Low-Tech Irrigation Strategies for Smallholder Vegetable Farmers in Kenya

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Abstract Climate change is making rainfall needed for horticultural production in Kenya more unreliable. Applied on-farm research and data from household panel surveys are collected within the framework of the interdisciplinary research project HORTINLEA, which stands for Horticultural Innovations and Learning for Improved Nutrition and Livelihood in East Africa. It is a research consortium of German, Kenyan, and Tanzanian universities and research institutes funded by the German Federal Ministry of Education and Research. Of 1232 surveyed smallholders, 87% perceive climate variability and change; 32% of major shocks experienced are weather-related often causing lower yields. Climate change adaptation is limited to incremental activities, such as crop portfolio changes. Transformative strategies, such as investing in micro-irrigation are rare. In this study, costs and benefits of climate-smart water management and its adoption potential are investigated. A subterranean micro-irrigation system has been constructed in Kenya from easily accessible materials (low-tech). Results indicate a water savings of 39–70% compared to watering can irrigation in vegetable production. Vegetable growth during dry spells, and the low-tech aspect attracted further smallholders to replicate this system.

Keywords Climate change adaptation · Low-tech micro-irrigation
Resource-smart water management

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1 Introduction

The majority of Kenyan agricultural production is gained through smallholder farmers with an average farm size of 0.2–3 ha (World Bank and CIAT 2015). Domestic food production is hence dependent on farmers who typically have a limited amount of resources to generate their products and are vulnerable to economic and climatic shocks (Dixon et al. 2004; Rapsomanikis 2014). Lack of information and income risk can be seen as main constraints for smallholders to adopt innovations and technologies (Rapsomanikis 2014), implying that adaptation strategies like irrigation on Kenyan smallholder farms remain neglected. With almost one-third of Kenya's 2014 gross domestic product (GDP) coming from agriculture (World Bank 2016), the sector can be considered an important backbone for Kenya's economy. Specifically, the horticultural sub-sector is of growing importance for the local economy (Weinberger et al. 2011; Maertens et al. 2012; Njenga 2015). Kenya's horticultural sector can be identified as an important provider of livelihood for smallholders and furthermore a key driver for realization of the country's "Vision 2030" development goals envisioning Kenya as a semi-industrialized middle income economy by 2030 (Njenga 2015). At the same time, only one-third of Kenya's total land area is considered productive for farming, with high potential farming areas with more than 2000 mm mean annual rainfall are scarce (Orodho 2006). Also, with less than 1000 m^3 per capita of annual renewable freshwater supplies, Kenya can be classified a water scarce country (UN 2014). Despite these challenges, much of Kenyan horticulture is operated on arid to semi-arid lands (Government of Kenya 2010).

Rainfed farming is not possible in these areas unless farmers resort to using rainwater harvesting or irrigation to grow crops. However, HORTINLEA household survey data conducted between 2014 and 2016 reveals that most Kenyan farmers (n = 1232) do not use irrigation on their homesteads and agricultural plots (Table 1). Overall, 25% of the indigenous vegetable crops are irrigated, for exotic vegetables (spinach, tomato, cabbage, onion, carrot) the rate is slightly higher with

Table 1 Overview of irrigation usage on plots of surveyed farms in Kenya

Does the household use irrigation on the plot to grow these crops?	Plots with				Total plots
	Other crops	Field crops	Exotic vegetables	Indigenous vegetable	
No	40 75.47%	2532 87.73%	458 64.15%	2454 75.32%	5484 79.35%
Yes	13 24.53%	354 12.27%	256 35.85%	804 24.68%	1427 20.65%
Total	53 100%	2886 100%	714 100%	3258 100%	6911[a] 100%

Source HORTINLEA (2014)

[a]This total describes total plots of the 1232 surveyed households, i.e., there are 5.6 plots per household

36%. Generally, the use of watering cans and hosepipe sprinkler are most commonly used. Drip and furrow irrigation is very rare.

Wasteful technologies, poor management and maintenance, lack of human capacity as well as high investment costs have been jeopardizing the sustainability of irrigation schemes (Kenyan Ministry of Water and Irrigation 2009; Gichuki 2010). In this paper, the focus is put on a rainwater smart low-tech as well as low-cost irrigation strategy. It must be noted that such strategies are complementary solutions to dealing with water scarcity in agriculture. Rainwater harvesting for crop production is understood here as techniques of inducing, collecting, storing, and conserving local surface runoff for agricultural production (Siegert 1994; Rockström 2000).

