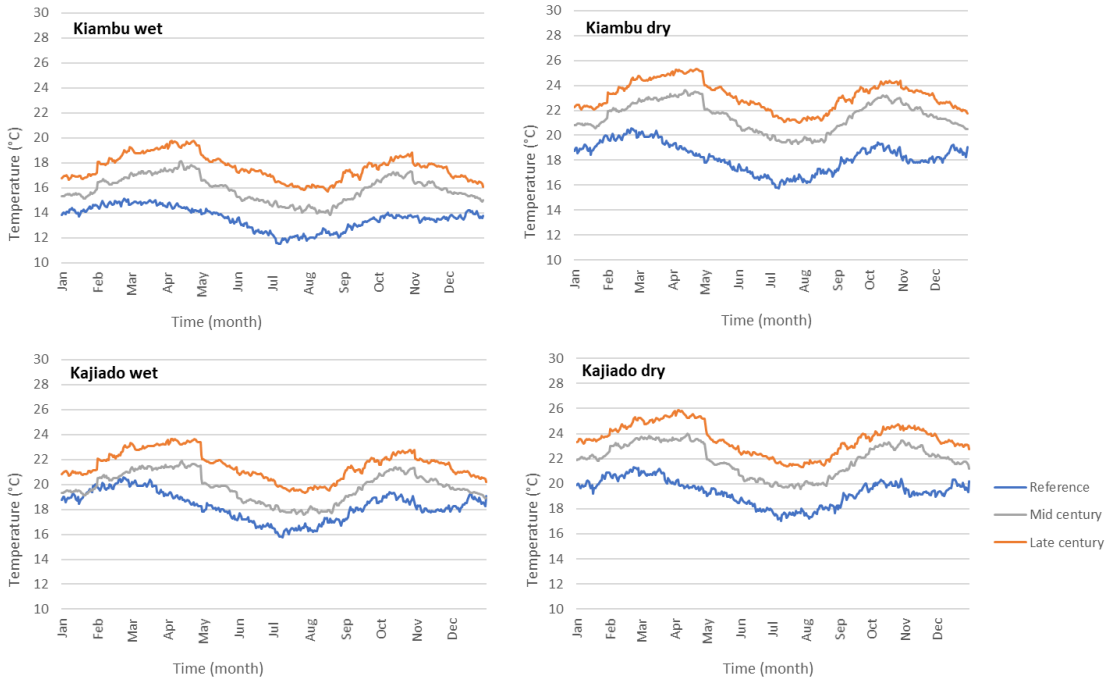


Figure 19 Projections on average temperature for mid and end century, for all research locations

Temperature is an important determinant of the crop development rate (Abrol & Ingram, 1996; Hatfield et al., 2011). The increase in average temperature during the entire growing season will likely lead to lower fruit set, and faster development of the fruit (Wheeler et al., 2000). Both effects (combined) result in a lower yield. Moreover, the negative effect of rising temperatures is enhanced by water deficits (Hatfield et al., 2011). Yield reductions under increased average temperatures could be alleviated or countered if crop growth accelerates under elevated atmospheric CO_2 concentrations (Wheeler et al., 2000). This however only could occurs when there is a water surplus. The next section discusses water availability during critical moments in the growing season.

8.1.3 Sensitivity to water deficit

According to de Oliveira et al. (2013), sensitivity to water deficits are generally highest during the reproductive stages. For some of the main crops grown in Kiambu and Kajiado, their research has specified this sensitive period. Maize is most sensitive to water deficits from the silking stage up to full development of the grain. Potatoes are most sensitive to water deficits from tuber formation up to harvest. Onion is most sensitive around bulb formation, and tomato is most sensitive between fruit set and harvest. In most cases, water stress is starting to play parts at the end of the wet seasons. In the following section, future trends in water availability after evapotranspiration during these sensitive periods are elaborated on. Trends in the difference between plant available water (PAW) and crop evapotranspiration (ET_c) represent whether the amount of water available to the crop after evapotranspiration is growing or decreasing. This will respectively be referred to as an increasing buffer (or a shrinking deficit) and a decreasing buffer (or an increasing deficit). Water availability is not only important for crop evapotranspiration, it also serves as a soil temperature manager (Cavero et al., 2009;

Dubuc et al., 2008). Shrinking buffers or increasing deficits hence indicate moments in which adaptation should be applied to prevent crop damage to heat and/or water stress.

8.1.4 Future water availability in sensitive periods

In the climate data analysis on crop water availability, an increased precipitation and crop evapotranspiration are projected. During the January to June, these trends result in decreasing water availability for all crops in Kiambu dry, Kajiado wet and Kajiado dry (Appendix 7). The crops are already experiencing water deficits in the reference period, and will experience further water stress in the March season. From July to December, crops in these areas will experience an increasing water availability, alleviating the existing deficiencies. Crops in Kiambu wet experience a decreasing water availability between May and September. Water availability is projected to grow during the rest of the year. Table 9 displays the effect of these trends in water availability on the water buffer or deficit experienced per crop in Kiambu dry, Kajiado wet and Kajiado dry. Table 10 displays the same effect for crops in Kiambu wet.

Table 9 Arrows in this table present the projected trends in the difference between plant available water (PAW) and crop water requirement (ETc) in Kiambu dry, Kajiado wet and Kajiado dry during periods in crop development that are most sensitive to water shortage. It shows results of the assessment for RCP8.5 end of the century, per crop. The resulting status of water availability is indicated by the different colours.

	January	February	March	April	May	June	July	August	September	October	November	December
Potato				↓	↓	↓				↑	↑	↑
Maize					↓	↓					↑	↑
Kale/spinach						↓						↑
Cabbage						↓						↑
Tomato				↓	↓					=	↑	
Beans				↓						↑		
Onions (green)					↓						↑	

↑ PAW - ETc increases ↓ PAW - ETc decreases ≈ No change in PAW - Etc Deficit Alleviated deficit Buffer

Table 10 Arrows in this table present the projected trends in the difference between plant available water (PAW) and crop water requirement (ETc) in Kiambu wet during periods in crop development that are most sensitive to water shortage. It shows results of the assessment for RCP8.5 end of the century, per crop. The resulting status of water availability is indicated by the different colours.

	January	February	March	April	May	June	July	August	September	October	November	December
Potato				↑	↓	↓				↑	↑	↑
Maize					↓	↓					↑	↑
Kale/spinach						↓						↑
Cabbage						↓						↑
Tomato				↑	↓					↑	↑	
Beans				↑						↑		
Onions (green)					↓						↑	

↑ PAW - ETc increases ↓ PAW - ETc decreases ≈ No change in PAW - Etc Deficit Alleviated deficit Buffer

Although all crops grow continue to experience water deficiencies, these are projected to get less severe in the September season. Crops in the dryer areas all face the same challenges. In Kiambu wet, crops that are likely to face extra challenges in development are potato, maize, kale/spinach and cabbage in the March season. In addition to those crops, tomatoes and beans face (alleviated) deficits during the September season. Knowing that circumstances regarding both heat stress and water availability are projected to get more challenging in the March season (compared to the September season), adaptation during the March season should be more elaborate than in the September season to reach the same effects.

As all crops are projected to face similar stresses under a changing climate, no differentiation among crops is applied in the eventual strategy. It could be reasoned that a 'cold weather crop' like potato will need adaptation to its growing circumstances sooner than a 'warm weather crop' like tomato (Luo, 2011). However, knowledge on the performance of local, stress tolerant varieties under climate change is insufficiently available to generate crop specific pathways. An option would be to base prioritization of implementation of adaptation measures for certain crops on empirical evidence of damage to those crops as a result of climate change.

8.2 Strategies

This section presents the strategies for adaptation to climate change in the four study locations based on the information gathered in this research.

8.2.1 Lessons from current practices

This research aims to give smallholder horticulture farmers in Kiambu and Kajiado the tools to deal with long term climate change. At this moment, most farmers seem not to have consciously adapted to long term changes in climate. However, some farmers did find ways to deal with current variability. For example, farmers use irrigation to prolong growing seasons. Doing so, they respond to fluctuations in market demand to get higher returns on their products. All farmers in both counties plant local varieties that suit the seasonal forecast by the Kenyan Meteorological Department (KMD) best. This is a well-established service in which the seed supplier adjusts the seeds sold per season, taking that task out of farmers' responsibility. Most farmers – especially in the dryer locations – farm for subsistence, and are not market oriented. Focus of farmers tends to be on short term processes and stresses.

Although the climate is more favourable in Kiambu compared to Kajiado, adoption of soil and water conservation (SWC) measures is higher and more varied in Kiambu. This could be the result of (a combination of) various aspects. Farmers in Kiambu experience more beneficial climatological circumstances to do horticulture. This could lead to less setbacks in yields and higher incentives to grow towards market oriented businesses. Another option could be that the SWC measures are more effective in the more humid circumstances in Kiambu. A third explanation could be past efforts by extension workers in promoting practices such as agroforestry.

Fan et al. (2013) describe two types of smallholder farmers with a main objective of providing for subsistence (Table 11). Subsistence farmers with profit potential are argued to be limited by soft constraints. Subsistence farmers without profit potential face soft as well as hard constraints to grow towards profit oriented agriculture. Climatological circumstances in Kiambu dry, Kajiado wet and Kajiado dry limit smallholder farmers in reaching stable, optimal production. This suggests that those farmers would be labelled as farmers without profit potential. However, adaptation focused on improving these physical conditions would support their growth towards more consistent production. Although farmers in Kiambu wet also experience climatological pressure, initial circumstances are more favourable to agriculture. This would imply that adaptation to climate change in humid areas like Kiambu wet should take into account soft skills to increase food security and increase the strength of the farmer's position on the market.

Currently, farmers in neither Kiambu not Kajiado unite themselves in (in)formal farmer collectives. As mentioned by extension staff, and supported by research (Fan et al., 2013; Heemskerk & Wennink, 2004; Parkinson, 2009), establishing collectives could have great benefits to farmers.

Table 11 Typology of different smallholder farmers with subsistence as main objective (Fan et

TYPE OF FARM		CHARACTERISTICS	STRATEGIES		
			Agriculture-based	Transforming	Transformed
Subsistence farms	With profit potential	Soft constraints to land size and agricultural production • Limited access to markets and information • Limited financial capital • Limited access to infrastructure • Limited access to smallholder friendly technologies	• Productive social safety nets • Investment in infrastructure, agricultural research and extension, and smallholder-friendly and climate-smart technologies • Access to innovative financial services	• Flexible arrangements for land transfer • Risk reduction and management tools • Access to market information (e.g., ICTs) • Pro-smallholder, nutrition-sensitive value chains • Social safety nets and improved access to housing, education, and health services for rural migrants • Vertical and horizontal coordination to meet safety, quality, and quantity standards • Enhanced role of farmers' organizations, particularly for women farmers	• High-value production • Reduced trade restrictions and subsidies • Flexible arrangements for land transfer • Efficiency- and quality-enhanced production systems • Vertical and horizontal coordination to meet safety, quality, and quantity standards
	Without profit potential	Soft constraints *plus* hard constraints to land size and agricultural production • High population density • Low quality soil • Low rainfall and high temperatures • Remote location	• Social safety nets • Nutrition-focused crop production for own consumption • Education and training for nonfarm employment • Migration to urban centers and other agriculture areas with greater profit potential	• Social safety nets • Improved access to housing, education, and health serviced for rural migrants • Education and training for nonfarm employment • Flexible arrangements for land transfer	

8.2.2 Farmer objectives

Where the Kenyan government sees horticulture as a way out of poverty, this might not be applicable to all farmers in this research. More realistically, the general objective used in this study is for smallholder farmers to provide for own subsistence. For most farmers in dry areas, this objective theoretically is the highest achievable as they are limited by climatological circumstances, plot sizes and low investment opportunities. However, as explained in the previous section, farmers in the more humid areas might have greater potential to grow towards market oriented horticulture.

Both the demand from farmers as well as the services provided by the extension office now centre around seasonal forecasting. This is very useful in preparing stakeholders on the trends in the year ahead (depending on the occurrences of the IOD and ENSO phenomena). However, long term climate change is not considered in the current system.

8.2.3 Potential adaptation measures

Smallholder farmers often do not have the financial capability to deal with unforeseen damaging events on their business, let alone to invest in new technologies or machinery (Fan et al., 2013; Kurukulasuriya et al., 2006; Thornton et al., 2006). Besides, the successful organization of smallholder farmers in formal groups has proven to be difficult (Parkinson, 2009). Logically, results from the multi-criteria analysis show that according to both farmers and experts, on-farm, cheap adaptation measures with low organisational requirements score highest. Although reasoning from different values, farmers and experts agree on the outcome of this multi-criteria analysis. This will likely be beneficial in implementation of adaptation options.

Adopting the proposed low cost, on-farm measures will definitely support farmers in becoming more resilient to climate variability. In combination with awareness building, this is seen as the first step in becoming resilient to long term climate change (Simões et al., 2010; Twomlow et al., 2008). However, these low cost, on-farm measures might lack robustness to be able to deal with climate change under the most extreme scenario. Measures that are more robust mostly are more expensive, and need higher

levels of organisation. Especially in profit potential areas like Kiambu wet, investing in organisational structures will support further adaptation to climate change. In the dryer areas, systematic on- and off-farm transformations could be undertaken to maintain horticulture. These system changes are not considered in the proposed adaptation strategies.

8.2.4 Hazards and opportunities in projected climate change

Hardly any difference between the impact of climate change on crops in Kiambu dry, Kajiado wet and Kajiado dry has been identified. Water buffers in those areas are already marginally or not existing. Further water stress is projected to increase water stress in all three locations. Crops in Kiambu wet are likely to experience less water stress compared to the other areas. Because of the relatively wet conditions, impacts of increasing ET_c are likely to be relatively low. Trends in mean temperature are very similar for all locations. However, since water availability and heat stress are related, crops in Kiambu wet are expected to suffer least from heat stress under increasing average temperatures. This is confirmed by Ochieng et al. (2016), who argue that increasing temperatures can have a positive impact on crop production in highland areas, while it will have a negative effect on crop production lowland areas as result of a likely water deficit, especially the semi-arid. In general, crops experience (if any) the same stresses. Therefore, the pathway proposed is a generic one to be used for all different annual crops grown. There is a difference however in when the crops are most sensitive to stress. Each crop could be targeted during these different crop stages to make the adaptation most efficient. Farmers will need the knowledge on (recognizing) different crop development stages to be able to generate this differentiation in timing of management among crops.

Using SWC, irrigation and heat stress prevention all are logical steps to take in adapting to the expected changes in climates in Kiambu and Kajiado. Although less measures on heat stress prevention are available, water can often be used as a tool to combat water and heat stress (Cavero et al., 2009; Dubuc et al., 2008). As already suggested in previous research, precipitation rates will increase in the coming decades (Christensen et al., 2007; Doherty et al., 2010). Moreover, runoff rates are projected to increase disproportionally. This could be the result of the current actual evapotranspiration being very close to potential evapotranspiration. More precipitation will hence hardly result in higher evapotranspiration rates. Instead, it will runoff via the surface. For smallholder farmers, the potential to collect water to be used for irrigation increases greatly – also in the dryer areas. The trend also shows the increase in water availability during the short dry season from January to March. This will give farmers more freedom to adjust their season start based on projections. In all areas, crops are likely to experience more damage by both water and heat stress during the March season compared to the September season. Al-Kaisi & Broner (2009) argue that crop water use during critical development should be used in irrigation scheduling. Accordingly, the extra water available in the antecedent period (January to March) can be harvesting in order to overcome to projected increasing water deficiency during the March season. In doing so, potato, maize, kale/spinach and cabbage should be prioritized in Kiambu wet. Crops in the dryer areas all face the same challenges.

8.2.5 Adaptation pathways

Kiambu wet is expected to suffer less from climate change than Kiambu dry, Kajiado wet and Kajiado dry. Combined with the relative high adaptation levels and the higher agricultural potential in Kiambu wet (based on Sombroek et al. (1982)), it is argued that adaptation to climate change in Kiambu wet has the potential to support smallholder farms in growing towards market oriented businesses. Focus in Kiambu wet should still be on adaptation to higher temperatures, and long term planning. Farmers in Kiambu dry, Kajiado wet and Kajiado dry are mainly limited to climatological circumstances in which they cultivate their crops. Their strategy therefore consists of measures that support agriculture for subsistence in these challenging circumstances. Measures are presented per phase, and each phase has a main aim. How fast one fast should follow after the other, depends on the speed of climate change.

The faster and more severe the changes in climate, the quicker adaptation should go through all phases. Since climate change in dry areas is expected to have a bigger damaging impact on crop growth, farmers in these areas will likely reach the last phase of the strategy earlier than those in the more humid areas.

Figure 20 presents the strategies as proposed on the basis of results of this research. Comparing the strategy for Kiambu wet to that of Kiambu dry, Kajiado wet and Kajiado dry, the only difference is in the later phases. Starting implementation in phase 1, farmers build the necessary resilience to current climate variability by retaining water on their fields. This results in a more optimal usage of the water that is available from precipitation. Incrementing adaptation in phase 2, a farmers prepare to overcome longer periods of droughts by using the projected increase in runoff to their benefit. More water will become available to be used for crop growth. Simultaneously, investments in heat stress prevention can be made, since the measures in phase 1 and 2 support optimal temperature regulation. Investing in specific heat stress adaptation will likely give this regulation by water retention and application extra momentum. Almost all measures that are proposed as part of the strategies up to this point are flexible and do not need high levels of organization. However, these measures probably lack robustness in managing long periods of extreme circumstances. After phase 3, the difference between strategies for different agro-climatic zones become important. Farmers in areas with high agricultural potential (in this case Kiambu wet), could further adapt to the projected climatic pressures by implementing larger scaled, more robust measures. These often require higher levels of organization, and higher costs of implementation and operationalization. However, these farmers have the potential to grow towards being, or already are market oriented. Their incentives to explore opportunities of investing social and financial capital in maximizing their yields is therefore assumed to be higher. This is already visible in the current (high) adaptation rate in the county. Farmers in low agricultural potential areas are assumed not to be able and/or willing to implement and operationalize larger scaled structures successfully. Therefore, their strategy omits phase 4. Finally, phase 5 requires a larger scaled system change, in which more stress tolerant crops are being cultivated depending on the seasonal forecast by the Kenyan Meteorological Department. Patterns in available water for example show that the March season might start earlier in the future. Planting earlier would mean that crops would not be exposed to high temperatures during their temperature sensitive development stages. This requires differentiated planning for the different crops cultivated. Another example of a system change within the horticulture domain would be to renounce horticulture in years that are projected to be extremely dry, or only farm during the September season instead of risking losing yields in both. Such risk avoidance strategies could be implemented supported by the existing network of climate forecasting by the Kenyan Meteorological Department. After phase 5, sector exceeding system change might be needed. These system changes go beyond the scope of this research, but will shortly be discussed in the next section.