Kenyan vegetable farmers are already subjected to challenges related to the naturally occurring seasonality of rainfall. Typically, the majority of precipitation occurs in the main rainy season from March to May (the "Long Rains") and a less intense period from October to December (the "Short Rains") (Government of Kenya 2010). Climate change is expected to pose challenges to Kenyan agriculture, further exacerbating an already vulnerable situation, especially of smallholder farmers. The HORTINLEA panel household survey reveals that 87% of smallholder farmers perceive climate variability and change. Of these farmers, 46% perceive more and longer rains, while 29% perceive less and shorter rains, and 11% more erratic and extreme rainfall. Of the households surveyed in the sub-humid and semi-arid areas (n = 424), 54% perceive less and shorter rains, only 14% more and longer rains, and 13% more erratic and extremes. This indicates a dichotomy between humid and drier regions, with a clear tendency of drier regions to dry up and wetter regions to become wetter. The following chart (Fig. 1) shows the perception of rainfall in the Kenyan counties and selected agro-climatic zones (ACZ) surveyed.

As a result of this, adaptation strategies achieving resilience to the repercussions of climate change while maintaining or even better enhancing productivity are direly needed. In fact specifically for the area around Kajiado County analysis of historical weather data shows that in the past temperatures have been rising, while the amount of annual precipitation has been declining. Figure 2 demonstrates this development from 1980 to 2012 based on weather data recorded by the operators of Jomo Kenyatta International Airport (JKIA), which is located very close to the border of Nairobi to Kajiado County.

Contrastingly, climate change forecasts for East Africa and Kenya seem to agree on an overall rise in temperature, the projections for precipitation are somewhat divergent (Niang et al. 2014). Nevertheless, farming in the region should take such chances of variability and volatility seriously due to farming's importance for feeding the population and fueling the economy. Smallholder's perceptions of experienced rainfall in the previous season reveal that those farming in humid counties, do not yet see it to be a constraining factor. For those farming in the sub-humid counties, the rate is a bit higher, while the in semi-arid county of Kajiado over 70% of the farmers' state there was too little rainfall. The chart below (Fig. 3) demonstrates how farmers experience rainfall in the counties surveyed.

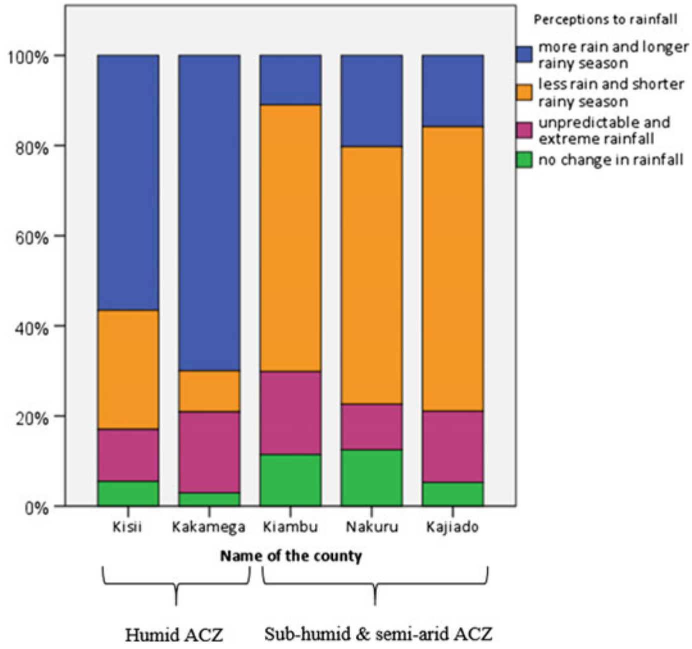

Fig. 1 Farmer perceptions of rainfall. *Source* HORTINLEA (2014–2016)

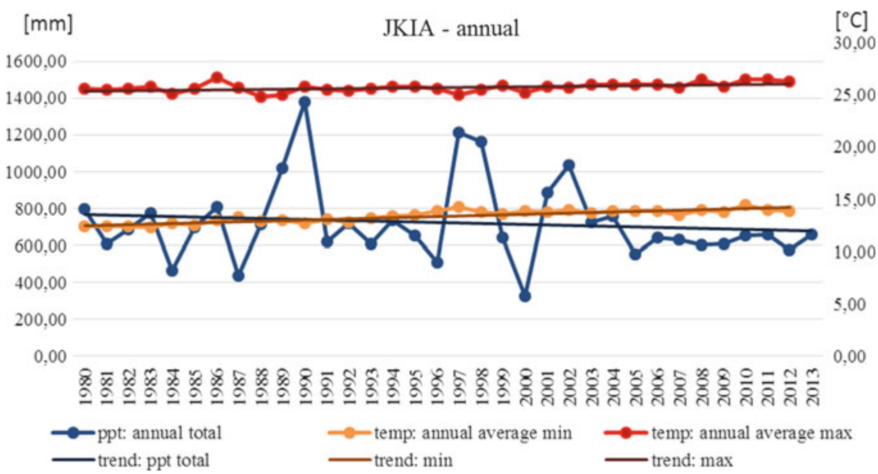

Fig. 2 Weather development at JKIA from 1980 to 2012

Of the major shocks that vegetable smallholders experience during the previous year 32% are weather-related, i.e., drought, flood, heavy rain, or storm often causing crop failures. Most Kenyan smallholders surveyed adapt to climate

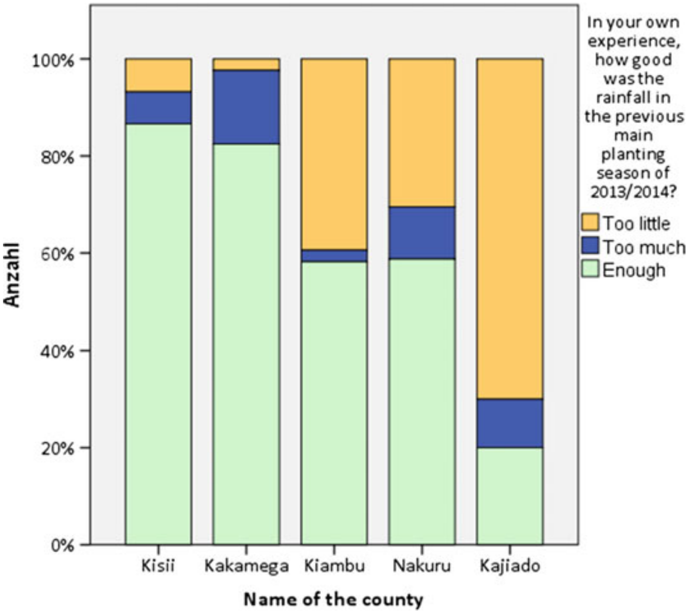

Fig. 3 Experienced quality of rainfall in previous planting season. *Source* HORTINLEA (2014–2016)

variability and change by diversifying their crop portfolio, i.e., using other species. However, in the semi-arid county of Kajiado, households have claimed either they do not know how to adapt (52%) or they realize a need to invest in irrigation, dams, trees, and ponds (31%).

In this research, the increased rainfall unpredictability and variability is zoomed in on by further field research in Kajiado County. Although this means the results will be limited to and valid for a specific region, the expectation is that such results can prove to be indicators for similar circumstances in other areas of East Africa. The visited smallholder farms can be considered typical for Kenya as they lack access to perennial water sources and depend on rainwater for agricultural production. In Kajiado irrigation has become common, because vegetable production is no longer possible without irrigation. Unpredictable rainfall patterns call for adopting (rain) water smart management strategies sustainably exploiting locally available water. Smart water management strategies range from improving storage, irrigation, drainage, rainwater harvesting, and economizing water resources. Additionally, there is a need for application of good agronomic practices, next to efficient water utilization and harvesting to maximize agricultural productivity (Oguge and Oremo 2014). Strategies involving farm design such as agroforestry, terracing, swales, intercropping, mulching, companion cropping, and crop rotation can assist in becoming more water efficient. Ideally, rainwater supply is stretched to last throughout the drier season of the year enabling continuous production, fostering more economic and social stability for the producers. Rainwater harvesting strategies are not new to Kenyan communities with the technologies mostly being simple, acceptable, and replicable across diverse cultural and economic settings. Hence this assists their adoption and replicability (Ministry for Water Resources Management and Development n.d.).

The goals of this research are to understand what is already being done at the farm level to cope with water supply shortages and dry spells, and what innovative irrigation practices are attainable to achieve better on-farm water management. The inventory of farm-level practices leads to the following research question: (1) how do Kenyan smallholder vegetable farmers currently practice rainwater management in semi-arid regions?

As smallholder farmers typically have limited financial resources for investing in their farm, the cost of rainwater management and irrigation innovations should be kept low. Innovations should be easily understood by farmers and not require specialization or a large capital investment, thus the focus is on low-tech rainwater smart innovations. Therefore, to add more depth to this research, a low-tech/low-cost irrigation method is trialed at a farm in the town of Kiserian, Kajiado County. This leads to the second research question: (2) how does a selected low-tech irrigation practice perform (resource and cost efficiency) on the selected farm in Kenya?

Finally, it is important to also discover what factors of an innovation might motivate or hinder Kenyan smallholder farmers to adopt such rainwater smart management practices. Such information is valuable for designing and organizing the promotion of sustainable irrigation innovations. Therefore, the final research question is: (3) what motivates or hinders smallholder vegetable farmers in adopting rainwater smart management strategies?

2 Material and Methods

2.1 Study Area

The farms surveyed for this research are located southwest of Nairobi in Kajiado County. One reason for choosing Kajiado is available panel survey data within the research project HORTINLEA and the prevalence of horticulture in these areas. This research focuses on selected smallholder subsistence and commercial farmers. The farms examined are mainly located in the northern part of Kajiado. Hence, they can be considered as peri-urban due to the proximity to the capital city. Figure 4 shows Kenya's ACZ as well as the locations of the farms surveyed within this research.