Adaptation strategies

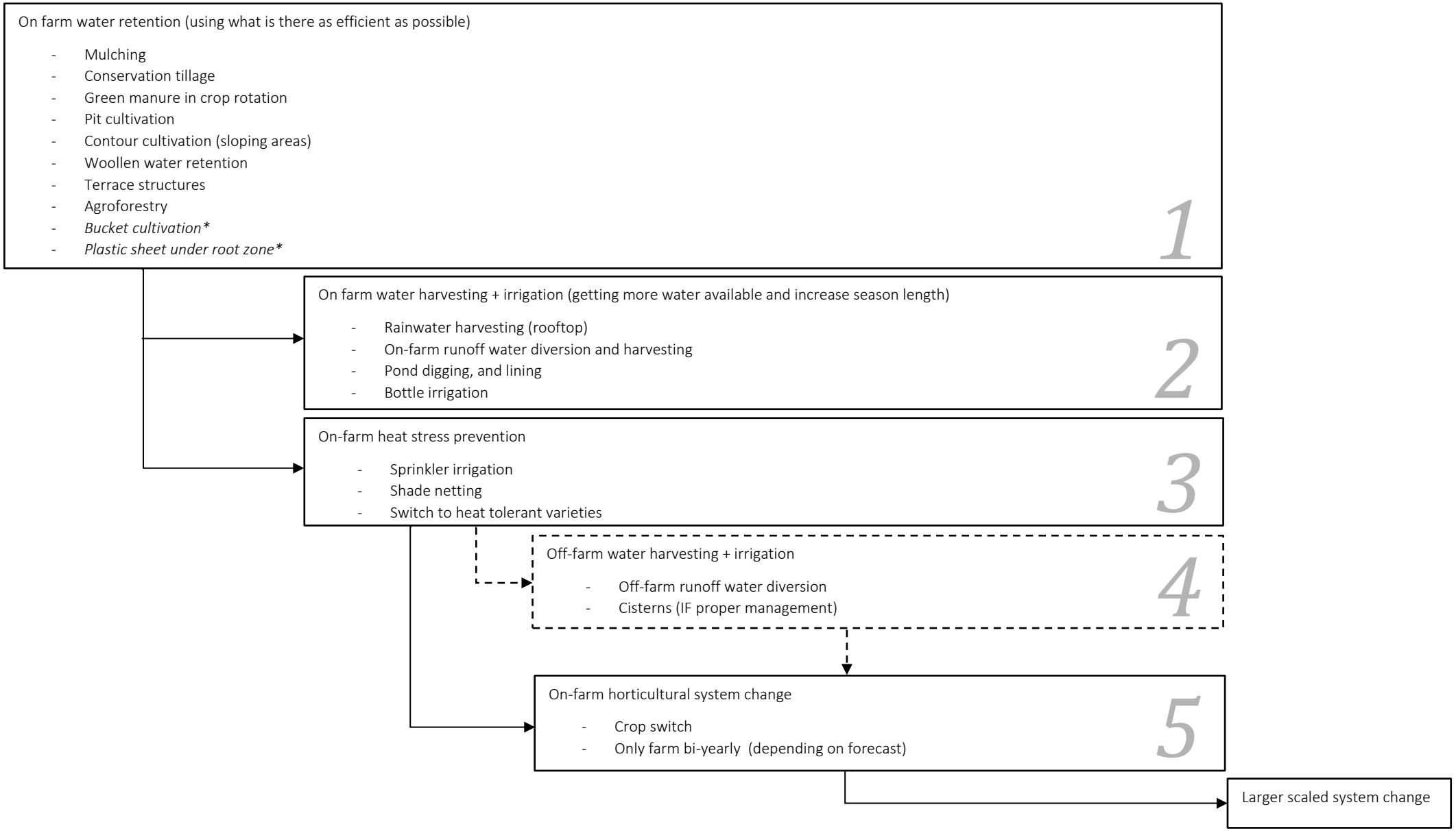


*Figure 20 Proposed adaptation strategies for four research locations. * Indicates measures that should only be applied in Kiambu dry, Kajiado wet and Kajiado dry due to a risk of flood induction. Note that the dotted path only applies to Kiambu wet.*

9. Discussion

This chapter first presents the main results of this research in a broader scientific context. It then reflects on strengths and limitations of the methods used in this research. Finally, concludes with an outlook on what further research could focus on to contribute to the research aim.

9.1 Integration of research results

This thesis indicates that despite deep uncertainty in future climate and socio-economic development, adaptation to climate change should take place in smallholder horticulture in Kiambu and Kajiado counties. Rising temperatures will likely result in higher crop evapotranspiration, increasing both water and heat stress to crops. Especially in sensitive crop development stages, both stresses will lead to reducing yield sizes. Confirming the hypothesis by Ochieng et al. (2016), the climate data analysis in this thesis research projects the already dry areas to experience the most rapid changes in climate.

Smallholder farmers usually have a low adaptive capacity (Fan et al., 2013; Kurukulasuriya et al., 2006; Thornton et al., 2006). In Kiambu and Kajiado, most smallholders experience an inadequate access to financial capital, and hence have low opportunity to invest in their farms. Recent studies however state that investment opportunities for smallholder farmers will likely not result in alleviated poverty in normal circumstances. Even if farmers are producing at maximized potential, small plots will not produce enough for them to prosper (Harris, 2019; Wichern et al., 2017). Stringer et al. (2019) therefore argue that the most viable pathway for smallholder farmers might be to exit agriculture as soon as their yields are consistently failing. Up to this point however, farmers in Kiambu and Kajiado seem to have held on to their plots as a form of collateral security. Especially in peri-urban areas (around Nairobi), value of land is high. Under further socio-economic change however, the amount of smallholder farmers deciding to abandon their agriculture might increase as more (and more secure) off-farm opportunities arise while yields might decline. Matsumoto et al. (2006) observed that the likelihood of households participating in off-farm activities is greater in low-potential areas. As also applies to other examples across the world: the more marginal agriculture is, the higher the importance of off-farm income in reducing poverty (Matsumoto et al., 2006). This also is witnessed in this study, where horticulture in Kajiado (drylands) has been observed to be more small scaled and extensive compared to horticulture in Kiambu.

Despite a general low adaptive capacity among smallholder farmers, it is argued that the capacity to adapt to changes in climate might vary throughout the research areas based on research by Fan et al. (2013). They distinguish between subsistence farmers ‘with profit potential’ and subsistence farmers ‘without profit potential’. It is assumed that the higher the climatological agricultural potential, the lower the chance for a farmer to frequently experience setbacks in yields, and the higher the adaptive capacity of a farmer in terms of financial capital and intrinsic motivation. Climate data analyses in this thesis have shown that the area with highest agricultural potential (Kiambu wet) will experience the least negative effects on crop growth as a result of climate change. Farmers in that area are expected to continue to produce a surplus more often (compared to the dry areas), being able to sell this on the local market to gain additional income besides their actual job. Therefore, two different adaptation strategies are presented. Both start with no-regret measures that at least account for current climate variability, and support long term climate change to some extent. A primary focus on water retention should ensure the most efficient use of available water possible. Next, extra water can be harvested to be used for irrigation purposes. Although an increased water availability will reduce heat stress, specific heat stress measures should be implemented to maximize the reduction of heat stress. For farmers with profit potential in agriculture potential areas, the next step would be to adopt large scale water harvesting techniques. Lastly, both farmer types could consider a horticultural system change in which

they for example switch to crop types that better suit the future climate, or a system in which farming is done only annually. Based on the climate data analysis, crops will suffer from less severe from changes in climate in the September season, compared to the March season. However, the September season is generally known to be more variable over the years (Behera et al., 2005). A switch to annual farming should hence consider the risks of this variability and its potential to result in failing crop yields. The forecasting system that is already in place is a suitable tool to base seasonal practices on.

Focusing adaptation on sensitive periods in crop growth could increase effectiveness and efficiency of adaptation (Al-Kaisi and Broner, 2009). Climate data analyses in this study for example showed that runoff will increase in all areas during both growing seasons and the short dry period from January to March. Retaining runoff water is one of the suggested measures to increase precipitation use efficiency. This could be used to the benefit of smallholder farmers to combat the lack of water available to crops. Especially in the dryer areas, the effectiveness of soil water nutrient management interventions like this could objectively be assessed in terms of i) enhanced infiltration of rainwater, ii) increased soil water capacity, iii) improvement of efficient use of stored water and iv) minimization of evaporation from the soil and improved soil quality (Biamah, 2005). However, the projected increase in precipitation and runoff could result in increased soil erosion and resulting decreased soil quality in these dry areas as a result of low vegetative protection (Hudson, 1987). In combination with inadequate soil water management, a poor soil quality results in low effectiveness of SWC measures (Biamah, 2005). Therefore, research advises to combine SWC measures in dry areas with measures that target to enhance soil fertility (Kiome, 1993; Biamah, 2005). Economically, this is only viable on favourable soils with high potential productivity (Kiome, 1993).

Kenya is developing rapidly. As Fan et al. (2013) argue: “the appropriate development pathway for smallholder farmers depends on the level of transformation within the country’s economy. This transformation will include increased productivity and commercialization in agriculture, alongside sector diversification and growth. The duration and character of the transformation vary across countries, but it includes several fundamental changes in structure of the economy: 1) a declining share of the agriculture in GDP and employment, increasing rural-to-urban migration, the rise of modern industrial and service economy and a demographic transition to lower birth and death rates (p. 5)”. The processes described are already visible in Kenya, or are likely to be encountered within the coming decade and will have great impact on the agricultural sector. Moreover, these processes will impact the factors determining the success of SWC mentioned above. As a result of rural-to-urban migration for example, the demand for food in the urban and peri-urban areas grows. The pressure on resources in peri-urban agricultural areas however is likely to increase due to (inadequately managed) changes in land use, and higher population rates. Food production would rely heavily on production in rural areas as a result of these processes. In those areas, part of the smallholder farmers (with low potential to prosper due to small plots and lack of investment opportunities) might sell their lands to find off farm sources of income, possibly moving to urban areas. The few farmers that do remain active in agriculture have access to more land. Rural-to-urban migration hence could give room to a less fragmented style of horticulture with a higher potential to become market oriented. Since this scenario would suite the vision of the Kenyan government on commercialization of agriculture, this process might even be supported through taxes, subsidies or large scale land consolidation.

This thesis aims to give smallholder farmers the tools to deal with climate change. However, the processes mentioned above play on an overarching scale, impacting the entire context in which this smallholder farming takes place. Using the adaptation turning point approach (ATP) is negotiable in this transforming context of which the long term development is (both climatologically and socio-economically) highly uncertain. In studies that examine a single, basal variable that shows linear behaviour in climate change projections (e.g. sea water level, atmospheric temperature or river

discharge), the turning point approach is successfully applied (Walker et al., 2013). In this research, turning points could have indicated moments in the future at which crops could not be grown climatologically. However, all indirect, non-linear processes that are on the base of crop productivity could not be accounted for. The proposed pathway therefore is not based on turning points. As all crops are likely to face similar stresses as a result of a changing climate, the pathway is suitable to be used for all crops cultivated in Kiambu and Kajiado. At what point in the future what crop needs adaptation measures to be implemented, could be based on empirical evidence of damage encountered in the field. Most crops already experience stress in current climatological circumstances, and will therefore benefit from the proposed measures at this moment.

The pathway approach was applied to undertake the necessary short term actions, while keeping options open to plan longer term, more fundamental system changes if that will appear to be needed. Especially in the socio-economic context of the research, acknowledging the need for short term action is considered highly relevant. Although generic, the adaptation pathway can be seen as a crucial first step towards climate resilient smallholder horticulture in Kiambu and Kajiado counties.

9.2 Reflection

The reflection in this section is split up into three subsections. First, the approaches used will be reflected on. Then, the methods used in this research are discussed in terms of strengths and weaknesses. The last subsection elaborates on the limitations and opportunities of the scope of this research, being on-farm adaptation to climate change.

9.2.1 Approach

This research could be improved in various aspects. However, having more (accurate) information available would not have eliminated the uncertainty as a result of the non-linear climate system and socio-economic context in which this case study is done. In the dynamic, unstable circumstances of this study, the use of the turning point approach is debatable.

There are two main arguments that undermine the use of this approach in this case study. Thresholds are argued to be reached when climate change results in conditions that stakeholders perceive as undesirable. Basing decision making on such turning points, by reacting with measures at the moment in time a turning point is about to occur, it is argued that “a social-ecological system is managed to *sustain* conditions for social-environmental activities (p.335)”, “from the aspiration to control change in a system assumed stable (p.336)” (Werners et al., 2013). First, the circumstances for horticulture are (and may have never been) ideal nor stable in (parts of) Kiambu and Kajiado. More generic, the second argument is that climate change should shift priorities in planning for sustainability “from preserving natural resources for future generations to strengthening resilience and adaptive capacity in social–ecological systems (p. 335)”. The scale of climate change and the challenges it will bring to Kenyan smallholder horticulture depends on development of the world’s economy and its greenhouse gas emissions. Moreover, adaptation to climate change in Kenya also takes place in a context of rapid demographic change that goes beyond the climate domain. These changes also affect horticulture severely by decreasing water availability and damaging the buffering function of the environment. It could be argued that especially in the dynamic system in which this case study takes place, waiting for turning points to (almost) occur is too passive to actually increase smallholder farmer resilience to climate change. Although turning points might have been a suitable tool to serve the communication around long term climate change adaptation, they cannot be identified accurately in the Kenyan context due to non-linear behaviour in climate trends.

No turning points have been identified in this research. That however does not mean that the ATP framework is not applicable to contexts similar to these. Sustainable planning is generally structured according to (variations on) the framework presented in Turner et al. (2003). The three main pillars that

determine eventual planning strategies are *exposure*, *sensitivity*, and *resilience* of the target group to external processes. The ATP approach also incorporates these three pillars and therefore seems very similar. On top of these basic pillars however, the ATP specifically focuses on objectives to be reached by stakeholders. Being focused on the future would imply that the ATP is highly suitable to use in the dynamic context of this research. Moreover, it enables a differentiation between strategies for stakeholders with different objectives. This would serve the general aim of avoiding the construction of blanket approaches to be implemented in areas or by stakeholder with other backgrounds and aims.

Going back to the objective of this study, this thesis aims to assess what smallholder farmers can do to reach their objectives of producing for subsistence. Although not based on turning points, applying the pathway approach by Haasnoot et al. (2013) is found to be very suitable to come to an adaptation pathway. Not knowing when turning points are about to occur could be seen as a restriction. However, if planned correctly, adaptation pathways account for uncertainty in future scenarios. Planning of adaptation without turning points would maybe even avoid implementors being too much focused on specific moments in time. Such a strong focus on when turning points are to occur could potentially lead to lock-ins or reactive planning while strengthening resilience and adaptive capacity in social–ecological systems needs proactive and continuous adaptive planning. It is therefore argued that to construct an adaptation pathway, the identification of specific turning points is not crucial as long as the adaptation pathway accounts for this uncertainty. The pathway approach puts a focus on short term goals that need to be realised, while working on long term climate change resilience. With smallholder farmers as a target group, an emphasis on short term objectives to be reached within this long term planning is very valuable. The pathways proposed in this research enable low level extension workers to see in what programmes to invest/for what programmes to apply.

9.2.2 Methodology

The results of the climate data analysis are reliable, but also highly uncertain. The choice of climatic indicators assessed steered the results and conclusion of this research into a particular direction. It for example did not take into account temporal variability in precipitation events, and extreme years as a result of ocean atmosphere interactions. Such years occur often and do influence the average data that is worked with in this climate data analysis. The final strategy is mainly based on the increasing precipitation and runoff projected in the research areas. In (extreme) dry years however, both precipitation and runoff might be very low, or might not occur at all. Shongwe et al. (2011) conclude that the intensity of precipitation events is likely to increase, translating into higher flood risks throughout East Africa. In both extreme situations, the proposed strategy would not be of use. Ideally, the climate data analysis would have a higher spatial and temporal resolution, and would have included indicators on the occurrence of extreme weather events. Then, for every scenario (extremely wet, extremely dry or 'normal'), a different set of agricultural practices or other coping strategies should be available to farmers. Kadomura (2005) argue that in extreme years, vulnerability to climatic risks could be reduced by improving short and long term coping strategies and disaster preparedness at all levels of governance. The phenomena that determine the occurrence of extreme years (El Niño Southern Oscillation and Indian Ocean Dipole) are badly represented by current climate modelling efforts. The long term trend in occurrence of extreme years therefore is uncertain.

The season lengths mentioned by interviewed farmers generally are rather short compared to general varieties of crops (Allen et al., 1998). In climatologically variable circumstances however, planting short season varieties is commonly done to lower the risk of crop failure (Maoncha et al., 2016; Sennhenn et al., 2017). Insight in agricultural performance of these local crop varieties under these changing circumstances is limited. In this research, agricultural performance is therefore argued to decrease based on literature review on independent climate variables. Moreover, complex interactions between temperature and water availability or CO_2 levels are disregarded. Crop modelling (on local varieties)

could give more accurate insight in crop performance under climate change. Despite deep uncertainty in climate projections and the impact of these changes on horticultural production, the adaptation pathway can be seen as a crucial base in adaptation that is needed for long term climate resilient smallholder horticulture in Kiambu and Kajiado counties. Although one generic adaptation pathway is established for all horticultural crops in the areas, it is argued that implementors can base prioritizations of adaptation on empirical evidence of damage encountered in the field.

A limited amount of interviews has been conducted. Moreover, the farmers that were interviewed have been selected by the extension officers. This could have led to a bias in interviewees. Having interview results validated by extension officers has confirmed accuracy of this established profile. The interview results match the general profile of a smallholder farmer as formed by extension officers in both counties. The profile also matches scientific literature on smallholder farmer practices, incentives and capital. The interviewed farmers hence were considered to be representative for the smallholder farmer communities in Kiambu and Kajiado. The generalized profile of a smallholder farmer resulting from the interviews served as a representation of the target group during the rest of the research. However, a generalization might be inaccurate. As argued in the pathway proposed, farmers in higher potential areas might have objectives or experiences that are not fully in line with this generalized profile. Conducting more interviews with specified categories of farmers (different sizes, objectives, experiences etc.) could have resulted in more differentiated adaptation pathways that are adjusted to the limitations and opportunities of farmers in different (climatic and socio-economic) contexts. The proposed pathway has shown that the potential to differentiate among different farmer profiles is present within the current set of methods used. Interviewing random smallholder farmers would have created a more diversified picture of the situation.

In addition to non-linear trends in climate projections, rapid socio-economic development in Kenya is the main important uncertainty in this thesis. Both sources of uncertainty limit the eventual robustness of the conclusion, independent of the quality of the results. Socio-economic transitions are not actively incorporated into the proposed pathway. However, the strategy proposed did account for uncertainty. Although the main incentive was to account for climatic uncertainty, the flexibility built into the eventual strategy also serves the adaptive management needs in socio-economic transitions.

To enable full adaptation of the smallholder farmer community within the socio-economic transitions taking place, focusing on agriculture alone will likely not be sufficient. The next section therefore discusses the scope of this research.

9.2.3 Scope

This thesis primarily focuses on on-farm adaptation, to meet the general low adaptive capacity of smallholder farmers. The greater the lack of scale benefits and freedom of experimenting, and the faster climate is changing, the sooner the limits of smallholders' capacity to adapt will be reached. The proposed pathway therefore is likely not to be robust under extreme changes in climate. As the risk to flooding is likely to become bigger (Shongwe et al., 2011) and temperatures will rise, the current fragmented style of horticulture might lose its ability to produce crops consistently. Damage to livelihoods as a result of extreme climatic circumstances goes beyond yield reduction. Damage to cropland, infrastructure and water supply systems could induce acute food shortages. Moreover, waterborne diseases or insect plagues are indirect effects of extreme climatic circumstances with an enormous impact on society. Such indirect effects should be addressed in long term planning. To guarantee a long term decrease of a smallholder farmer's vulnerability to climate change, larger system changes should be considered in which disaster risk management is incorporated (Kadomura, 2005).

An often mentioned opportunity to beneficially influence micro climates is large scale environmental restoration (Barrow, 2002; Lemenih et al., 2010; Aronson and Alexander, 2013). A downward trend in

water availability is likely to be the result of external factors influencing water availability like a growing human and animal population. Changing land use patterns as a result of these trends result in higher pressure on available water bodies and soil quality, an important determinant of water holding capacity (Biamah, 2005). Large scale restoration could restore these ecosystem services, enabling the ecosystem to regain its buffering function (Barrow, 2002; Lemenih et al., 2010; Aronson and Alexander, 2013). In such large scale restoration, the role of the government would be key in terms of policy making and enforcement. Smallholder farmers however are not in the position to undertake such practices independently.