Kajiado County is located at the southern edge of the former Rift Valley Province, bordering Tanzania to the South. The county's population counts over 800,000 people, while it covers an area of about 21,000 km^2 experiencing an arid to

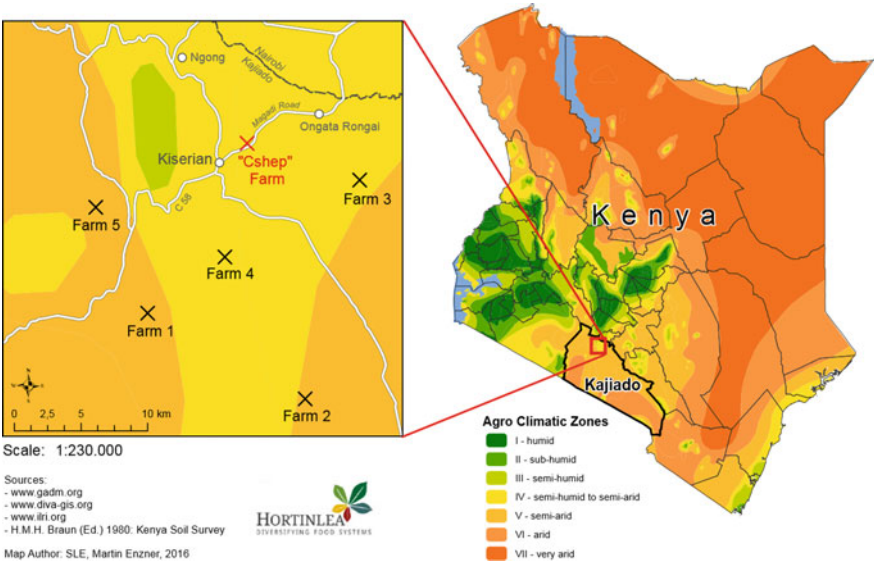

Fig. 4 Location of farms observed in Kajiado (left) and ACZ of Kenya (right)

semi-arid climate with mean annual precipitation ranging from 300 to 800 mm (Boone 2007; Bobadoye et al. 2016). The county also has a bimodal rainfall pattern incorporating two distinct rainy seasons (Bekure 1991), with the average amount of rainfall decreasing when moving from the northern to southern parts of the county (Bobadoye et al. 2016). From this it is evident that the county endures a high level of temporal and spatial rainfall variability.

Like most Kenyan counties, Kajiado is confronted with scarcity of vital resources such as water and social amenities needed to enhance the economic and livelihood of its inhabitants (Chogo 2015). Most streams in Kajiado are seasonal and thus unreliable, while in parts of the county available groundwater has high salt levels (County Government of Kajiado n.d.). As an important resource for Kajiado's economic activities in cultivation and livestock rearing combined with a growing population, the demand for water in the county is growing rapidly and is estimated to be around 223,000 m^3 daily (Rutten 2005). Of this daily supply, 31,000 m^3 are needed for livestock, 8000 m^3 for wild animals, 15,000 m^3 for human consumption, and 170,000 m^3 for irrigation, however, boreholes, natural wells, and rivers only supply a daily maximum potential of 180,000 m^3, leading to a daily shortfall of 40,000 m^3 (ibid.). For this reason, strategies banking on rain-water harvesting are of great importance to help balance this deficit. In Kajiado, especially in its northern areas, with the help of irrigation horticulture has been gaining popularity, as rainfed farming proves to be unsustainable due to erratic rains (County Government of Kajiado n.d.). Nevertheless, unpredictability and unreliability of rainfall have had devastating effects on people's livelihoods, for example, in the drought year of 2009 crop failure in Kajiado was reported at more than 90%

while livestock losses were in excess of 70% in most areas (County Government of Kajiado n.d.).

2.2 Data Collection in Kenya

To receive an in-depth understanding of how smallholder vegetable farmers operate their farms and specifically manage their water resources, this research is grounded upon in-depth on-farm experience in Kenya from January to October 2016. The expectation from this is the ability to answer a wide scope of research questions, i.e., what rainwater management practices are used by Kenyan vegetable smallholder farmers, how a specific low-tech irrigation method perform for these smallholders and what might motivate or hinder uptake of rainwater smart farm practices. Within this specific research design, the data collection is based on on-farm investigations at five farms in Kajiado. This was mainly done with the help of semi-structured qualitative interviews and the drafting of farm profiles. Additionally, one specific low-tech irrigation method was tested on a case study farm.

The low-tech irrigation method is a subterranean micro-irrigation construction, which can be self-constructed from inexpensive as well as recycled materials. The construction is known as the "Green River Principle" (GRP) (Korrmann 2014). With the help of the on-farm trial the performance in crop production as well as its resource efficiency are examined. The data on the GRP's resource usage was collected during the dry season from May till October 2016 (May 14–October 24, 2016). The motivation for capturing the results in the dry season is to discover methods allowing for production throughout the whole year, hence enabling improved farmer livelihoods. The GRP was installed at the demonstration farm belonging to the Kenyan community-based organization "Community Sustainable Agriculture and Healthy Environmental Program" (CSHEP). This demonstration farm is approx. 25 km southwest of Nairobi in Kiserian, Kajiado County (Fig. 4).

Through CSHEP, it was possible to get in touch with various small-scale vegetable farmers in the area. Through interviews information was gathered on which on-farm water management and irrigation strategies farmers are using. Furthermore, they were asked to share their experiences and expectations in terms of water management in times of climate variability and change. The selection of smallholders was mainly based on the availability of contacts through CSHEP's network, functioning in the sense of a referral system, meaning one contact would lead to another contact. This data collection method in qualitative research can be described as snowball sampling, and it has the advantage of locating subjects appropriate for the study, while allowing for an introduction of the interviewer to populations which might otherwise be hard to get in touch with (Berg 2001; Noy 2008).

2.3 Green River Principle

The basic idea behind the GRP is to develop an irrigation system which is accessible for small-scale and subsistence farmers with low investment capacity, and thus often not able to afford conventional micro-irrigation systems like drip irrigation pipes. Making irrigation more accessible can assist in overcoming livelihood problems such as food insecurity, low income, and productivity. Three key criteria were considered for its design which guarantees the achievement of the previously mentioned problems. The first criterion is that the GRP is easy to understand and to build meaning adopters can easily reproduce it themselves and spread the knowledge to their community. One training can be enough to make people understand the idea behind and qualify them to train and instruct other people. With this knowledge, farmers should be able to adapt and further develop the GRP to their specific needs. The second criterion is to develop an irrigation system that recycles material, which are usually disposed of and be found all over the world. The GRP uses old plastic bottles, foil, and recycled newspaper, which can virtually be found nearly everywhere. Another benefit is that all these materials normally end up as waste causing pollution and creating problems for the community. With the GRP, the goal is to recycle resources, giving them a second life as something useful for the community and environment. All materials used to build the GRP are easy accessible in Kenya and can even be collected as scraps or as recycled material, which reduces the construction costs. The third criterion is to bring the investment cost for building such a micro-irrigation system to a level where even the poorest smallholder farmers can raise the amount needed. Due to the design and materials needed, the cost can be cut down to the absolute minimum. If farmers are willing to collect the materials second-hand and perform the necessary installation work themselves the costs will decrease even more. Finally, GRP has the benefit that it functions as a subterranean micro-irrigation system. Intense sunshine and erratic rainfall make such an underground system using minimal amounts of water, especially relevant for water scarce farming conditions.

To build the GRP only a flexible tube, plastic foil, plastic bottles, newspaper, and any type of water supply are needed. Ideally, the water being fed into the system is harvested rainwater, as was the case in this trial. For one row with a length of 10 m experience shows that around 100 bottles are required. The first step in building the GRP is to cut the base and head of used plastic bottles in order to connect them creating a main drainage pipe. The bottles used should ideally have a volume of one liter to guarantee enough space for water flow. The removed heads and bottle bases are cut into smaller scrap pieces and filled into the aforementioned main drainage pipe. This gives the main pipe more structure and prevents it from being squeezed or compacted after it is buried. Both ends of the main pipe need to be finished off with a bottle where only the base has been removed leaving the bottle neck and opening intact. Each pipe ending is then connected to a flexible tube. At the one end the pipe connects the system with the water storage supply, while the other one should after installation penetrate the ground enabling a source of ventilation.

The entire main drainage pipe made from plastic bottles must be perforated to guarantee water can consistently and evenly flow out throughout the length of the pipe. The next step is to cover the main drainage pipe with layers of plastic foil and newspaper. The pipe gets furled into a previously prepared sheet of plastic foil. This foil should be prepared as such that it is covered with newspapers and a thin layer of soil. This layer of newspaper and soil acts as a buffer preventing irrigation water from seeping to quickly through the main drainage pipe. The plastic foil is there to prevent that soil or crop roots grow into the drainage pipe causing blockage. Figure 5 presents a technical overview of the trench setup and the installed main drainage pipe of the GRP.

After construction the GRP is buried into the growing bed so that it can work as an underground crop irrigation source. The optimal growing bed length that the system can effectively irrigate has a length of 10 m like the system itself. If the constructed main drainage pipe length exceeds 10 m the system will lose stability and cannot be securely transplanted into its final position. By adding parallel rows the system can be extended to a bigger plot size. In fact the trial GRP system used for this research had a total of five rows. The total plot size under irrigation was 60 m^2. The growing bed rows should be kept at a width of 1 m apart, leaving a small path allowing for work on the vegetables. Furthermore the rows should be dug approx. 50 cm deep. The elected depth of 50 cm is chosen to ensure that the system is not damaged by tillage in the subsequent seasons, as the GRP should stay in the growing beds for a period of at least 5 years or longer. Before laying the drainage pipe down into the rows, the trenches should be lined with an additional plastic foil serving as a barrier between the irrigation pipe and the underground preventing water losses to deeper soil layers. After laying the pipe into the trench, the GRP should be covered with organic waste materials and at least 30 cm topsoil. For best results and to maximize efficiency the system should be adapted to the on-farm soil conditions. For example, in sandy soil a max depth of 30 cm is unproblematic. In case of soils with higher amounts of clay and silt the row depth