What action smallholder farmers are able and willing to undertake to deal with potential future climate is key in this research. From a sociological perspective, it is recently argued that smallholder adaptation decisions are likely shaped by the attempts of smallholder households to manage risks across multiple social– ecological sectors over time, rather than changes in climatological circumstances (Burnham and Ma, 2018). Assessing historical adaptation motives with their multi-scalar pathway approach, Burnham and Ma (2018) found that "a critical need for adaptation and development interventions is to create synergies with ongoing smallholder adaptation and livelihood practices and enable them to continue to manage not just climate change but the multiple stressors, uncertainties, and opportunities they face in culturally appropriate ways (p. 260)". Processes shaping smallholder decision making for example are market demand driven by urbanization, technology development, state policy or social reform (Burnham and Ma, 2018). Acknowledging these dynamic processes to co-form smallholder decision making is of great value, especially in the context of rapid development. Often, adaptation measures "offer a single path to address a single stressor (a change in climatic conditions in this case) without taking into account the existing local social institutions; while in reality smallholder households operate within social relations and norms that are shaped by legacies of past and ongoing adaptation pathways (p. 259)". Using different weightings in the multi-criteria analysis (MCA) in this research was aimed to put the adaptation of new measures in a 'multi-scalar' context. However, applying the extensive sociological methods used by Burnham and Ma (2018) in addition to an MCA is regarded to be of strong support to the methodology used in this research. It will likely increase the potential implementation success of adaptation strategies, by partly linking development planning and adaptation planning in a dynamic context.

9.3 Opportunities

Despite the deep uncertainties that exist in long-term (climate) predictions, it is necessary to explore the sensitivity of the environmental and social systems, and economically valuable assets to climate change (Hulme et al., 2001). This study attempted to do so. The presented adaptation pathway could be seen as a coarse sketch of what adaptation opportunities are out there. However, more in depth or higher quality analyses might not even change much to the current outcomes as the future is highly unpredictable in terms of climate projections and socio-economic development. Although the pathway proposed is not very conclusive or specific, it can already be used to create a wider adoption of baseline adaptation to climate variability and long term change.

Generalisation of physical and socio-economic contexts leads to the formulation of a blanket approach that might turn out successfully for one farmer, but fail for others. To further enrich the proposed pathways, adaptation planning in Kiambu and Kajiado is believed to benefit from differentiation. The success of different SWC measures to adapt horticulture to climate change among others depends on soil type and quality, and farmer capital and motivation. Generating more farmer profiles, soil characteristic profiles and agro-ecological zone profiles will likely enable the development of more specific adaptation pathways. Differentiation also partly tackles the uncertainty that socio-economic development brings if potential future scenarios (like the scenario sketched in Section 9.1) are taken into account. With this, the successful implementation becomes more realistic.

Besides differentiation, it is argued that expanding the set of methods used in this thesis with the multi-scalar pathway approach as used by Burnham and Ma (2018) would combine valuable lessons from past adaptation pathways (to any dynamic process) with insights in future change (climatological as well as socio-economic). The analysis of historical pathways of adapatation to change can be valuable to highlight how different adaptation pathways arise for different social groups. It gives insight in different levels and forms of vulnerability, and the limitations and opportunities that facilitate or constrain adaptation across these social groups (Câmpeanu and Fazey, 2014; Fazey et al., 2016). It is believed that combining the historical analysis of pathways with the adaptation pathway approach by Haasnoot et al. (2013) to be on the basis of adaptation planning could partly bridge the gap between development planning and adaptation planning. In a dynamic socio-economic context that is determined by economic growth and societal transitions, bridging this gap is believed to be crucial in achieving the objectives of both indivual niches.

10. Conclusion

Although precipitation and runoff are projected to increase, projected rising temperatures are expected to have a negative impact on smallholder horticulture in Kiambu and Kajiado counties. Adaptation to climate change is not widespread in these areas. Despite deep uncertainty in climate projections and the impact of rapid socio-economic development on horticultural production, this thesis indicates that adaptation should take place in both counties to meet the smallholders' objective of consistently producing for subsistence.

In general, smallholder farmers have a low adaptive capacity. It is therefore argued that the negative effect of climate change on horticultural yields should be minimized by the implementation of small-scale, cheap soil and water conservation (SWC) measures. However, this thesis also indicates that the adaptive capacity of farmers might vary throughout the research area. It is assumed that the higher the agricultural potential of an area, the higher the adaptive capacity of the farmer. Therefore, two different adaptation pathways are proposed. In addition to small-scale, cheap SWC measures to target water retention, water harvesting and irrigation and heat stress prevention, farmers with profit potential are argued to be able to further adapt using larger scale measures when uniting in farmer collectives to ensure proper management. Both pathways will certainly help to increase resilience to current climate variability, and will lay the base for adaptation to long term climate change. However, both might reach their limit before the end of the century. Then, a larger scale system change should be considered either within horticulture, or abandoning it.

10.1 Methodology

The success of SWC measures in a specific context is dependent on the physical limitations and opportunities of the location, and the limitations and opportunities of the target group. It is therefore argued that further differentiation of adaptation pathways could serve the goal of providing location specific adaptation pathways, taking into account the different backgrounds within the smallholder farmer community.

There is no scientific literature on the use of the adaptation turning point approach (ATP) in developing countries with the aim to improve resilience of an agricultural sector to climate change. This thesis has shown that successfully constructing specific turning points is difficult (if not impossible) as horticultural production in the research area is determined by future non-linear trends of interacting climate variables. Moreover, dynamic socio-economic processes under rapid development are of high relevance to smallholder farmer decision making. It is argued that smallholder farmers mainly make day-to-day decisions to manage a wide range of risks, of which climatological circumstances are 'only' one of many stressors. Assessing which adaptation pathways would be most suitable to implement in a context like this might hence need a more holistic approach. One approach that could be used to take on this more holistic view is the multi-scalar pathway approach. The multi-scalar pathway approach focuses on smallholder decision making in the past, based on dynamic processes in all relevant domains (e.g. market and economy, institutional, technological). A follow-up using the adaptation pathway approach by Haasnoot et al. (2013) could use this knowledge to assess what measures could work in a dynamic system, taking climate change into account. This combination of measures could be seen as a form of holistic development planning.

10.2 Recommendations

The awareness of farmers to adapt to current climate variability and climate change might already be present. However, farmers at this moment mainly acknowledge water scarcity as restriction to optimal yields, while damage by increasing temperature might be bigger on the long term. On top of that, decreasing water availability likely has to do with the increasing pressure on water resources under

socio-economic development rather than a decrease in precipitation that smallholders have observed. Farmers who did not yet implement adaptation measures sometimes assume adaptation to climate change to be too expensive for them to be able to afford. From these issues, it could be stated that smallholder farmers at this point misconceive the main climatic threats to their livelihood, and their own capacity to deal with it. As a result of these factors, implementation of techniques in smallholder farmer communities is proven to be difficult as the sense of ownership often lacks. To mobilize smallholder farmers, the proposed strategy should be accompanied by an elaborate education and training programme in which both extension services and farmers are engaged. This would support farmers in understanding how to use water in a sustainable way, and what realistic ways are out there for them to implement independently.

Policy makers should create an environment in which the pathway proposed can be adopted by smallholder farmers as basic adaptation to climate variability and change. This could for example be done by creating and – more importantly – enforcing policy on ecosystem protection and land use planning. Climatic circumstances during extreme years are not discussed in this thesis, while these occur very often. The proposed adaptation pathways might (partly) be useful to implement during the extreme dry years, but do not account for years in which large floods occur. Such years need completely different action planning. Therefore, the focus of policy makers should also be on disaster risk reduction and disaster response planning to increase off-farm smallholder resilience to extreme wet and dry years.

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Appendix 1: Interview outlines

Semi-structured interviews are prepared to follow the same line of topics with each of the interviewees. Open questions were asked. Answer options were prepared in case the interviewees did not know what to answer at all. However, giving the answer options was avoided as much as possible.

1.1 Farmer interviews

1. Current cropping scheme
   1.1. Cropping calendar and varieties (**why** that variety, **when** did you switch to this variety)
   1.2. Current fertilizer use
   1.3. Current irrigation practices
2. Where do you sell your crops? *Only subsistence/local market/supermarkets/…*
3. Is agriculture your only source of income? *Yes/No, livestock/No, poultry/No, fish/…*
4. From the following list, what would you identify as main sources of yield gaps:
   - Technical constraints
     - Declining soil fertility and poor soil fertility management
     - Use of uncertified and/or poor quality seeds
     - Inappropriate land preparation methods
     - Inappropriate farming practices under current climate
     - Sub-optimal plant population levels
     - Late planting and/or late application of inputs
     - Unavailability of high yielding varieties
     - Pest and diseases
     - Use of old low yielding varieties
     - Weeds
     - Others…
   - Socio-economic constraints
     - Limited access to credit
     - Poor access to information/extension service
     - Limited and/or high cost of labour
     - Limited access to profitable market
     - Lack of awareness of improved technologies
     - Risk aversion of farmers in the face of climate variability
     - Others…
   - Institutional constraints
     - Land tenure
     - Absence of well-organized farmer groups
     - Inadequate public investment in advisory services and infrastructure (e.g. rural roads, education, health)
     - Inadequate institutions and policies (e.g. enforcement of regulations)
     - Others…
5. How well is access to seed, seedling and tree markets? *Very well/physically unable to benefit/economically unable to benefit/…*
6. How well is access to credit? *Very well – not at all*
7. Are there any farmer's cooperatives in the area? *Yes/no*
   7.1. **If yes:** What do they do?
   7.2. **If not:** Would it help to have one, to improve your farm?
8. Perceived climate change

8.1. Impact on yield
9. Expecting climate change
10. Did/Do farmers already adjust their farm practices to historical/potential changes in climate? *Yes/No/…*
    - If yes: What measures did you implement, and why did you decide to implement these? *Water harvesting/soil conservation/crop change/irrigation system/agroforestry/income diversification/greenhouse/…*
    - If yes: How do they affect your yield? *Positively/negatively/not at all/…*
    - If yes: *Are they still sufficient for farming?*
    - If no: Why not (yet)? *Lack of money/lack of knowledge/not needed/…*
11. Where would you see your farm/yields in 5 years from now? And in 20? Just like now, serving my subsistence/increased yields to serve (bigger) local market/increased yields to serve export market/…
12. Threshold (objectives)
    12.1. What weather conditions would force you to change your practices in horticulture to live up to this goal? Two consequent dry years, less than .. days of rain between .. and ../…
13. What changes should be made in policy/government support for you to consider to adapt to a changing climate?
14. Weighing of indictors in MCA
    - Cost efficiency
        - Operating and maintenance costs
        - Short term returns
        - Long term returns
    - Organisation
        - Implementation dependence (independent – government interference)
    - Effectiveness
        - Time to effectiveness
        - Reducing sensitivity to climate change
            - Drought
            - Extreme rain events
            - Heat stress
            - Erratic rainfall (predictability)
        - Robustness under different climate scenarios
        - Flexibility under different climate scenarios
    - Co-benefits
        - Economic benefit
        - Social benefit
        - Environmental benefit

1.2 Extension workers

1. How many farmers do you serve in your county?
2. Are you aware of any county/country objectives for horticulture sector?
   2.1. Contribution of smallholder farmers to reaching these objectives
3. What is the average farm size in your district? …
4. Do farmers use any form of fertilizer? *No/Yes, organic/No, inorganic/…*
5. From the following list, what would you identify as main sources of yield gaps:
    - Technical constraints

        - Declining soil fertility and poor soil fertility management
        - Use of uncertified and/or poor quality seeds
        - Inappropriate land preparation methods
        - Inappropriate farming practices under current climate
        - Sub-optimal plant population levels
        - Late planting and/or late application of inputs
        - Unavailability of high yielding varieties
        - Pest and diseases
        - Use of old low yielding varieties
        - Weeds
        - Others…
    - Socio-economic constraints
        - Limited access to credit
        - Poor access to information/extension service
        - Limited and/or high cost of labour
        - Limited access to profitable market
        - Lack of awareness of improved technologies
        - Risk aversion of farmers in the face of climate variability
        - Others…
    - Institutional constraints
        - Land tenure
        - Absence of well-organized farmer groups
        - Inadequate public investment in advisory services and infrastructure (e.g. rural roads, education, health)
        - Inadequate institutions and policies (e.g. enforcement of regulations)
        - Others…
6. Did/Do farmers already adjust their farm practices to historical/potential changes in climate? *Yes/No/…*
    6.1. If yes: What measures did they implement? *Water harvesting/soil conservation/crop change/irrigation system/agroforestry/income diversification/greenhouse/…*
    6.2. If yes: How do they affect their yield? *Positively/negatively/not at all/…*
    6.3. If no: Why not (yet)? *Lack of money/lack of knowledge/not needed/…*
7. Where (according to you) would farmers see their farms/yields in 5 years from now? And in 20? *Just like now, serving their subsistence/increased yields to serve (bigger) local market/increased yields to serve export market/…*
8. What changes should be made in policy/government support for you to consider to adapt to a changing climate?
9. Could you tell me about land ownership in this area? *Privately owned/rented/…*
    9.1. Could land ownership hamper farmers to adapt to CC? *Yes/no/…*
10. How well can smallholder farmers access the markets to seed and trees? *Very well/physically unable to benefit/economically unable to benefit/…*
11. Are there any farmer collectives/initiative present in the area? *Yes/no*
12. Would such an initiative support farmers to take measures on climate change adaptation? *No, farmer can achieve it on his/her own/Yes, economically beneficial/Yes,* organisationally beneficial/…
13. Are people diversifying their income? Yes/No, livestock/No, poultry/No, fish/…
14. Weighing of indictors in MCA

- Efficiency
  - Investment costs
  - Operating and maintenance costs
  - Short term returns
  - Long term returns
- Organisation
  - Implementation dependence (independent – government interference)
- Effectiveness
  - Time to effectiveness
  - Reducing sensitivity to climate change
  - Robustness under different climate scenarios
  - Flexibility under different climate scenarios
- Co-benefits
  - Economic benefit
  - Social benefit
  - Environmental benefit

15. How many farmers do you reach with your programmes on soil and water conservation? Are they specifically aimed to combat the effect of climate change?
16. Contact through Whatsapp, could I use it to send a questionnaire to farmers?

1.3 Expert interviews

1.3.1 Water Resources Authority

The Water Resources Authority (WRA) allocates water resources among the various (sometimes) competing needs. They strive to do this in a sustainable and equitable way, involving stakeholders in the process. An interview was conducted to explore the potential of adopting tube wells as adaptation strategy.

1. You are in charge of water allocation from allocation. On what data is this allocation based?

❖ Basin levels

❖ GW levels

❖ Rainfall

2. Density of measurements is sufficient?
3. Do you have data on historical groundwater/basin levels in Kiambu and Kajiado?
4. Do you have any idea on aquifer sizes?
5. Groundwater is salty in some locations, is this something to worry about?
6. How many borehole permits have given out for Kiambu and Kajiado counties?

❖ According to land size and production?

7. What will happen after large scale implementation of boreholes?
8. Community development is mentioned on your website, in what form are you achieving this?
9. What should change in policy/governmental support for farmers to be financially able and willing to start adapting to climate change?

1.3.2 Water Research and Resource Center

The Water Research and Resource Center (WARREC) is part of Jomo Kenyatta University of Agriculture and Technology (JKUAT). Among others, they implement projects in the field of agricultural water. As they have experience with smallholder farmers as a target group, they were asked about previous projects that they have executed. Main topics discussed are the incentives that farmers need to invest in climate change adaptation (or increased water availability), and policy support needed to stimulate the farmers in doing so.

1.3.3 Department of Soil and Water engineering

Within the department of soil and water engineering as part of JKUAT, the interviewee works on climate data analyses relevant to smallholder farmers in different counties. The main topic discussed therefore was the perception of farmers on how the climate changes, and what strategies would be best to cope with the changes projected.

Appendix 2: Multi-criteria analysis framework

Measure	Cost-efficiency			Organisation	Effectiveness							Co-benefits			Total score	Weighed score
	Return on investment		Maintenance costs	Responsible party	Time horizon	Robustness	Flexibility	Reducing sensitivity				Environmental	Economic	Social		
	Short term	Long term						P decrease (drought)	P increase intensity (extreme rainfall events)	T increase (heat stress)	Erratic rainfall (predictability)					
Water retention																
On-farm runoff water diversion to infiltration basins	5	5	5	4	5	5	4	4	3	3	5	5	4	4	**4.44**	**4.40**
Runoff water harvesting from external catchment	5	5	5	4	5	5	4	4	3	3	5	5	5	2	**4.36**	**4.39**
On-farm pond/percolation pit	5	5	5	5	5	5	5	4	3	3	4	5	5	4	**4.82**	**4.47**
Gley method	5	5	3	5	5	3	4	3	1	3	5	3	5	2	**4.10**	**3.58**
Rock catchment	5	5	1	2	3	1	1	5	3	3	5	3	1	5	**2.73**	**3.07**
Cistern	3	5	3	3	5	3	1	4	3	3	5	4	5	4	**3.55**	**3.59**
Rooftop rainwater harvesting (above ground)	3	5	5	5	5	5	4	4	3	3	5	5	5	3	**4.53**	**4.36**
Rooftop rainwater harvesting (underground)	3	5	3	5	5	5	3	4	3	3	5	5	5	3	**4.30**	**4.19**
Woollen water retention in root area	5	5	5	5	5	5	4	3	2	3	4	5	4	3	**4.56**	**4.18**
Plastic sheet under crops	5	5	5	5	5	5	4	3	1	3	4	3	4	3	**4.38**	**3.76**
Soil conservation																
Fanya juu	3	5	3	5	3	5	3	3	4	3	3	5	5	5	**4.31**	**3.88**
Jessour	3	5	3	5	5	3	3	3	4	3	3	5	5	5	**4.31**	**3.88**
Tabia	3	5	3	5	5	5	3	3	4	3	3	5	5	5	**4.43**	**4.05**
Growing with contours	5	5	5	5	5	5	5	3	4	3	3	5	5	5	**4.89**	**4.40**
Contour bunds	5	5	5	5	5	5	4	3	4	2	3	5	5	5	**4.81**	**4.23**
Mulching	5	5	5	5	5	5	5	3	2	4	5	5	5	3	**4.74**	**4.45**
Small pit cultivation	5	5	5	5	5	5	5	3	2	2	4	5	5	3	**4.69**	**4.20**
Increase OM content	5	5	5	5	5	5	5	3	2	2	3	5	5	3	**4.68**	**4.11**
Conservation tillage	5	5	5	5	5	5	5	3	3	3	5	5	5	3	**4.74**	**4.45**
Green manure	5	5	5	5	5	5	5	3	2	2	4	5	5	3	**4.69**	**4.20**
Raised bedding	5	5	5	5	5	5	5	1	5	1	1	3	3	3	**4.31**	**3.57**
Agroforestry																
Mango	3	5	5	5	3	5	3	4	3	4	5	5	5	3	**4.35**	**4.19**
Macadamia	1	3	5	5	1	5	3	4	3	4	5	5	5	3	**3.90**	**3.81**
Banana	3	5	5	5	3	5	3	4	3	4	5	5	5	3	**4.35**	**4.19**
Papaya	3	5	5	5	3	5	3	4	3	4	5	5	5	3	**4.35**	**4.19**
Cropping practices																
Adjust cropping calendar	5	5	5	5	5	5	5	4	4	4	2	5	4	3	**4.66**	**4.44**
Switch to climate tolerant varieties, or short cycle when season starts late	5	5	5	5	5	5	4	5	3	5	3	5	4	3	**4.63**	**4.52**
Crop change/diversification	5	5	5	5	5	5	4	4	3	3	4	5	4	3	**4.59**	**4.35**
Bucket cultivation	5	5	5	5	5	3	4	3	1	3	3	4	4	3	**4.32**	**3.67**
Irrigation																
Drip irrigation	3	5	3	5	5	5	3	4	2	3	4	4	3	4	**4.10**	**3.83**
Bottle irrigation	5	5	5	3	5	5	4	4	2	3	4	4	5	4	**4.16**	**4.03**
Hydroponic system	3	5	3	5	5	3	2	4	4	4	4	5	5	4	**4.21**	**4.03**
Tube wells	1	3	3	4	5	1	4	5	2	3	5	1	4	1	**2.94**	**2.95**
Heat stress prevention																
Shade nets	3	5	5	5	5	5	4	2	2	4	2	3	4	3	**4.20**	**3.58**
Plastic rain shelter	5	5	3	5	5	3	4	2	4	4	2	4	4	3	**4.19**	**3.75**
Greenhouse farming	5	3	1	5	5	3	2	4	4	4	4	2	5	3	**3.71**	**3.40**
Sprinkler irrigation	3	5	5	5	5	5	4	4	2	4	4	2	4	2	**4.09**	**3.74**
Post-harvest quality conservation																
Zero-energy cool chamber	3	3	5	4	5	5	4	2	4	2	2	4	5	3	**3.95**	**3.60**
Charcoal cold room	3	3	5	4	5	5	4	2	4	2	2	4	5	3	**3.95**	**3.60**
Solar dryer	3	3	5	4	5	5	4	2	4	2	2	4	5	4	**4.03**	**3.61**
Road protection	5	5	5	4	5	5	4	4	3	3	5	5	5	2	**4.36**	**4.39**
Off-farm adaptation																
Livelihood diversification	5	5	5	5	5	3	4	4	3	3	3	5	5	4	**4.62**	**4.13**

Appendix 3: Interview results

2.1 Kiambu (farmers and extension staff)

In Kiambu and its neighbouring county Murang'a, a total of 8 farmers were interviewed in this research. Half of those farmers were visited for an orientational visit only. The other 4 (all located in Kiambu county) have been interviewed on further details on their climate change experiences. The results of the interviews are presented below, structured per theme of interest.

The extension officer interviewed (extension officer #1) is head of the crop department of sub-county Gatondo South. In Gatondo South, these extension services reach about 30,000 farm families with her extension services and is in the field with them on a weekly basis. These 30,000 farmers are distributed among four wards through which extension services are provided on the lowest spatial level. Farmers interviewed are from the wards Kiamwangi and Ngenda. Within Kiambu, these wards have a relatively dry and wet climate respectively. This slight difference in climate however is not reflected in their farming practices.

Farm information

Farmer responses
Smallholder farmers (0.5 to 5 acres) in these counties primarily cultivate their products for household subsistence. The surplus (if any) is sold on the local market. One farmer supplies the export market with its organic produce. Except for the biggest farmer (5 acres), all respondents depend on additional sources of income besides their agriculture. Five out of eight farmers also own small scale dairy production. One farmer had recently diversified to catfish production. One farmer family depends on the income generated by a fulltime job practised by one of the household heads, while another farmer also owned a shop. In the latter two cases, agriculture is seen as a side-business. Main crops cultivated in the area are banana (practised by 7/8 farmers), maize (5/8), avocado (4/8) and mango (3/8). Other crops cultivated (to a lesser extent) by interviewed farmers are macadamia, beans, chili, tomato, spinach, kale, gravelia, eucalyptus, coffee, nightshade, orange, sweet potato and squash. All crops that are rainfed are planted slightly before or at the onset of the two rain seasons. Harvest takes place between 3 weeks to 6 months after planting, depending on the crop. All farmers strive to use the two growth seasons a year. All respondents that perform dairy farming use cow manure as fertilizer. One of the other farmers uses inorganic fertilizer. The last two farmers do not use fertilizers. However, one of them does incorporate nitrogen binding crops in his/her rotation. Irrigation is used by half of the farmers. Half of those using irrigation practise drip irrigation, the other half applies water on the field manually.
Extension
According to extension officer #1, the mean farm size of smallholder farmers in Gatondo South is less than two acres. Almost all farmers use organic fertilizer. All land in Kiambu is privately owned by the farmer. Around 85% of the total amount of farmers is reached in the extension services provided. Most of this is demand driven service, but extension officers also host programmes and trainings. Contact with the farmers goes via SMS, phone calls, farmer groups and radio.
Interpretation interviewer

Main crops in this area also include beans, spinach/kale, tomatoes and Irish potatoes. These are often cultivated for own consumption in a domestic garden.

Main cause of yield gap

Farmer responses

The following list is presented to four smallholder farmers in Kiambu. The number behind each potential constraint indicates how many farmers identified it as main constraint applicable to their farm.

- Technical constraints
  - Declining soil fertility and poor soil fertility management → 2
  - Use of uncertified and/or poor quality seeds → 2
  - Inappropriate land preparation methods → 1
  - Inappropriate farming practices under current climate → 4
  - Sub-optimal plant population levels → 1
  - Late planting and/or late application of inputs
  - Unavailability of high yielding varieties
  - Pest and diseases → 3
  - Use of old low yielding varieties → 2
  - Weeds
  - Others…
- Socio-economic constraints
  - Limited access to credit → 3
  - Poor access to information/extension service
  - Limited and/or high cost of labour → 1
  - Limited access to profitable market
  - Lack of awareness of improved technologies
  - Risk aversion of farmers due to lack of knowledge on climate variability
  - Others…
- Institutional constraints
  - Land tenure
  - Absence of well-organized farmer groups
  - Inadequate public investment in advisory services and infrastructure (e.g. rural roads, education, health)
  - Inadequate institutions and policies (e.g. enforcement of regulations)
  - Others…

Farmer collectives are present in the area in the form of informal groups. According to one of the farmers, setting up a formal farmer collective stranded due to mistrust among farmers. Being part of a farmer group could help farmers gaining access to higher quality farm inputs and reaching a bigger market.

It is difficult for farmers to get a loan through the commercial banks. However, on a more local level, table banking within farmer groups works to get access to money. Farmers also use saving and credit cooperatives to do so. However, a maximum amount of money can be taken out per time. This limits the farmers in their investments.

Extension

Extension officer #1 was asked to highlight the main constraints to reaching optimal yield, faced by farmers in her sub-county.

- Technical constraints
  - Declining soil fertility and poor soil fertility management
  - Use of uncertified and/or poor quality seeds
  - Inappropriate land preparation methods
  - Inappropriate farming practices under current climate
  - Sub-optimal plant population levels
  - Late planting and/or late application of inputs
  - Unavailability of high yielding varieties
  - Pest and diseases
  - Use of old low yielding varieties
  - Weeds
  - Others…
- Socio-economic constraints
  - Limited access to credit
  - Poor access to information/extension service
  - Limited and/or high cost of labour
  - Limited access to profitable market (only quality issue)
  - Lack of awareness of improved technologies
  - Risk aversion of farmers in the face of climate variability
  - Others…
- Institutional constraints
  - Land tenure
  - Absence of well-organized farmer groups (minimal trust)
  - Inadequate public investment in advisory services and infrastructure (e.g. rural roads, education, health)
  - Inadequate institutions and policies (e.g. enforcement of regulations) (real estate)
  - Others…

Being part of a farmer group could help farmers reaching a bigger market by providing a collective yield that is stable in terms of quantity and quality. Their collective negotiation power is stronger compared to that of a single farmer, getting a higher price for the products sold. Besides, a former farmer collective would enable farmers to eliminate the 'middle man' (broker), thereby saving extra money.

Interpretation interviewer

Most constraints identified by farmers are of technical nature. All farmers acknowledged the fact that their current practices are not well equipped to deal with the current climate.

Declining soil fertility has been pointed out as main constraint by the two farmers that are located in an erosion prone zone.

What stands out is the mentioned constrained of using low yielding varieties, while high yielding varieties are not unavailable according to the farmers. This cannot be explained by any of the farmer's elaborations.

The difference between the main constraints identified by the extension worker compared to those identified by the farmer is especially evident in the socio-economic (lack of awareness on technologies and risk aversion under climate change) and institutional (absence of farmer groups and inadequate institutions and policies) categories. Probably, this can be explained by her involvement in those processes on a higher institutional level.

As an additional technical constraint, she mentions late planting and/or late application of inputs based on her experiences with rainfed agriculture in the area. Farmers are waiting for the rains to start their cultivation. Sometimes they wait too long (unpredictable showers), and start preparation too late.

Main constraints in Kiambu county, according to these interviews, are i) inappropriate farming practices under current climate, ii) pest and diseases, and iii) limited access to credit.

Perceived climate change

Farmer responses
The following climatological trends have been identified, as described by 8 farmers in Kiambu. The number behind each potential constraint indicates how many farmers identified it as main constraint applicable to their farm. - Erratic rainfall → 8 - Late wet season onset → 3 - Shortened wet season → 2 - Badly distribution of rain → 3 - Less rainfall → 3 - Higher temperatures → 5 - Lower temperatures → 1
Extension
Extension officer #1 confirms that among farmers in her sub-county, water shortage is key issue. It results in a lack of water for irrigation, making most farmers fully dependent on rainfall to meet their crops' water requirements.
Interpretation interviewer
During the month of the field visit (September 2019), the temperature was way lower than what farmers were used to. This might have influenced the response of the one farmer mentioning lower temperatures as an observed change in climate. Farmers telling about their experiences with a changing climate seem to talk about climate variability instead. Being dependent on rainfall for their crop growth, their main focus seems to be on timing and duration of the rains, which both are highly variable. Possibly, farmers reflect on the circumstances during the last five to ten years when they have to describe changing patterns. In these five to ten years, a lot of other factors could have played parts in determining water availability that are not taken into account. These interview results therefore should be validated by a climate data analysis. A rising temperature is less dependent on external factors. In Kiambu county, main focus in adaptation to climatic circumstances is on climate variability rather than long term climate change. Both the demand from farmers as well as the services provided by

the extension office centres around seasonal forecasting. Long term planning around the expected changes in climate does not happen.

SWC measures undertaken

Farmer responses

The following soil and water conservation measures are used by 8 farmers in Kiambu. The number behind each measure indicates how many farmers implemented it on their farm.
 	
- Water harvesting
  o From external catchment → 1
  o Shallow well → 4
  o Rainwater harvesting for purpose of irrigation → 3
- Water retention (on property)
  o Storage tank → 3
  o Ponds → 2
  o Pit cultivation → 4
  o Growing with contour → 2
  o Terracing → 5
- Planting tolerant varieties → 8
- Crop diversification → 6
- Mulching → 5
- Conservation agriculture → 2
- Agroforestry → 6
- Greenhouse agriculture → 1
- Irrigation → 4
 	
At least four of the interviewed farmers in Kiambu county consider their farms to be well-equipped to deal with a changing climate.

Extension
Extension officer #1 estimates that around 25% of all farmers under her supervision are implementing a wide variety of soil and water conservation measures on their farms. 37,5% is in the process of implementing a few measures, while the other 37,5% does not act to deal with climatological stresses at all. She says that is mainly due to ignorance. Only for 15-20% of the farmers, it is a matter of lack of access to proper resources. According to Extension officer #1, these farmers are not aware of the fact that implementing (some of the) soil and water conservation measures does not require a lot of resources. She confirms that most people that did apply soil and water conservation on their farm feel secure about the future productivity of their farms, even under a changing climate. The measures that have been implemented around Gatondo sub-county are the following: Water harvesting, shallow wells, boreholes, water tanks, retention ditches, water ponds, crop diversification, conservation agriculture, composting, mulching, benched terracing, trash lines, fanya juu (napia grass), fanya chini (in gradual areas), tolerant crops/varieties and agroforestry (macadamia, avocado, papaya, gravelia). Agroforestry is widely implemented in the county, originating approximately 15 years ago. This was initiated by the agricultural extension office. At that time, decreasing soil quality and small plots due to the subdivision of land per generation influenced farm productivity negatively. Farmers found out

that farm productivity increased significantly by planting trees (cash crops), and widely adopted the practice.
Interpretation interviewer
Planting tolerant varieties is an adaptation technology that is widely adopted. This can be explained by the seed supply executed by the local Agrovet. This institution gets informed about what variety will work in what area in what systems. Therefore, they are able to hand out seeds that perform well under local circumstances. Their advice is also based on the seasonal forecast issued by the Kenyan Meteorological department, distributed via extension officers. Farmers that implement measures on their farm did so to i) reach bigger markets, or at most to ii) manage current climatological circumstances, being highly variable temperatures and water availabilities. Some however did (when implementing measures) not even realize that these measures could induce climate proofing of their farm. Moreover, in the future, when droughts may occur more often, the measures currently implemented might not suffice. Farmers thinking to be well equipped to a changing climate can be attributed to the tendency of farmers to confuse long term climate change with climate variability.

Future objective/policy support

Farmer responses
All four respondents to this question mention the aim to expand their production in the near future. Two of the four farmers focus on their dairy production in this expansion. One of the other farmers wishes to be able to supply schools and supermarkets with vegetable crops in 5 years from now. What goes for all four farmers, is that water availability is the only climatological hazard preventing them from expanding their production. Irrigation, one mentions, is the key to growth. In reaching their objective, farmers are asked how policy/government could support them. According to them, the price for tank water for the purpose of irrigation should go down (like the water for domestic use). Another policy potential mentioned is in banning the cultivation of trees like Eucalyptus, that withdraw water in large quantities.
Extension
The Kiambu county objective for horticulture is 'to increase food security at household level in order to increase household income and reduce poverty, and to create employment (for youth)'. Extension officer #1 knows that the farmer objective is similar to that of the county of Kiambu. Focus for most farmers however is on providing food for their domestic use since most farmers have diversified to fulltime jobs besides agriculture. Policy and governmental support that could contribute to reaching this objective could according to Extension officer #1 be found in the field of land use planning to prevent natural resources from degrading. Key aspect is the actual enforcement of existing policies. For example, riparian land should not be used for agricultural purposes. Another example is the ban on Eucalyptus plantations. Governmental support is given in the form of programmes and installation of technologies. To qualify for receiving a programme that involves new technologies like the excavation of a water pan, sub-counties have to identify the location in their area that is likely to be most vulnerable to drought. The county government then selects a pre-set amount of locations, depending on their budget.

The two agricultural training centres in Kiambu county are under the responsibility of the county government. Demonstrations and trainings on sustainable farming practices ought to be planned regularly. However, poor management led to minimal use of the centres.
Interpretation interviewer
The surplus is sold on the market and provides income. Increasing production would safeguard domestic production and a raising income. However, since most farmers have additional sources of income, increasing their production is not prioritized. Currently, the Water and Sanitation Act of Kiambu county describes the need for people to adopt water harvesting techniques. It indeed is widely adopted but main driver for this widespread adoption is people's suffering from water shortages, not the regulation telling them to do so.

2.2 Kajiado (farmers and extension staff)

In Kajiado, five farmers were interviewed in this research. Two of these farmers answered questions on their experiences with climate change and the effects on their horticulture. The results of the interviews are presented below, structured per theme.

Two extension officers were interviewed in Kajiado county. Extension officer #2 is the agricultural extension officer for Kitengela ward (lowest spatial level government). Extension officer #3 currently is livestock extension officer, but has been crop extension officer in the past. Their combined answers are given in the 'extension' box below. In their ward, they serve around 200 farmers directly. Their indirect range logically is bigger than that.

Farm information

Farmer responses
In Kajiado, five farmers were interviewed in total. Two of these farms are large (30 acres) and hence do not represent our target (the smallholder farmer). However, the information gathered on these visits is mainly basic information on practices and the production potential of the area. Three out of five farmers interviewed in Kajiado county primarily cultivate their products for household subsistence. The surplus (if any) is sold on the local market. One farmer supplies the local market, while one other farmer supplies the export market. Except for these two biggest farmers (30 acres), the respondents depend on additional sources of income besides their agriculture. Main crops cultivated in the area are maize (practised by 4/5 farmers), beans (3/5), spinach/kales (4/5) and tomato (3/5). Other crops cultivated (to a lesser extent) by interviewed farmers are chili, gravelia, mango, nightshade, sweet potato, papaya, onion, sorghum and cassava. All crops that are rainfed are planted slightly before or at the onset of the two rain seasons. Harvest takes place between 3 weeks to 6 months after planting, depending on the crop. All farmers strive to use the two growth seasons a year. Two of the farmers have mentioned to use cow manure fertilizer. One of them combines the manure with the application of inorganic fertilizer. Irrigation is used by three out of five farmers. Half of those using irrigation practise drip irrigation, the other half applies water on the field manually. Irrigation is only used by one smallholder. The other two smallholders were limited by lacking physical and economical access to water.
Extension
In Kajiado, not all people are able to farm due to unfavourable climatic conditions. Most farmers cultivate vegetables on a very small scale, for domestic consumption. Via extension services, they are taught how to adapt their domestic garden to climatic circumstances. High intensive farms are included in the extension service, but often have their own means to adapt. Also, it is hard for government officials to work with large commercial farms. Therefore, the main target of their extension work is the local (domestic) farm that needs empowerment to contribute to one of the main pillars of the government – food security. Most farmers in Kajiado county are smaller than one acre. Around 8% of the people leases his/her land, the rest is privately owned. Most land in Kajiado is owned by the Maasai tribe, that use it primarily for cattle grazing. To smallholder farmers applies that if any vegetable surplus exists, it will be sold on the local market. Maize and beans are primarily cultivated for domestic use. Smallholder farmers do not solely depend on farm for income, some diversified to fish or pig farming or run a business in their daily jobs.

The extension services offered on ward level mainly are demand driven. In some cases, input comes from the Kajiado county government. Wards sometimes get the opportunity to fill in the content of the programme themselves, on the basis of what they think is needed to be learnt. However, money should be made available on county level in those cases. In their extension services, they reach all 200 farmers as long as there is money available to provide free transport or lunch. People often have to travel great distances to attend seminars and trainings.

Interpretation interviewer
The target group in this area is the smallholder farmer that the extension officers are referring to. Three of the farmers interviewed for this study do not fall under that group, and are only asked about their current practices and their experiences with climate change.

Main cause of yield gap

Farmer responses

The following list is presented to two farmers in Kajiado. The number behind each potential constraint indicates how many farmers identified it as main constraint applicable to their farm.

- Technical constraints
  - Declining soil fertility and poor soil fertility management
  - Use of uncertified and/or poor quality seeds
  - Inappropriate land preparation methods → 1
  - Inappropriate farming practices under current climate → 2
  - Sub-optimal plant population levels
  - Late planting and/or late application of inputs → 2
  - Unavailability of high yielding varieties
  - Pest and diseases → 1
  - Use of old low yielding varieties
  - Weeds
  - Others…
- Socio-economic constraints
  - Limited access to credit → 2
  - Poor access to information/extension service → 1
  - Limited and/or high cost of labour → 2
  - Limited access to profitable market → 1
  - Lack of awareness of improved technologies
  - Risk aversion of farmers due to lack of knowledge on climate variability → 1
  - Others…
- Institutional constraints
  - Land tenure
  - Absence of well-organized farmer groups → 2
  - Inadequate public investment in advisory services and infrastructure (e.g. rural roads, education, health) → 1
  - Inadequate institutions and policies (e.g. enforcement of regulations)
  - Others…

Farmer collectives are present in the area in the form of informal groups. According to one of the farmers, setting up a formal farmer collective fails because there is no common goal among people in the area. Being part of a farmer group could help farmers gaining access to higher quality farm inputs and reaching a bigger market.

Access to credit in the area is mentioned to be an issue hampering investments on farm. One of the farmers however has never tried to get a loan. The other farmer that responded to this question mentions the local Women's Group as source for budget. For her however, the problem is that paying off her debts is going slow and does not allow her to take out a new loan when she needs one.

Extension

The extension workers were asked to select all constraints leading to yield gaps that apply to smallholder farmers in their ward. Initially, all potential constraints were selected. However, after a prioritization, the main constraints are **bold** in the overview below. The number below the constraint indicates the ranking that is applied (1 – most important, 5 – least important).

- Technical constraints
  - Declining soil fertility and poor soil fertility management
  - **Use of uncertified and/or poor quality seeds (4)**
  - **Inappropriate land preparation methods (5)**
  - **Inappropriate farming practices under current climate (1)**
  - Sub-optimal plant population levels
  - **Late planting and/or late application of inputs (2)**
  - Unavailability of high yielding varieties
  - **Pest and diseases (3)**
  - Use of old low yielding varieties
  - Weeds
  - Others…
- Socio-economic constraints
  - Limited access to credit
  - **Poor access to information/extension service (4)**
  - **Limited and/or high cost of labour (1)**
  - Limited access to profitable market
  - **Lack of awareness of improved technologies (2)**
  - **Risk aversion of farmers in the face of climate variability (3)**
  - Others…
- Institutional constraints
  - **Land tenure (3) – size**
  - **Absence of well-organized farmer groups (4)**
  - **Inadequate public investment in advisory services and infrastructure (e.g. rural roads, education, health) (2)**
  - **Inadequate institutions and policies (e.g. enforcement of regulations) (1)**
  - Others…

For extension workers, the existence of formal farmer groups would mean an easier access to the farmers in distributing information from the government. Besides, being a formal farmer collective could enable funds more easily compared to an individual farmer.