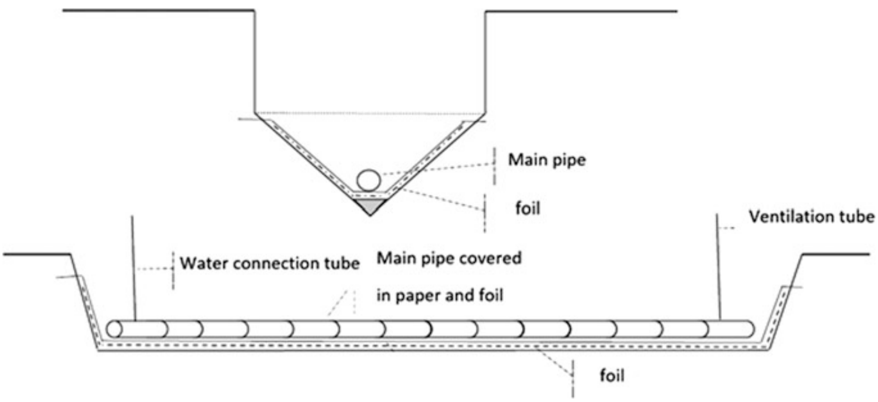

Fig. 5 Technical overview of GRP drainage construction. *Source* Adapted from Korrmann (2014)

should be less in order to make it easier for the roots of planted crops to reach the system. The following graphic (Fig. 6) schematically shows the constructed GRP with water access, while Fig. 7 presents photographs of the different installation phases of the GRP.

3 Rainwater Management Methods Used in Kajiado

In the area around Kiserian, five small-scale farmers (Fig. 4) were visited and profiles of their farms, water management, and irrigation strategies were collected. Table 2 shows that all farmers use some form of micro-irrigation system. In most cases, this is with the help of water pipe drip irrigation. Furthermore, nearly all farmers were collecting rainwater with the help of roof catchments from where the collected water is stored in various storage facilities. The common practices for water storage are using tanks with a holding capacity of 5000–10,000 l. These tanks are comparatively cheap, easy to install, and have a long life expectancy. Also, more advanced storage facilities have been observed on the farms. Storage basins, which can also be used as fishponds, are a new technique to combine farm diversification, water management, and a multiple production cycle. Figure 8 provides photographs of the storage facilities found in Kajiado County.

4 Resource Efficiency of GRP

The GRP system trialed in Kiserian consists of five installed channels which irrigate a total plot size of 60 m^2. Per channel one growing bed with four crop rows can be applied and planted. To compare the efficiency of the GRP with common irrigation practices used by farmers a control plot of the same size is planted with the same crops. The soil type found at the trial farm is vertisol (locally known as “black cotton soil”). This soil typically has high expansive clay content that forms deep cracks during the dry season, while it adopts a very sticky texture when moist. This

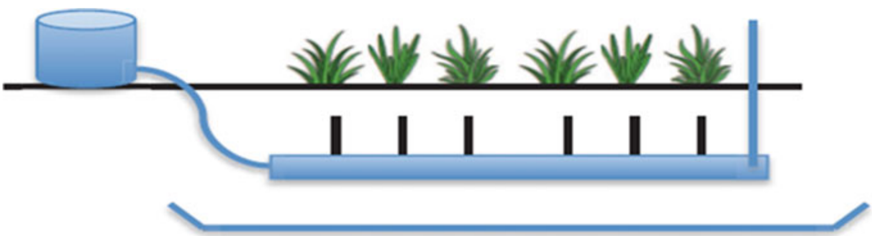

Fig. 6 Schematic drawing of GRP setup. *Source* Korrmann (2014)

Fig. 7 Step-by-step GRP construction phases. *Photos* Lucas Zahl

means the soil shrinks and swells depending on the amount of water it holds making it rather difficult to handle.

Normally, if crops are grown throughout the dry season (in this research: May 14–October 24, 2016) a common method used by smallholder vegetable farmers is to irrigate the crops with the help of a watering can. Irrigating with watering cans requires an ideal amount of 10 l water per crop row twice a week. This amounts to a weekly demand of 80 l water for each growing bed, meaning for a total of five growing beds 400 l of water are needed per week to irrigate the 60 m^2 plot area. This means for a dry season period of approx. 23 weeks ideally 9,200 l are available for irrigation ensuring crops will mature properly. However, rainwater storage losses resulting from a leaking storage tank made it inevitable to "borrow" water from a second storage tank, which is also in use for domestic consumption. This meant not enough water was available for an ideal amount of watering can irrigation. Hence, a less ideal amount of 5 l twice a week per crop row was applied. This amounted to a weekly water usage of 40 l for each, or 200 l for the five growing beds.Over the entire dry season this results in a total water use of 4,600 l with watering can irrigation. In contrast throughout the dry season the GRP system, equally consisting of five growing beds à four crop lines planted with the same crops, consumed a total of 2,800 l water achieving the same yield. Depending on the water availability when irrigating with watering cans, the GRP system can achieve an estimated water savings of 39% up to 70%.