Land tenure is a identified to be a constraint in terms of average plot size, not in terms of ownership.

Interpretation interviewer

Smallholder horticulture in Kajiado is not as widely spread compared to Kiambu. This explains the lack of community co-support in for example farmer groups.

Both respondents were fully reliant on rain to fulfil their crop water requirements. Therefore, they are extra prone to climate variability. Having to adjust their planting practices to the seasonal forecast, they sometimes get surprised by the onset of the wet season. Land preparation has not been fully performed, leading to a yield gap for that season.

The most important constraints in Kitengela ward, according to these interviews are i) inappropriate farming practices under current climate, ii) late planting and/or late application of inputs, iii) limited access to credit, iv) limited and/or high cost of labour, and v) absence of well-organized farmer groups.

Perceived climate change

Farmer responses
The following climatological trends have been identified, as described by 5 farmers in Kajiado. The number behind each potential constraint indicates how many farmers identified it as main constraint applicable to their farm. - Erratic rainfall → 4 - Late wet season onset → 1 - Shortened wet season → 1 - Badly distribution of rain → 0 - Less rainfall → 4 - Higher temperatures → 2 - Lower temperatures → 0
Extension
Kajiado has suffered prolonged periods of droughts in which no (or barely any) rainfall occurs. The previous extreme dry spell started in 2008 and lasted until 2010. People could not harvest anything as a result. As most smallholder farmers fully rely on rainfall, planning their practices is difficult under erratic rains. People have to wait for the onset of the wet season, which is perceived to be a burden.
Interpretation interviewer
Similar to Kiambu county, farmers telling about their experiences with a changing climate seem to talk about climate variability instead. Being dependent on rainfall for their crop growth, their main focus seems to be on timing and duration of the rains, which both are highly variable. Possibly, farmers reflect on the circumstances during the last five to ten years when they have to describe changing patterns. In these five to ten years, a lot of other factors could have played parts in determining water availability that are not taken into account. These interview results therefore should be validated by a climate data analysis. A rising temperature is less dependent on external factors. As in Kiambu county, main focus in adaptation to climatic circumstances is on climate variability rather than long term climate change. Both the demand from farmers as well as the services provided by the extension office centres around seasonal forecasting. Long term planning around the expected changes in climate does not happen.

SWC measures undertaken

Farmer responses

The following soil and water conservation measures are used by 5 farmers in Kajiado. The number behind each measure indicates how many farmers implemented it on their farm.
 	
- Water harvesting
  o From external catchment → 1
  o Borehole → 2
  o Rainwater harvesting for irrigation purpose → 0
- Water retention (on property)
  o Storage tank → 1
  o Ponds → 1
  o Pit cultivation → 1
  o Growing with contour → 1
  o Terracing → 0
- Planting tolerant varieties → 5
- Crop diversification → 4
- Mulching → 2
- Conservation agriculture → 0
- Agroforestry → 2
- Greenhouse agriculture → 1
- Irrigation → 3

Extension
An estimated 10% of the farmers is implementing soil and water conservation technologies on their farms. This percentage is low due to lack of financial resources, fear of the future (for example, irrigation is not adopted because people are afraid to exhaust water available for domestic use) and lack of knowledge. Farmers that did implement measures on their farms, mainly implemented the following measures: ❖ Water harvesting ❖ Water pans ❖ Dam liners (very few) ❖ Planting trees ❖ Terracing ❖ Mulching (very small scale, only vegetables)
Interpretation interviewer
As for Kiambu county, the planting tolerant varieties is an adaptation technology that is widely adopted. This can be explained by the seed supply executed by the local Agrovet. This institution gets informed about what variety will work in what area in what systems. Therefore, they are able to hand out seeds that perform well under local circumstances. Their advice is also based on the seasonal forecast issued by the Kenyan Meteorological department, distributed via extension officers. Diversification happened especially after historical subdivision of land, it is a must for stable income generation. Now, it is also a way to cope with climatic circumstances. Farmers that implement measures on their farm did so to manage current climatological circumstances, being highly variable temperatures and water availabilities. In the future however, when droughts may occur more often than at this moment in time, these measures might not suffice. Farmers thinking to be well equipped to a changing climate can be attributed to the tendency of farmers to confuse long term climate change with climate variability.

Future objective/policy support

Farmer responses
The two farmers that were asked this question were both smallholder farmers that fully rely on rainfall for their farms' water supply. One of them responds that within 5 years from now, he/she will still grow the same amount of food as her current produce. He/she believes that her land is producing its potential yield under the current climate already. If he/she will be able to buy more land in the area, he/she would like to expand her farming and upscale her business. The other respondent wishes to diversify her crop supply in the near future. In reaching these objectives, water availability is the main issue encountered. According to one farmer, policy support will not help to reach the objective in any way. An option she does mention in terms of governmental support is the organisation of seminars and trainings. The other farmer touches upon the point that she has seen the government support (relief aid) disappear from the area. Also, most government support in Kajiado is targeting the Maasai and their cattle, since they are the original inhabitants of the area.
Extension
The main objective of the ward of Kitengela on agriculture is to make room for commercial income generation, growth of farms into market oriented businesses in which people are empowered. Most farmers do not share the objective to grow bigger, according to both extension officers. Farming for their own domestic use and the local market, they fear competition of commercial farms when they grow their production. Supplying a bigger market comes with a lot more policies and regulations to be met. Commercial farmers already struggle with them, so smallholder farmers remain discouraged and passive. Another issue that keeps smallholder farmers from investing in production expansion is the high price of inputs for commercial farming. The government in the past tried to overcome this by subsidizing fertilizers. However, this offer was not widely used. Extension officer #3 thinks that investments need to be made in research to pest resistant crops. Drought resistant crops are widely available already. Both extension officers agree on the need for a land use planning policy and its enforcement. Kajiado county has a demonstration farm for trainings. However, these are mainly targeting the livestock keeping community from pastoralist areas. The functioning of the crop section of the demonstration farm has deteriorated. Greenhouse farming trainings that have been mentioned in the Kajiado comprehensive report, have not been trickled down to Kitengela ward. Moreover, smallholder farmers are not in the position to implement greenhouse farming practices.
Interpretation interviewer
The yield surplus is sold on the market and provides income. Increasing production would safeguard domestic production and a raising income. However, since most farmers have additional sources of income, increasing their production to commercial levels is not prioritized.

2.3 Expert interviews

2.3.1 Water Resources Authority

Groundwater level is monitored every month (level and quality) at stations across the country. Very many in Central and Western Kenya.

GW development → mapping out aquifers. Major aquifers are in northern area and along the coast. Mapped out in various parameters (amount of water, status of water quality). So, when drilling a borehole, they know exactly how deep it should be (production level of boreholes at different depths in terms of m3).

Farmers mainly use:

- Shallow wells 10 – 15 meters deep (dug), these are recharged;
- Boreholes 70 – 150 meters majority (pump is needed, mainly commercial users).

Effect of climate change on water availability from aquifers: Level is dependent on incoming rain, if rain changes (quantity or pattern), it will influence the water level. Surface water level has gone down quite a lot. People do not trust surface water flows anymore because flow rates have gone down due to catchment degradation, and because of contamination of the water. → Groundwater is more trusted. Delays in rainfall/intensity/flash floods/drought will influence groundwater in same share. Groundcover is lost, water table fluctuates a lot due to bare soils.

Climate change is taken into account in permit issuing: They assess what they have, in terms of quality and quantity. That they allocate and regulate. In times of drought, people should pump less. 'Law says we control them, but we are talking to human beings.' Pumping shifts per village/households to keep livelihood running.

Farmer request borehole with a production of a certain amount of m3/day. Assessment is made on availability. If they cannot meet request, request should be decreased. Assessment is based on current availability, permit is issued for 5 years from assessment onwards. 5 year permit (… m3) already difficult, because a lot of changes occur within 5 years. Many other people will apply for borehole, policy says that they should serve everyone. If more people request for boreholes, the available water will be divided over all borehole owners. Therefore, it could happen that a farmer that is now receiving a daily amount of water, will have to deal with less water in the future. Besides, boreholes should be 80 meters apart at minimum. The maximum amount of boreholes per area is not reached in Kajiado and Kiambu. In Nairobi, it is a disaster already, boreholes are almost banned. Mission to turn people back to surface water (distrust), conserve catchment and remove pollutants.

Is there a focus on Artificial Aquifer Recharge? Yes, they encourage water conservation in terms of 1) harvesting water, 2) storm water management law (no policy!), 3) change building codes.

Where do you draw the line? Based on density of boreholes and the amounts that we are withdrawing. Aquifer can collapse. They know how much they can withdraw. They will not withdraw *35%* of initially available in the most ideal, generalized situation.

In Kajiado, private borehole have dried up. They can continuously pump without WRA knowing), dry up because you did not set a limit. WRA orders people in really dry areas/dry times to their neighbours.

Programmes to citizens include the promotion of planting indigenous trees and bamboo (especially in riparian land), since they are not taking much and even conserve and purify the water.

In dry times, they order different users of aquifers to pump in shifts to spread use. The prioritization is as follows:

1. Domestic — Has priority!
2. Hydropower — Water can be re-used
3. Horticulture
    - 3.1 First store water, then use GW!
    - 3.2 Irrigation at night
    - 3.3 Irrigation water saving
        - 3.3.1 No open unlined furrows
        - 3.3.2 No daytime sprinkling
4. Tea process

Two permits should be issued:

- To drill (quantity)
- Allow to use (quality)

Salty water from aquifer can be caused by rock formation and fluoride content. The water getting more and more salty over time is a sign of exploitation of the aquifer.

Water spent on desalinization should be spent on conservation and dams.

2.3.2 Water Research and Resource Center

National programmes:

- Smart water for agriculture
    - National irrigation acceleration platform

What they often encounter is that for example a water pond is dug, however no financing for shading → a lot of water is lost through ET. People do not know how to handle water.

To increase Kenyan food production, irrigation is a must.

Extension is malfunctioning. Disconnect between farmers and extension. Capacity building is key, but not happening. External development organisations are coming in to support extension (how can we develop … to reach farmers effectively?).

Soil and water conservation (SWC) technologies. How sustainable are they? Most projects target a group (farm bond). Small projects are not so fruitful (is it really making people resilient?), individual farmers should be targeted.

Problem of project implementation:

- Assumption that technologies work (blanket implementation) everywhere
- Sustainability of those projects is a problem (capacity building, ownership)

WARREC is working on:

- Irrigation technology
- Water stress assessment (drones)

- How to improve irrigation in this country
    - National irrigation acceleration platform (NIAP) → network of partners (finance, policy, technology providers, users) in masterclasses, energy is an issue in this as well (access to water, but not able to get harvested water to farm)

Governmental support needed to mobilize farmers:

- Access to credit (link financial institutions to farmers) CAPping, incentives!
- Normally, funding goes to local institution, farmers need to access credit via local institution. There exists a disconnect of coordination.
- Capacity building
- Enabling policies
    - Finance
    - Training

At this point, a lot of conservation activities, catchment conservation are ongoing. The (local) governments are aware of climate change. Projects are proposed to be done, but not actually implemented due to budget constraint and low willingness to act. Initially, they are not aware that it is long term.

Kiambu water and catchment conservation fund.

2.3.3 Department of Soil and Water engineering

Aim: Smallholder agriculture, helping to deal with climate variability.

Climate change policy, does it well address the problems?

2 A lot of people make public policy documents with regard to climate change

3 Not very bad, but there is a lot of talk about climate change, but we should talk about variability

3.1 T is increasing, but not the most important factor in farming

3.2 A lot of people say, P has changed. He thinks that it are other environmental conditions have changed, not water. For example groundcover/population density/cattle intensity (increasing pressures). Rainfall patterns have not really changed, according to him. Variability has been there for ever. Farmers refer to last 5/10 years instead of long term when talking about climate change. In this 5/10 year time span, some other factor have changed (economic, soil fertility), rainfall was just varying.

4 Participatory scenario planning (every start of the season), his input is used to reflect on historical data together with farmers, and then compare these data with farmer perception. Together with a seasonal forecasts, these element will be used in advising the farmers on how to act.

5 Data on Kiambu will be processed soon.

6 Focus in Kenya is on forecast data, instead of focus on historical data (in combination with forecast) while looking back at historical data (with the target groups) allows for reflection on their perception of climate change. Time is limited (2 days in Kenyan projects vs 5 days in Tanzania/Malawi).
7 Risk reduction should be based on historical data instead of basing on forecast that might not become true.

Approach mainly focused on crops → Maasai do not crop anything → for them, NDVI mapping is better.

Focus on rainfed farming, most vulnerable. Harvested water is supplemental → should know how to handle the water.

Storage of water should be promoted. If you can cope with variability, you don't have to fear climate change. Focus on extremes, also in long term climate change. Frost can occur in Kiambu.

How to finance these adaptation options (like a storage tank).

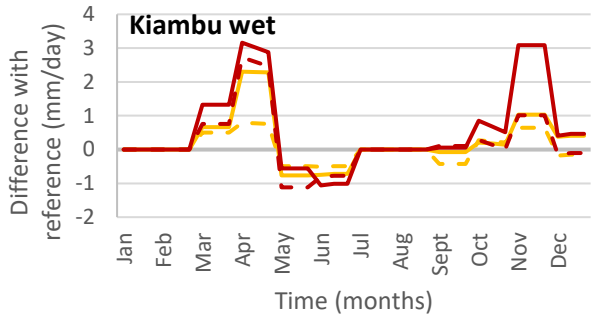
8 Economic analysis of rainwater harvesting (paper)
9 Estimation tool for rainwater harvesting tank size → Excel file

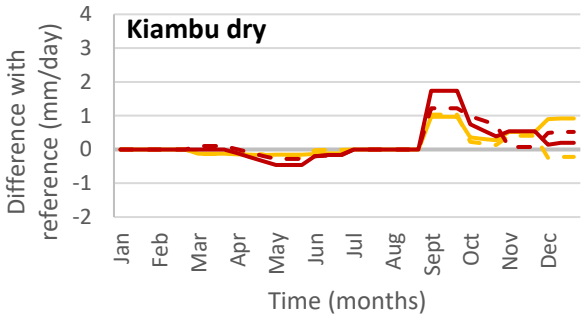
Graphs on historical data in Kajiado and Kiambu → To be received

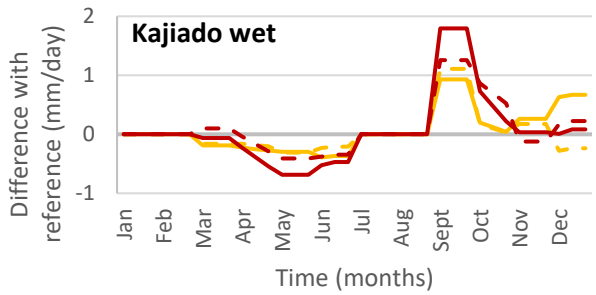
Appendix 4: Data analysis for all crops

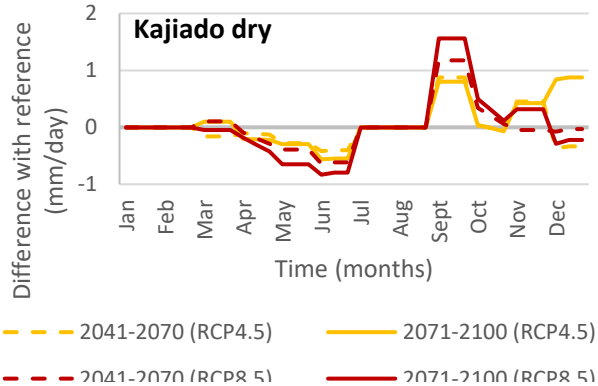
PAW – ET_c for all main crops studied under RCP4.5 and RCP8.5 during mid and end century, relative to reference period. A value > 0 indicates a growing water availability, whereas a value < 0 indicates a declining water availability.

Maize

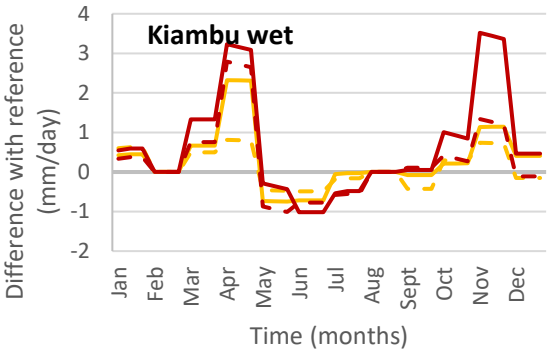


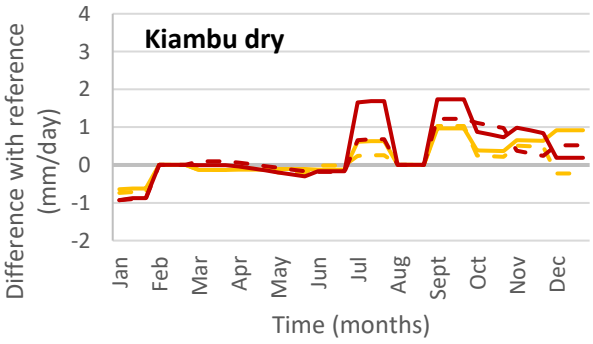


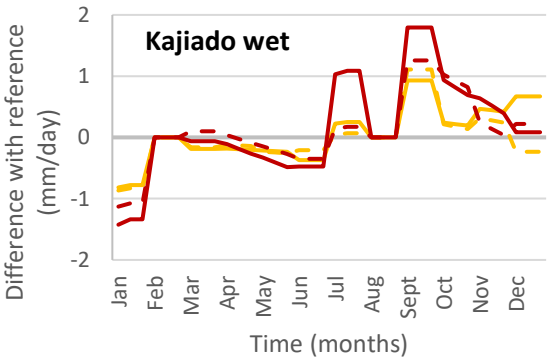


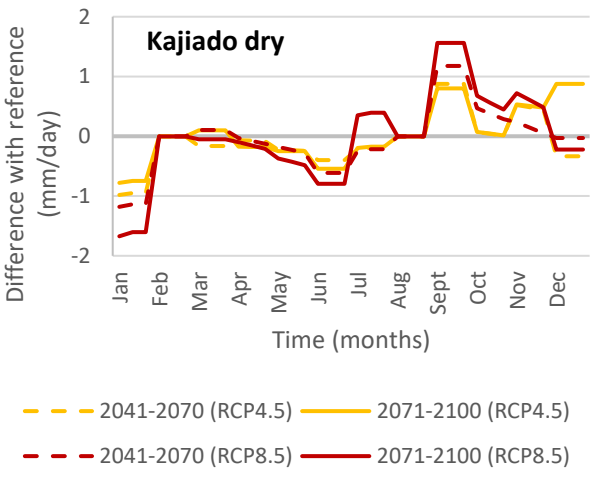


Cabbage

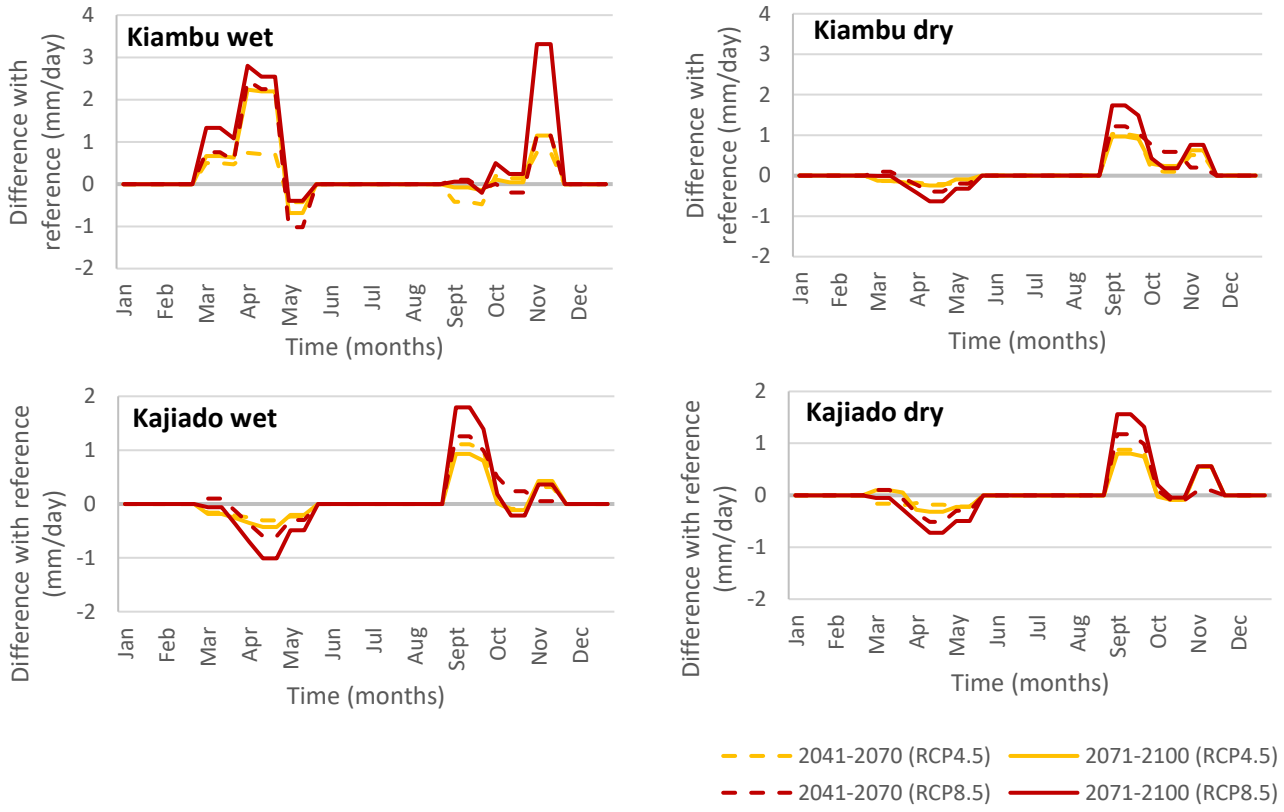




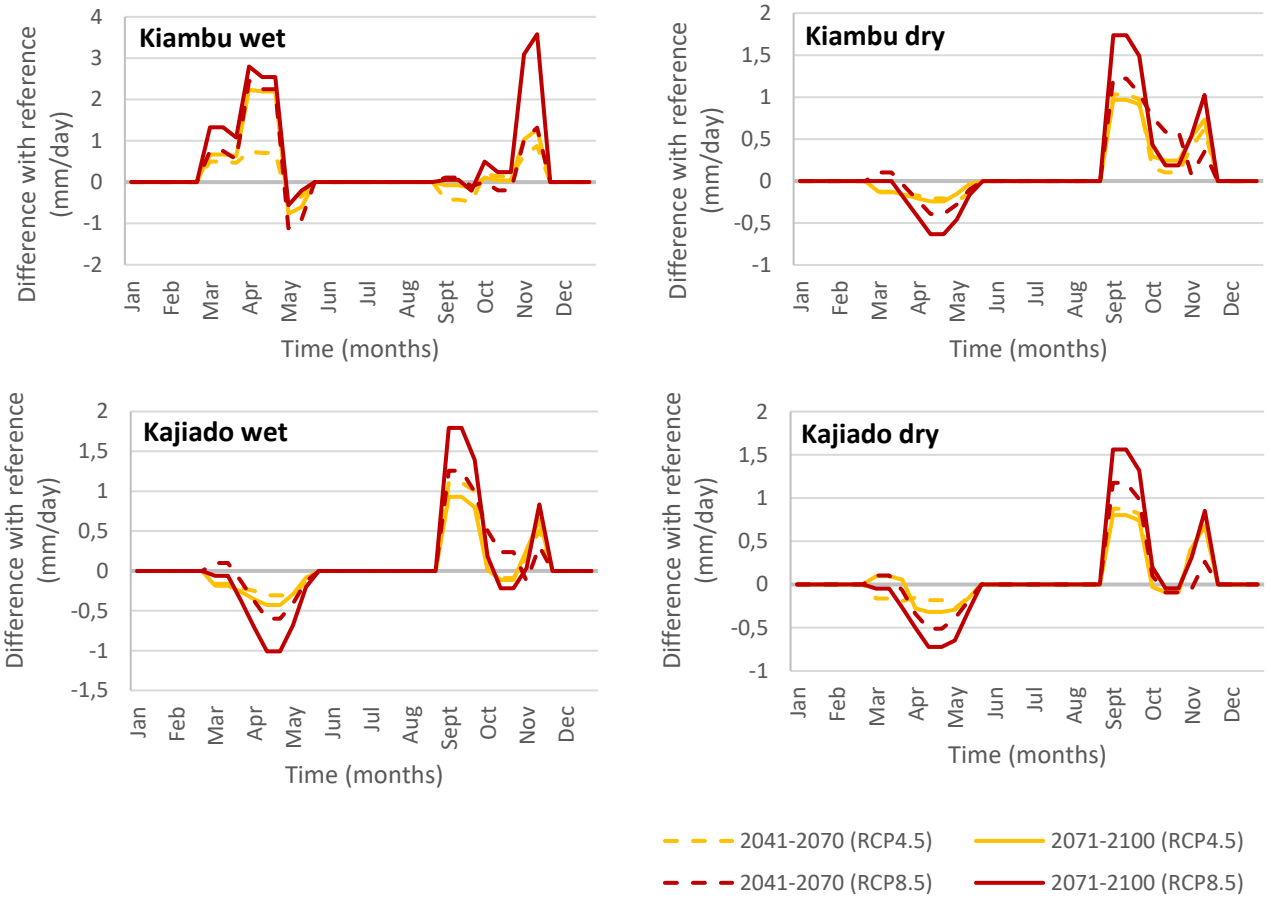




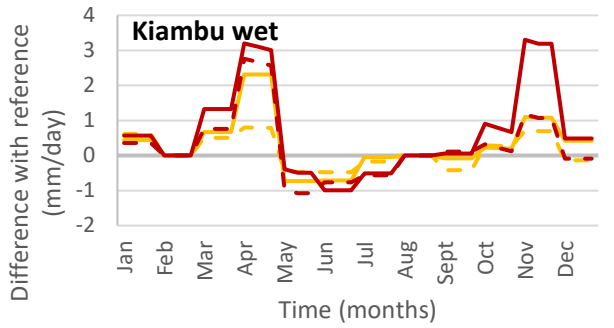
Tomato

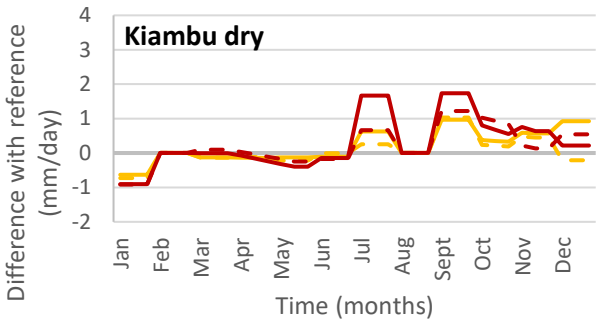


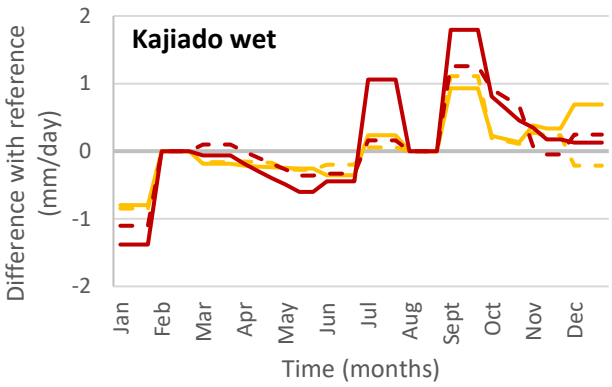
Beans

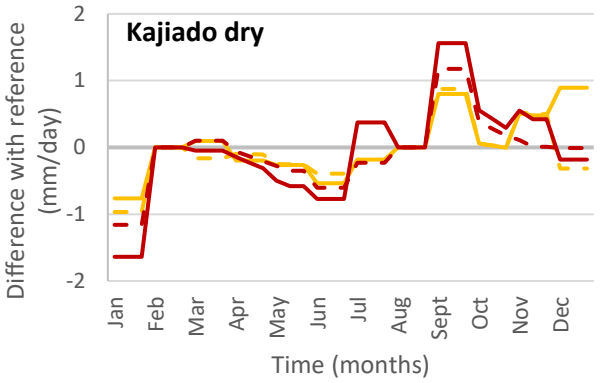


Onion



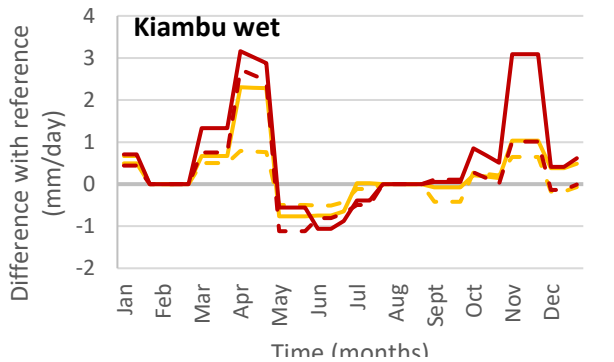


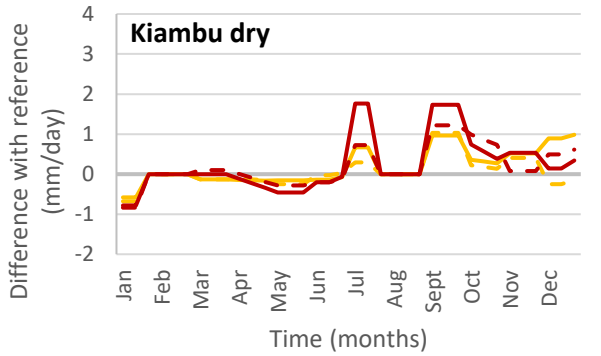


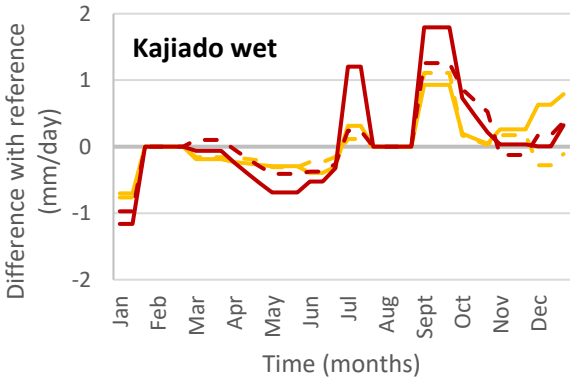


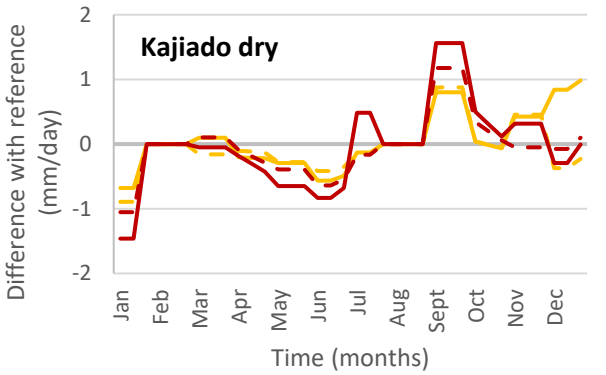


Potato











Appendix 5: Folder with potential adaptation measures

This folder is used to give extension officers and 3R project team members insight in all measures taken into the MCA during the scoring process.

5.1 Water retention

All measures in this section target water retention as one of their main aims. These measures hence could result in an extra source of water available for agriculture in areas characterised by erratic rains, long periods of drought and a limited soil moisture holding capacity. Most measures are based on existing projects performed in areas where water scarcity already had a great impact on households and their livelihoods.

5.1.1 Runoff water diversion to infiltration basins (*943/1390)*

A system of hand dug canals (main diversion canal and secondary and/or tertiary canals) conveys and distributes the captured water from ephemeral rivers, roads and hillsides to the cultivated fields. Agriculture under this system would thus receive runoff water besides rainwater to supply its water requirements. The runoff harvested, could be stored for later use or could be lead to the field immediately. The measure provides water to fulfil crop water requirements, increases soil moisture and recharges the ground water level. Besides, it supports the control of runoff water (UNEP-DHI Partnership, UNEP-DTU, & CTCN, 2017).

To avoid water loss, the receiving fields could be divided into rectangular basins bordered by ridges. This also minimizes erosion risk. Another option would be to lead the water to infiltration pits. Centring crops around such pits would further improve irrigation efficiency.

This practice needs preparedness for immediate action by the farmers: When high rainfall is expected and the in the catchment, farmers should be available to start erecting the embankment across the bed of the stream. Similarly, each farmer starts to maintain the canal which leads water to his field. A schedule should be prepared collectively, defining the date and time each farmer is allocated his turn to irrigate. When the water reaches the field, it could be spread either through flooding or distributed in furrows which are opened and closed using a local tool.

While the diversion canals and basins for tree planting are permanent structures under proper maintenance, basins for annual crops are seasonal. Maintenance is needed every season before the onset of rains. Soil fertility (and hence water retention) could be improved by additional measures such as composting and mulching. (WOCAT SLM Technologies, 2010; WOCAT SLM Technologies, 2011)





5.1.2 Runoff water harvesting from external catchment (1487)

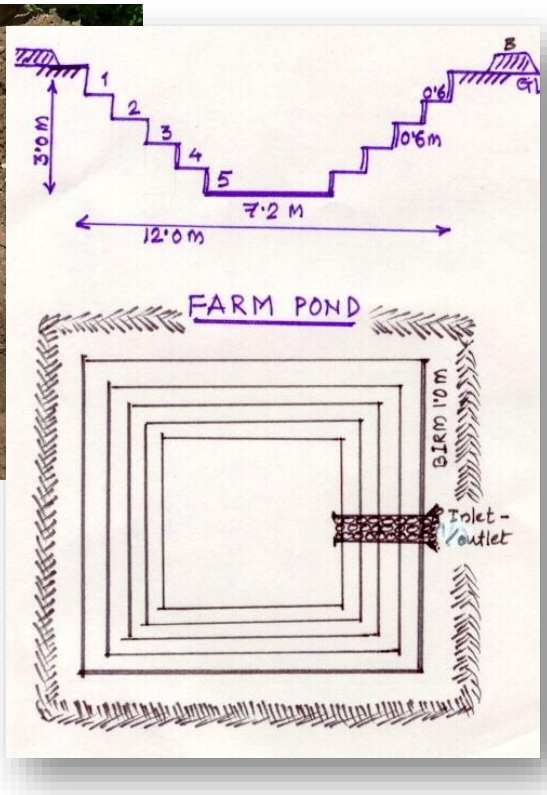
This measure consists of non-graded, hand dug ditches that collect and retain runoff water from roads and/or built-up areas outside the target catchment in which agriculture is performed. These ditches hence provide an extra source of water that could be used for irrigation, on top of the water that is available in the catchment itself. Water is lead from the road to the ditch through a hand dug diversion channel. Besides serving as a source of irrigation water, this measure increases soil moisture and recharges the ground water level. The ditches are accompanied by a soil bund to reduce erosion. (WOCAT SLM Technologies, 2011b)

5.1.3 On-farm pond/percolation pit (1075/1474/619/2844)

Digging a pond on the lowest site on his/her field, a farmer gets access to groundwater as well as the runoff water that is captured. Ponds in the pathway of water runoff intercept the downflow of water and sediments, and thereby reduce erosion. The water that is not used for irrigation purposes, can infiltrate in the soil to retain the aquifer.

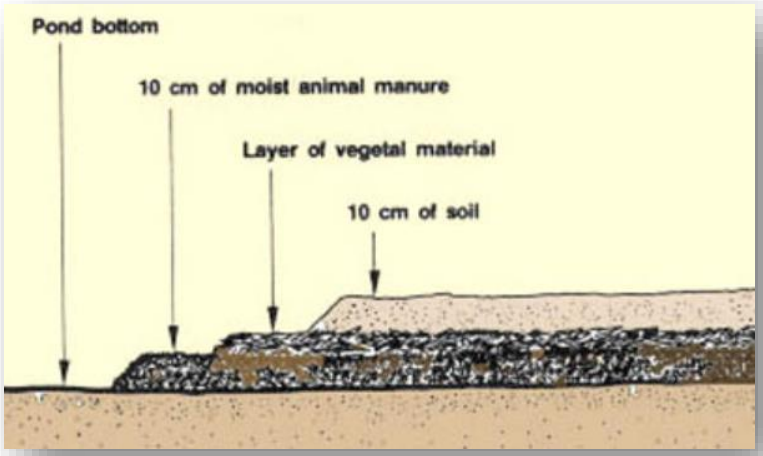
Bigger ponds could be built with an inlet to collect and dispose excess runoff. To stabilize the pond, one could plant local grass species in it. To keep the pond operational, it must be desilted on a regular basis. Main benefit of this measure is that it is localized and it does not have to consume much land. (WOCAT SLM Technologies, 2011c; WOCAT SLM Technologies, 2011d; WOCAT SLM Technologies, 2016; WOCAT SLM Technologies, 2017)





5.1.4 Gley method

The gley method can be used to line ponds and canals. By adding organic materials like banana leaves, grass and manure to the bottom soil of the pond and treating it with cardboard and/or soil, an impermeable layer will be formed as the result of anaerobic decay (FAO, n.d.). This layer prevents leaking and hence results in a higher irrigation efficiency. Especially for farmers without access to groundwater, this technique could be used to retain rainfall and runoff water at the surface. Note that the impermeable layer results in a hampered aquifer recharge.



5.1.5 Rock catchment (580)

The rock catchment system is a large scale water harvesting system constructed on a gently sloping hillside. The (bare rock) hillside is the surface from which rainwater is harvested by a concrete dam. To withstand the force of the collected water, this concrete dam should be reinforced by iron bars. A weir in this dam creates the opportunity to lead water through a metal piping system towards downstream storage reservoirs (masonry tanks). From the tanks, communities can draw water at 'kiosks' where the storage level is being gauged.

The length, height and thickness of a weir varies with the size and the slope of the rock catchment area. On average, a weir will be 10 meters long, 2 meters high and 0.5 meters thick. (WOCAT SLM Technologies, 2017b)



5.1.6 Cistern (1413)

In the cistern system, runoff water is retained and stored in underground storage tanks (cisterns). These tanks are lined with gypsum or concrete to avoid vertical and lateral infiltration, covered by a stone construction and can be of individual or communal use. Each cistern system consists of three parts. The *impluvium* is the sloping catchment area bordered by a diversion channel. The water from this area is concentrated in the *sediment settle basin*, and then lead to the *storage reservoir*.

The size of cistern systems vary from 5-200 m^3 (private) up to 70,000 m^3. It is estimated that a tank with a capacity of 35 m3 can meet the annual domestic water needs of a family and its livestock (Ennabli, 1993). (WOCAT SLM Technologies, 2011e)



5.1.7 Rooftop rainwater harvesting (1460/1497)

The rooftop rainwater harvesting system consists of a catchment roof, conveyance pipes, and a storage jar. The storage tank can be made out of cement for it to be well isolated. To avoid losses through evaporation from the storage tank, it must be placed in the shadow of the house and covered by a (tin) lid. The lid should be large enough to fit a person for occasional maintenance and cleaning. Tanks can have a storage capacity up to 2000 litres. To lead rainwater from the roof gutter (made from longitudinally split pipes) to the tank, conveyance pipes should be installed. These can be made from polythene, plant material or plastic bottles (image).