In terms of resource efficiency, the GRP is a system that does not require special products that are solely designated for a GRP construction. The water tanks can be generic tanks meaning second-hand tanks are also feasible. The main drainage pipe can be built from used plastic bottles which would normally end up as waste.

Table 2 Overview of observed irrigation and water management practices in Kajiado County

	Interview partner (Name, Farmers Group)	Location (village, sub-county, county)	Water source	Water storage facilities	Irrigation system
Farmer 1	Mary Nyankwar Maloba, Puan Farmers Group	Corner Baridi, Njoronyori, Ngong Sub-county, Kajiado County	–Community boreholes –Rainwater harvesting from roofs	–Tanks –Fishponds	–Water pipe drip irrigation –Watering can irrigation –Sprinkler irrigation
Farmer 2	Edward Machanga, Nalepo Farmers Group	Nkorol, Ngong Sub-county, Kajiado County	–Natural spring –Rainwater harvesting from roofs	–Tanks	–Water pipe drip irrigation –Watering can irrigation –Bottle drip irrigation
Farmer 3	Maxwel Karasha, Kunda road Farmers Group	Kiserian, Ngong Sub-county, Kajiado County	–Community boreholes	–Tanks	–Water pipe drip irrigation –Watering can irrigation
Farmer 4	Pastor Peter Okeyo	Twala, Ngong Sub-county, Kajiado County	–Rainwater harvesting from roofs	–Tanks –Storage basins	–Water pipe drip irrigation –Watering can irrigation –Furrow irrigation
Farmer 5	Esther Kiruthi, Community Sustainable Agriculture and Healthy Environmental Program (CSHEP)	Kiserian, Ngong Sub-county, Kajiado County	–Rainwater harvesting from roofs	–Tanks –Storage basin	–Bottle drip irrigation –Watering can irrigation –Subterranean micro-irrigation (Green River Principle)

Furthermore, the buffer layer between the pipe and plastic foil can be made from old newspapers. Hence, there is no need to buy a special material exclusively designated for use in the GRP. The GRP has a life expectancy of at least five years and stays underground for this period. The benefit here is that after constructing the GRP, it can remain under the growing beds without requiring further maintenance. Because the system is buried deep enough it is protected from sunlight exposure, which increases life time. Also, it being underground reduces chances of breakage caused by tillage.

Fig. 8 Different water harvesting methods found in Kajiado County. Photos: Lucas Zahl

5 Cost Efficiency of GRP

In our example at the CSHEP demonstration farm a total amount of 27,300 Kenyan Shilling (KES) was spent to set up the GRP system consisting of five rows with a length of 10 m and the potential to irrigate a plot area of 60 m^2. After applying the exchange rate this amounts to an expenditure of 220.10 €, as presented in Table 3. The bigger part of the money was spent on the pipes (2,800 KES), the five water storage tanks (5,400 KES), the plastic foil (6,950 KES), and the hired labor

(5,200 KES). All these costs can be cut down if the farmer is willing to collect the materials on his own, however, this may take longer. By direct connecting to an on-farm water supply or main storage tank the costs for acquiring a special tank can be avoided. Except from buying new plastic foil, the other components can be purchased second-hand or they are even items already available at the farm and can be re-used. Also, the required plastic bottles for the main drainage pipe can be easily collected from local streets, where they frequently end up as unmanaged waste.

When the investment costs are contrasted against the amount of harvested and sold crops gained in one dry season growing period the cost efficiency of the system is considerable. During the growing period, different African indigenous vegetables were planted and sold at farm gate. The crops were *Corchorus olitorius* (Engl.: Jute mallow, Swahili: mrenda) (28 bunches harvested), *Coriandrum sativum* (Engl.: coriander, Swahili: dhania) (105 bunches harvested), *Brassica carinata* (Engl.: Ethiopian kale, Swahili: kanzira) (62 bunches harvested), *Crotalaria brevidens* (Engl.: slenderleaf, Swahili: mitoo) (41 bunches harvested), *Brassica oleracea* (Engl.: kale, Swahili: sukuma wiki) (115 bunches harvested). This resulted in a total yield of 351 bunches with a weight per bunch between 0.25 and 0.5 kg, which could be sold for 20–30 KES per bunch. These sales generated a total income of 8070 KES in one dry season. Compared to our investment costs of 24,550 KES and an expected similar amount of yield in the coming seasons the breakeven point for the GRP is after approx. one and a half years (3 seasons). A breakeven can be achieved much earlier, in case the farmer would decrease the investment costs. This could be achieved by collecting instead of buying used materials like bottles and newspaper, avoiding the need to hire external labor, or using a larger single water supply instead of one tank per growing bed. With an assumed life expectancy of approx. five years the GRP offers a simple, cost-efficient, and resource conservative irrigation method that easily can be used as an adaptation strategy to difficult external climate conditions.