A tap should be installed around 20 cm above the ground. This height allows for water to be collected in the typical 15 litre water vessels and could avoids collection of too much water in bigger vessels as well as minimising the dead storage of water (Nakarmi et al. 2003). Trained masons can easily install the entire system. (WOCAT SLM Technologies, 2018; WOCAT SLM Technologies, 2019)



5.1.8 Underground rainwater harvesting (1417/1595)

Where the roof is catching the rain as in the previous measure, this measure stores the water in an underground tank. Besides storing water to be used in dry spells without rain, it offers a way in which water is kept cool in a warm environment. The harvested water runs from the roof to the tank through gutters and pipes. (WOCAT SLM Technologies, 2017c; WOCAT SLM Technologies, 2019b)

A hole (3 m wide, 2 m deep) is excavated to build the tank. The walls are constructed with concrete bricks and mortar, followed by a mortar lining. The base is also lined with mortar. To reduce losses through evaporation, the tank is sealed – except for the lid. Again, the lid should be large enough to fit a person for occasional maintenance and cleaning.



5.1.9 Woollen water retention in root area (1508)

Planting trees (or crops) in a bed of wool prolongs the source of soil moisture in the root zone of the tree. Subsequently, this could support the tree to survive longer periods of drought while staying productive. Combined with precision irrigation, it helps to increase irrigation efficiency since less water is lost through evaporation or leakage to deeper aquifers. A plastic pipe could be installed leading water directly from irrigation to the wool.



It is estimated that 10 kilograms of wool, enough for one tree to be based in, retains around 8 litres of water. A substitute for wool (if not locally available) would be hay or pressed sawdust. (WOCAT SLM Technologies, 2017h)

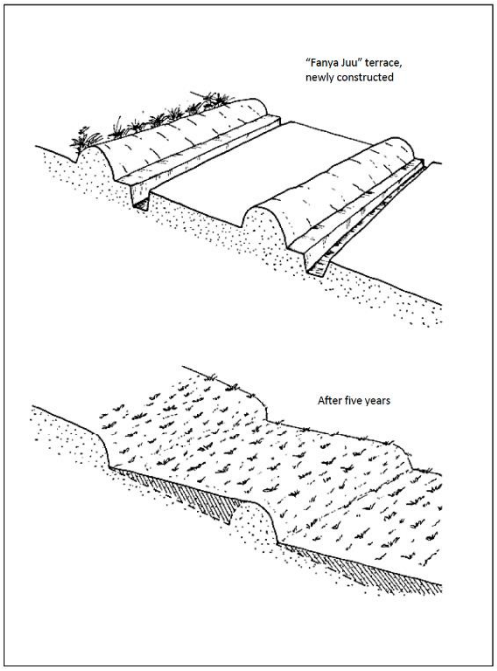
5.1.10 Plastic sheeting

Applying a layer of plastic under fresh, uncontaminated soil destined for crop production is a method to reduce both water and fertilizer leakage. It could work as a support to other measures on the farm, reducing the need of investment in large scaled equipment and labour (for example to excavate a larger pond).

It is estimated that leakage of water and fertilizer may be reduced with 85% using this method.

5.2 Soil conservation

This category of measures has the primary objective to ameliorate and maintain soil quality. In the context of a changing climate, this improved soil quality entails better water retention and discharge in longer periods of drought and times of extreme rainfall. Besides, the higher yield that restored soils could bring, might be an extra driver for the smallholder farmer to adopt these techniques.



5.2.1 Fanya juu (2274)

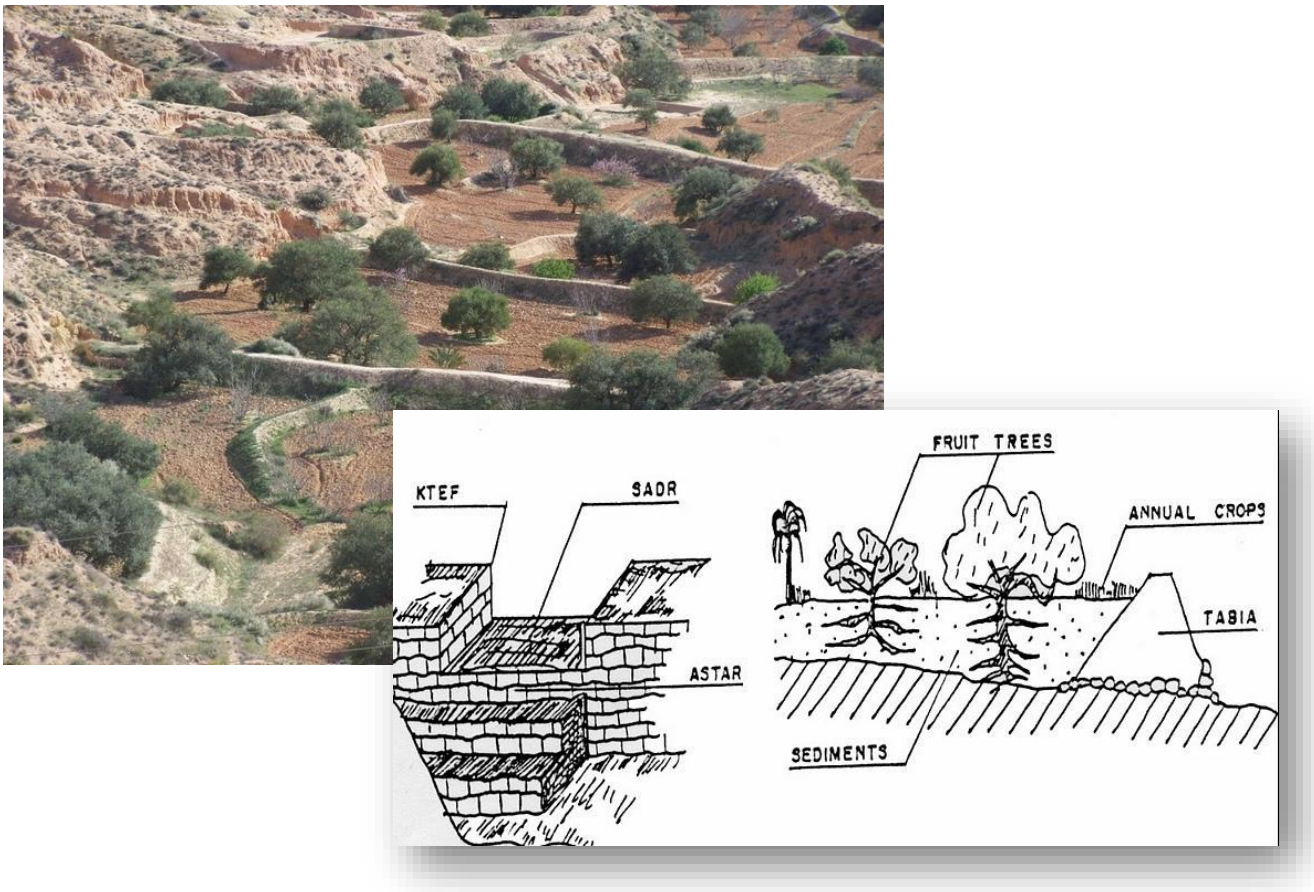
Fanya juu is a technique to reduce soil and water runoff on sloping cultivated land. It consists of earthen or stone banks on the contour, accompanied by a trench along its lower side. The formation of bench terraces is triggered as the land in between several bunds will level off over time (erosion and sedimentation). Soil and rainwater are retained between the bunds. As a result, conditions for crop growth improve immediately – due to increased soil moisture availability – as well as in the long term, due to soil quality conservation (Hailu, Moges, & Yimer, 2012). (WOCAT SLM Technologies, 2019f)

5.2.2 Jessour (1013)

Jessour are a series of hydrological units consisting of three components: the impluvium, the terrace and the dyke. The impluvium is the catchment area for every unit and is bordered by natural water divides. Each impluvium receives and discharges not only rainwater, but also all excess water from upstream units. Over time, terraces start to emerge after sediment is deposited against the built dykes. Agriculture is often practised on these terraces. With artificial soils of over 5 meters deep, these areas are suitable to cultivate fruit trees on.

The technique creates levelled agricultural plots, thereby recharging the underlying aquifer, controlling flood water runoff and erosion of soils. The dykes are built with a central or lateral spillway to drain any excess water.

The ratio between the area where the harvested water is applied (production area) and the total area from which water is collected (catchment area) is estimated to be 1:5. (WOCAT SLM Technologies, 2019g)



5.2.3 Tabia (1420)

Similar to the Jessour technology, Tabias comprise an earthen dyke that captures runoff, increasing infiltration and reducing erosion ((UNEP-DHI Partnership et al., 2017). Different from Jessour, Tabias have a lateral bund that directs excess runoff water along the dyke. Besides, Tabias sometimes have a small floodwater diversion dyke (image) that directs extra water from a (ephemeral) river or runoff path towards the Tabias, enlarging the catchment size. Trees especially grow well along the spillway lateral to the Tabia, since water infiltrates well there.

The ratio between the area where water is applied (production area) and the total area from which water is collected (catchment area) varies from 1:6 to 1:20. (WOCAT SLM Technologies, 2019h)



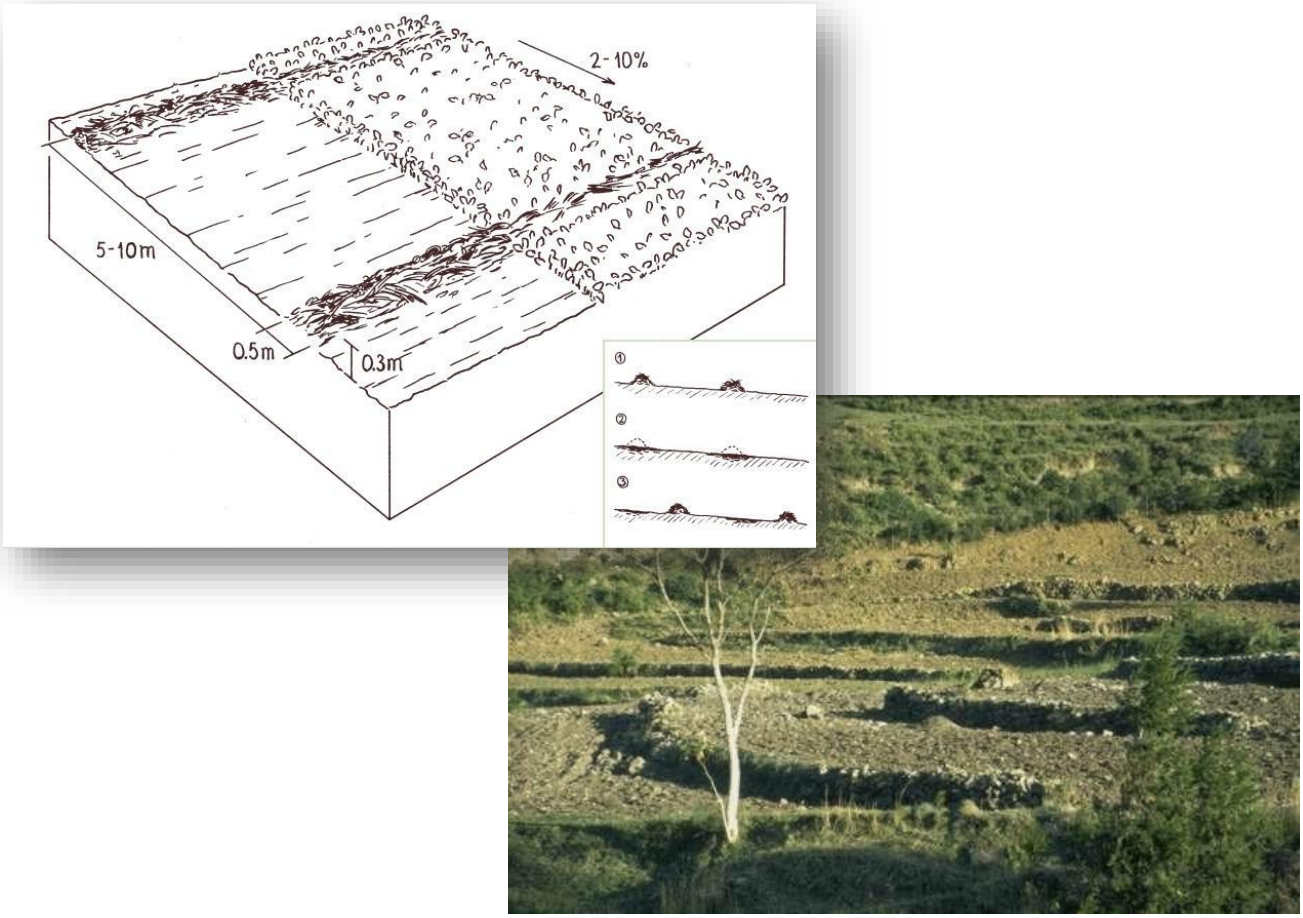
5.2.4 Growing with contours (2836/2895)

Contour farming entails following the natural elevation contour when ploughing and planting. Doing so creates a water break, which reduces gully formation and loss of water and fertile soil through surficial runoff. The water break reduces the speed of runoff water, allowing it to infiltrate into the soil. (WOCAT SLM Technologies, 2017i; WOCAT SLM Technologies, 2019i)

5.2.5 Contour bunds (1683/1581/1616/1389/1652/990)

Placing series of bunds along the natural elevation contour is a way for farmers to promote the formation of rough terraces on sloping lands. The technology aims to control soil erosion, promote water retention, and hence increase crop production in a simplistic manner. Since bunds are permeable structures, they will not pond runoff water, rather they will slow it down to increase the infiltration of water into the soil (UNEP-DHI Partnership et al., 2017).

Bunds can be made out of (bundles of) dry vegetative material, stone piles, earth and/or any organic 'waste' like weed or crop residues that is locally available. The structures can be stabilized by planting crops or trees in its direct surroundings. (WOCAT SLM Technologies, 2017j; WOCAT SLM Technologies, 2019j)



5.2.6 Mulching (1222/3142)

Mulching involves covering the soil with mulch (crop residues) after harvesting. Adding mulch to the patch of land at the beginning of the dry season improves infiltration, reduces evaporation of soil moisture and acts as a barrier against wind and water erosion (UNEP-DHI Partnership et al., 2017). While present on the soil, the crop residues will start to decompose and be incorporated into the soil. Soil structure as well as fertility will benefit from this, which again will benefit water retention. Doing so, mulching can be used to overcome rainfall variability. This form of mulching technology can be of added value to multiple measures introduced here.

Another type of mulching uses black plastic to cover the crops. Such impermeable plastic prevents water evaporation. Condense water will drop back to the crop. In combination with precision irrigation, this could improve irrigation efficiency in areas that face long periods of drought. Black, opaque plastic should stop weed growth and the attraction of insects. Both effects (less nutrient competition and insect plagues) are highly favourable for crop growth. Besides, plastic mulch reduces the impact of extreme rainfall on the soil. (WOCAT SLM Technologies, 2017k; WOCAT SLM Technologies, 2018b)



5.2.7 Small pit cultivation (1395/1549)

By placing crops or trees in their individual slightly excavated pits, the soil moisture status on sloping lands can be improved due to the retention of water in so called micro-catchments. Besides, sheet erosion can be controlled by protecting the pit with a small earthen or stone bund. In regions with erratic rainfall, this technology uses the rainfall that is present effectively. (WOCAT SLM Technologies, 2019f; WOCAT SLM Technologies, 2019g)



5.2.8 Increase organic matter content (1228/1220)

Adding organic fertilizer, and thereby increasing the organic matter content of the soil, boosts biological activity in the soil. As a result, the soil's capacity to store nutrients and the structure of the soil. An improved soil structure benefits infiltration and retention of rainfall and runoff water (UNEP-DHI Partnership et al., 2017). In short, the productivity of one's farm will increase – also in longer periods of drought. As organic fertilizer, farmers can use compost that consists of straw pen manure with litter or household waste. (WOCAT SLM Technologies, 2017l; WOCAT SLM Technologies, 2017m)





5.2.9 Conservation tillage (940/1297/1187/1140)

Conservation tillage is a practice built on three main pillars: (i) minimum soil disturbance, (ii) permanent soil cover and (iii) crop rotation.

Where regular ploughing inverts the soil, disturbing its cover and all biological activity, the soil is often stripped under conservation tillage. Alternative practices to prepare the soil for a new growing season are ripping or stripping. Ripping the soil creates small furrows in which manure can be added. Stripping will loosen the soil by lifting it, and letting it fall into its place (image). Both methods however do not invert the soil, leaving crop residues on the surface. As a result, soil structure and microbial activity improves. The soil is less exposed to runoff, and allows for better infiltration of water. Rainfall from events at the beginning of the wet season can be stored in the rooting zone, prolonging the source of soil moisture available to crops in the dry season (UNEP-DHI Partnership et al., 2017). Besides, the rate of evaporation is decreased. These effects can be enhanced by adding mulch to the soil.

In earlier projects in Kenya, yields from small-scale conservation tillage have turned out over 60% higher than under conventional ploughing. Moreover, due to early crop maturity under conservation agriculture, farmers gain market access when prices are still high. Crops are fully grown in earlier, since they can be planted earlier in the season, when under inversion tillage the farmer has to wait for the

soil to become moist before ploughing. (WOCAT SLM Technologies, 2017n; WOCAT SLM Technologies, 2018c; WOCAT SLM Technologies, 2019m; WOCAT SLM Technologies, 2019n)

Minimal soil disturbance has one major downside. Due to a higher risk of weed infestation, labour intensive weeding is key to a successful system. Besides, special equipment is needed for the ripping or stripping of the soil.



5.2.10 Green manure with leguminous crops

East-African farmers experienced the benefits of applying the green manure technology in the form of higher crop-yields, improved soil fertility, increased availability of soil moisture and reduced erosion and weed infestation (Fischler & Wortmann, 1999).

Green manure can be created by leaving uprooted or sown crops on the field as a mulch. Optionally, the crops can be incorporated into the soil by ploughing them under shortly after flowering. Leguminous crops are able to fix atmospheric nitrogen and make it available for the crop. Depending on crop residue quality, nitrogen could be released slowly or rapidly. Rapid release promotes early nitrogen uptake by the cultivated crop. However, this may result in leakage of the amount of nitrogen that exceeds crop demand. Slow release does guarantee a continuous supply of nitrogen in the crop's growing period, but might not boost the crop's performance in smaller quantities (Sakala, Kumwenda, & Saka, 2003).

5.2.11 Raised beddings

Planting crops on raised beds can prevent anaerobic stress in the root zone after flooding during the rainy season (De La Peña & Hughes, 2007). Planting crops on raised beds, allows for reducing adverse impact of excess water on crop production, active water harvesting in combination with irrigation of crops in terms of rainfall scarcity. The latter benefit can be obtained by intersecting the raised platforms by drainage canals, optionally protected by lining or mulch (Altieri et al., 2017).

5.3 Cropping practices

This section treats cropping choices that farmers could take, different from their current cropping patterns. Besides environmental benefits, economic benefits are often found in other practices.

5.3.1 Agroforestry

Agroforestry has the potential to contribute to climate change adaptation, mitigation and food security (Mbow, Smith, Skole, Duguma, & Bustamante, 2014; Mbow, Van Noordwijk, et al., 2014; Verchot et al., 2007). Regarding adaptation of Kenyan horticulture to changes in climate, agroforestry has the potential reduce the impact of climate extremes on crop growth. The shade providing tree canopy can create a

suitable micro climate for crops to be grown. However, this shading effect could also hamper crop growth if solar radiation is blocked too much. Research could be performed to explore agroforestry options that would serve the local circumstances best (Mbow, Van Noordwijk, et al., 2014), in terms of biophysical (hydraulics, soil fertility) and financial (diversification, income risk) impact (Verchot et al., 2007).

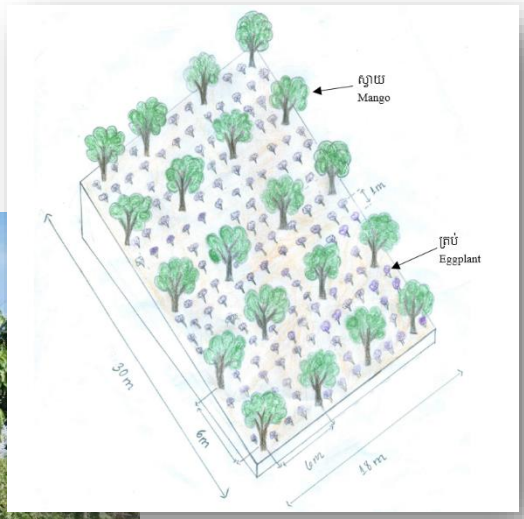
Major side benefit of the technology is that it can be performed in degraded areas, where it increases soil fertility (Mbow, Van Noordwijk, et al., 2014). Besides, trees sequester carbon in the soil and their woody products, serving climate change mitigation. The trees' products (being both fruits and wood) could be sold as an extra source of income, making the farmer less dependent on his/her horticultural crops (Mbow, Van Noordwijk, et al., 2014). Three examples of agroforestry practices are briefly presented below.

Eggplant mango intercrop (2255)

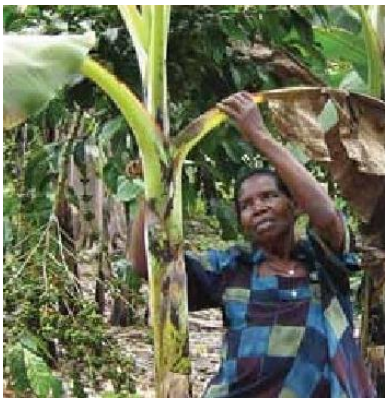
Eggplants covered by straw mulch interact beneficially with mango trees. In the dry season, the trees provide shade to the annual crops while the mulch retains soil moisture in the root zones. The soil is prevented from eroding by the annual crop and mulch cover, and its quality will improve when the mulch is decaying. On top of this, mulch could provide co-benefit of weed control on the parcel.

To overcome the lack of income when the mango trees are not yet producing fruits (in the first three years, depending on the variety), extra eggplant can be cultivated in the free space between the trees. To avoid nutrient exploitation and disease outbreaks, the farmer should consider adopt a rotation of the annual crop. (WOCAT SLM Technologies, 2018d)





Banana coffee intercrop



As in the previous system, the bigger tree crop in this intercrop (banana) providing shade to the smaller crop (coffee) is one of the major benefits of this practice. The right amount of shade (less than 50%) reduces the stress on coffee, without hampering its growth. Moreover, shade even can even improve bean quality. The banana tree can provide mulch to the system, which supports root development for both crops and improves the availability of nutrients (especially K, potassium) in the soil. The mulch also minimizes soil erosion and retains soil moisture. (Wairegi, van Asten, Giller, & Fairhurst, 2014)

Establishing optimal conditions for both crops requires careful management of soil and canopies (image). Besides, it takes longer for the system to become productive since coffee is not an annual crop.

Banana pea intercrop

Combined with cowpea cultivation, timely irrigation and fertilization, banana yields increase. Besides, intercropping the two crops suffers less from weed infestation compared to a banana monoculture.

5.3.2 Adjust cropping calendar

To avoid crops being exposed to extreme temperatures, a farmer could explore opportunities to adjust his cropping calendar according to the expected changes in climate. Key would be to avoid exposing the crop to extremely high temperatures in its most vulnerable stage (seedling).

5.3.3 Switch to climate tolerant varieties

To support previous measure of adjusting one's cropping calendar, a farmer might need his/her crop to mature earlier. A crop variety with a shorter growing cycle could still deliver the same yield as his/her current variety. Another option would be to use heat tolerant varieties.

This measure is highly depending on farmer's access to the seed market.

5.3.4 Crop change/diversification

(Partly) changing to a climate resilient crop could be an option to deal with the effects of climate change. Examples of crops that grow well under high temperatures are tomatoes, beans, pumpkin & zucchini (Nekesa & Meso, n.d.), corn, sweet potato, cowpea, eggplant, okra, Armenian cucumber, peppers, broccoli, millet-groundnut, mushroom, passionfruit, carrots and parsnips. While some of these crops need a lot of water, this could be overcome by irrigation.

Diversifying one's farm to cultivation of multiple crop species is a way to avoid years without any income.

5.3.5 Bucket cultivation

Bucket cultivation is a low-tech technology that allows for full control of soil circumstances. Besides preventing leakage of nutrients and water, bucket cultivation prevents soil erosion in extreme events. Especially for farmers who's soil quality is a main limiting factor for crop growth, bucket cultivation might be an appropriate solution. In a previous project in Kenya, cabbage was planted to grow in buckets. Sprouting occurred multiple times, compared to the one time sprouting under conventional tillage.

5.4 Irrigation

Measures in this section aim at providing an extra source of water to crops on the field. Under climate change, it will be beneficial for farmers not only to rely on rainfall.

5.4.1 Bottle irrigation (1029)

This water efficient drip irrigation technology only requires plastic bottles. Its main purpose is to supply water to crops with the lowest water loss possible (UNEP-DHI Partnership et al., 2017). The bottom of the plastic bottle (1.5 or 2L) is removed and saved to serve as a cover later. The bottle will be put into the soil upside down like a funnel, with a slightly open lid. The lid of the bottle should be opened carefully, to achieve a drip rate of around five drops per second. After 90 minutes, the plant will have received the full 1.5L of irrigation water. Tape should arrange the lid in the exact position when the bottle is partly buried the soil. Placing the bottle right next to the seedling results in the irrigation water being added to the rootzone directly. This method reduces evaporation, since no surficial irrigation is needed. This effect can be enhanced by adding mulch around the crop. (WOCAT SLM Technologies, 2019o)





5.4.2 Tube wells

Creating new, or deepening existing tube wells can be an option to reach fresh water from subsurface or deeper groundwater aquifers in longer periods of drought (UNEP-DHI Partnership, UNEP-DTU & CTCN, 2017). Tube wells are easily constructed using a hand auger and a narrow pipe. The latter is driven into a subsurface aquifer. To reach deeper aquifers, one should consider constructing a borehole. A pump is required to transport the water from the aquifer to the surface where it can serve irrigation purposes.

Usage of tube wells should go according to strict coordination. If not, the groundwater source is likely to be overexploited due imbalanced recharge. Besides, in areas with a highly variable climate (prone to flooding and/or droughts), tube wells are prone to contamination.

5.4.3 Solar pump

A solar powered pump could be used to transport water from a source (being an underground aquifer or a storage tank) to the field. Solar pumps introduced by the Practica Foundation are wired for remote sensing, allowing for after-sale services and feedback on its functioning and carbon mileage. Taking labour hours into account, this system is cheaper than for example a foot pump. These solar pumps however cannot deliver enough pressure for sprinkler or drip irrigation when pumping water directly from the aquifer. An adapted sprinkler or in-between storage tank would be needed. In the latter case, gravity could reinforce pressure in the system.

5.5 Heat stress prevention

Measures in the following section aim to create cooler conditions for a crop to grow in. Some do so by creating a more suitable micro-climate, others target to alter the crops' physiological development.

5.5.1 Shade netting

Hanging shade nets that provide shade to the field crops during the warmest hours of the day can reduce the exposure to extreme air temperature stresses. The reduced incoming solar radiation can

also have a beneficial effect on surficial soil and leaf temperatures, and on the crops' water use efficiency (Mditshwa, Magwazaa, & Tesfay, 2019; Stamps, 2009). However, if the netting is applied such that air movement is hampered, temperatures under the netting are often increased under the netting, compared to outside (Stamps, 2009). The extent to which a net hampers air movement depends on net porosity, net location relative to the crop and the timing of installation of the net (Manja & Aoun, 2019).

5.5.2 Plastic shelter

Clear plastic rain shelters prevent saturation of the soil and the direct impact of extreme rainfall on developing fruits. Preventing flood damage and resulting in a reduced air temperature, plastic shelters have been responsible for the higher yields of crops. In combination with shade cloth, shelters can be used to reduce temperature stress. Shade shelters also prevent damage from direct rain impact and intense sunlight (De La Peña & Hughes, 2007).

5.5.3 Greenhouse farming

In a low-tech greenhouse, cropping circumstances like temperature and water availability can be controlled mechanically. Farmers adopting the technology are less dependent on the seasons, allowing the farmer to cultivate crops year-round with a reduced chance of disease outbreaks (Pack & Mehta, 2012).

5.5.4 Sprinkler irrigation

Applying sprinkler irrigation to crops can reduce air temperature around the crop. In a study on endive, the temperature difference around the crop after applying sprinkler irrigation was measured to be 3 to 11 degrees Celsius (Dubuc et al., 2008). Besides cooling the air, the incidence of tipburn significantly reduced. In a similar study on the canopy temperature of maize, sprinkler irrigation reduced air temperature with 4 to 6 degrees Celsius, and plant transpiration by 58% (Cavero et al., 2009). Hence, less water is lost.

5.6 Post-harvest quality conservation

Post-harvest quality losses are a major struggle for Kenyan farmers (Dolan et al., 2000; Wesonga, Atela, Goosen, & Koomen, 2018). The following measures support quality conservation after harvest.

5.6.1 Zero-energy cooling chamber

A cooling chamber can lengthen sufficient crop quality after harvest by two weeks. This zero-energy cooling chamber is a low-tech and low-cost method to achieve this. A whole in the soil is excavated (by hand), and its walls are lined with bricks and mortar. Keeping the bricks wet is the only maintenance that is needed to keep the technology running. It uses evaporation to cool the inner space, that can be used as storage space. (AgriProFocus and Verbos Business Development, 2018)



5.6.2 Charcoal cold room

Another cooling room that has been introduced on demonstration plots is a charcoal cooling room. The cooling room has walls made out of charcoal. These walls are kept wet throughout the day (sometimes using a simple drip irrigation system in the gutter of the room). Evaporation of the water from the walls keeps the room colder and moister, conserving crop quality. (AgriProFocus and Verbos Business Development, 2018)



5.6.3 Solar dryer

This measure is not aiming to preserve fresh crop quality, but to add value to the product before it is sold on the market. By processing the crop to a high value product directly after yield, post-harvest losses will be prevented.

The market for dried crops and fruits might not be large enough to serve the potential supply (after potential large scale adoption of the technology) yet. (AgriProFocus and Verbos Business Development, 2018)



5.6.4 Road protection

Post-harvest losses can be the result of hampered physical market access after extreme rainfall. To avoid damage to infrastructure, proper drainage is key. Measure 1.1.2 could serve this objective, retaining water for irrigation purposes at the same time.

5.7 Off-farm adaptation

5.7.1 Livelihood diversification

A diversified livelihood gives household a number of income options to rely on, making them more income and food secure. Examples of diversification options performed in other Kenyan climate change adaptation programmes were beekeeping, improved production of small livestock and crop diversification (Macoloo, Recha, Radeny, & Kinyangi, 2013).

Appendix 6: Multi-criteria analysis scoring framework

6.1 Organisation

The organisation indicator gives insight in the processes of organisation and implementation of the adaptation measure. It addresses the potential feasibility of measures in terms of implementation requirements, implementation responsibility and financing, the cultural acceptability of newly introduced technologies etc. This information would mostly be interesting in the implementation process, but will determine the chances of success of a measure. Therefore, it is taken into account in this MCA.

Executive party

The executive party – the one responsible for implementation – can be one of the options listed below. It indicates the institutional, or collective needs. Since the aim of this research is to mobilize smallholder farmers, it is considered most optimal if the individual household can implement a measure without external support or approval. Scoring is based on this prerequisite.

- National government (1)
- Regional administration (municipality) (2)
- Water board/company (3)
- Farmer cooperative (4)
- Household/individual (5)

6.2 Effectiveness

The effectiveness variable describes the extent to which the measure actually contributes to climate change adaptation after its implementation. The sub-criteria chosen reflect the time horizon of the measure becoming effective, its functioning, and its functioning under different climatological scenarios.

Time horizon

Time horizon refers to the time it takes for a measure to start being effective. The chance of a measure to be implemented by a smallholder farmer increases with shorter time horizons.

- Long (>5 y) (1)
- Medium (2 to 5 y) (3)
- Short (<2 y) (5)

Reduction of sensitivity

Sensitivity measure the nature and degree to which a system is adversely affected by significant climatic variations. Unlike exposure, sensitivity relates to the extent to which a system can withstand variations in climate. This variable has scored the most important climatic pressures to horticulture according to the 3R team: drought (a periodical decrease in precipitation), extreme rainfall events, heat stress and erratic rainfall (lower predictability). The reduction of sensitivity to the main hazards (identified by the 3R team) are assessed. These are droughts, extreme weather events, erratic rainfall and heat stress.

- Sensitivity is increased (1)
- Sensitivity is not decreased (2)
- Sensitivity is decreased, but not significantly (3)
- Sensitivity is decreased a lot (4)
- Sensitivity is fully eliminated (5)

Robustness

The robustness of a measure reflects the extent to which a measure achieves its objectives under different climate scenarios.

- *Regret* do not provide benefits under most climate projections (1)
- *Low-regret* actions are relatively low cost and provide benefits under most, but not all projected changes in climate. (3)
- *No-regret* actions and their (indirect) consequences are cost effectively achieving objectives under current climate conditions, as well as in situations in which uncertainty surrounding future impact does not allow for improving policy responses. Besides, they do not intervene the achievement of other policy objectives. (5)

Flexibility

The flexibility of a measure indicates whether a measure could be easily adapted to different scenarios (climatic or socio/economic). Adapting in this sense would imply that the measure could be adjusted, or implementation could be incremented in terms of magnitude if conditions change of if changes appear different from those we expect today.

- Adjustment is impossible due to technical impossibilities or too high costs (1)
- Adjustment would be technically possible, but very costly (2)
- Adjustment would be technically possible under reasonable costs (3)
- Adjustment is technically possible and affordable, but takes time (4)
- Measure is technically easy to adjust, costs and time to invest are low (5)

6.3 Efficiency

This variable gives insight in the economic viability of adaptation options in terms of their costs and benefits ratio. The lower the costs of achieving the desired outcome, the higher the cost-benefit.

Operating and maintenance costs

Operating and maintenance costs are made to run a measure after implementation. Costs could for example be related to energy use, service costs or material costs.

- Maintenance and operation costs remain very high to keep the measure running in the long term (1)
- Maintenance and operation costs are initially high, but likely to reduce in the years after implementation (3)
- Maintenance and operation costs are low, and will remain low in the long run (5)

Short term returns (<2 y)

Return of costs refers to the time it takes for the implementor to earn back his investment and operating costs. This could be in the form of income, or other benefits regarding social or environmental capital. Short term returns reflect the profitability of a measure 2 years after implementation.

- Measure is not profitable (1)
- Measure has not been profitable yet, but will be from this point on (3)
- Measure has become profitable (5)

Long term returns (>5 y)

Return of costs refers to the time it takes for the implementor to earn back his investment and operating costs. This could be in the form of income, or other indirect benefits regarding social or environmental capital. Long term returns reflect the profitability of a measure 5 years after implementation

- Measure is not profitable (1)
- Measure has not been profitable yet, but will be from this point on (3)

- Measure has become profitable (5)

6.4 Co-benefits

Side effects

This variable refers to effects of the measure outside of its target domain. These effects can be positive, being benefit to other policy objectives (e.g. social, economic or environmental) which were not targeted in the first place. However, they can also be negative. The latter case would be referred to as maladaptation.

- The measure directly harms the achievement of this policy objective significantly (1)
- The measure poses potential harm to the achievement of this policy objective (2)
- The measure does not affect this policy domain, positively nor negatively (3)
- Benefits are present for this policy objective, but remain limited (4)
- Multiple, large benefits are present for this policy objective (5)

Appendix 7: Trends in PAW – ETc during sensitive periods

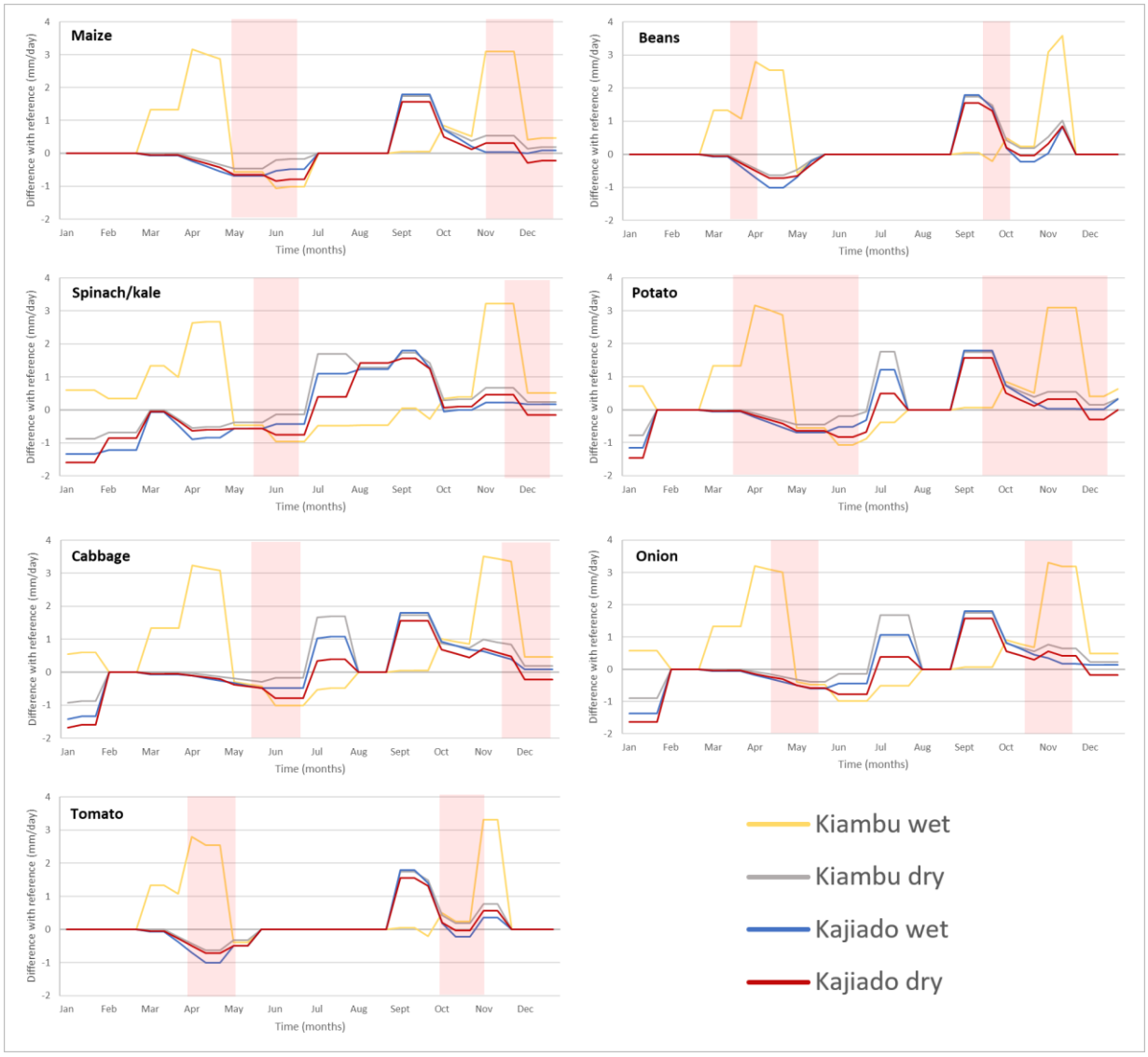


Figure 21 Projections of the difference between plant available water (PAW) and crop water requirement (ETc) under RCP8.5 at the end of the century, per crop and per area. PAW-ETc presents whether the water buffer or deficit increases or shrinks. Red areas indicate periods in the growing season in which the crop is most vulnerable to water deficits.