Table 3 Overview of expenses for GRP system on 60 m^2 plot size

Materials, services and consumables	Unit	No. of units	Cost/unit in KES	Total KES
Labor for construction	Hours	26	200	5200
Pipes	m	10	280	2800
Tanks	100 l	5	1080	5400
Plastic Foil (50 m × 1 m)	Piece	1	6950	6950
Plastic bottles	Piece	1000	3	3000
Old newspaper	10 kg	2	600	1200
Total				24,550
in €				220.10[a]

[a]111.54 KES = 1 EUR, exchange rate on March 28, 2016 retrieved from https://finance.yahoo.com/currency-converter/. Accessed Dec 19, 2016

6 Local Adoption of Rainwater Smart Management and Irrigation

In general, it could be observed that farmers are willing to test innovations and new technologies. However, the reported largest obstacle for installing an own low-tech irrigation system were the required investment costs. Further reported challenges are poor access to information and markets. Farmers claim that they often, if any at all, solely receive information on farming innovations from extension officers or neighbors. Another obstacle was the issue of not enough or too expensive trainings, poor networking, lack of formal education, and specialized knowledge. Moreover, challenges in being able to reach produce markets with large demand for (indigenous) vegetables or problems with post-harvest storage and processing were described. Such issues inhibit farmers' innovativeness as they are uncertain if they will achieve sufficient returns to reasonably invest in irrigation innovations. Finally, it must be noted that it also became evident that some farmers remain skeptical if rainwater harvesting and irrigation innovations can actually work for them. They emphasize that they would need a demonstration proving its functionality before they can be convinced. Nevertheless, after CSHEP offered trainings introducing the GRP, three smallholder farmers have autonomously adopted the system on their own farms.

7 Outlook

The farm structure in Kajiado County is family-based with small acreage, a low level of hired labor force and low investment in agricultural machinery, farm management and maintenance systems. Potentials are often not fully capitalized and investment strategies for a future orientation and positioning on the market do not exist. These circumstances impede adaptation and resilience to new challenges like the changing climate conditions. In general, the response of farmers to innovative techniques and methods is high and the majority is open to try them on their farms. If a method implies low investment costs, simple handling, and low maintenance effort; it has high chances to be accepted by farmer communities. The most frequent observed challenges of farmers in Kajiado are the unstable and changing weather conditions creating an enormous unreliability in planning, the hard work farmers face in their daily routine, and their unstable income situation influenced by market access and dependence on the weather. Resource efficient rainwater irrigation strategies like the GRP offer chances to confront these challenges. Although the GRP can theoretically be built to cater to any plot size, at this stage it is most suitable for irrigation of subsistence or semi-commercial gardens. By collecting more data on the GRP demonstration, its potential can be documented more precisely enabling a higher level of scientific relevance. In addition, limits of the system can be observed and adjusted to the local conditions. All in all, a new rainwater smart irrigation technique like the GRP will only be successfully integrated and spread in a community, when it takes the basic needs of small-scale and subsistence farmers into consideration. Only then stability of production and improvement of livelihood can become achievable. A follow-up trial should test a system which leads water through diverging pipes from, e.g., one 500-l water tank instead of five 100-l tanks. Additionally, the expenditures on the recycled materials (plastic bottles & newspaper) could be saved. A redesign using a locally manufactured 500-l water storage tank, which can be purchased at an original price of 4,600 KES, as well as collecting the recycled material could cut down the investment costs by approx. 20%.

During the rainy season, Kenya faces many problems related to heavy rainfalls causing environmental disasters such as negative impacts of erosion, landslides, and flooding. The large amounts of water that can be collected during the rainy season are in fact in demand for manifold uses, e.g., for domestic use, irrigation, and livestock rearing. A benefit of using rainwater is that it is much cheaper compared to relying on scarce conventional water supply systems. Technical solutions for a constant water supply like boreholes, abstraction from surface streams, deep wells, and dams need high investments for their construction and maintenance making them inefficient and less attractive for many small-scale and subsistence farmers. Another problem that Kenyan smallholders face is that the on-farm water storage capacity is on a very low to critical level, meaning large amounts for irrigation can barely be stored. In a water scarce country like Kenya to tackle such shortcomings the future goal should be to promote highly efficient rainwater management and irrigation strategies such as the GRP system combined with improved water harvesting and storage facilities on-farm.

Today locally organized community-based organizations (CBO) like CSHEP are among key players in on-farm trainings of farmers and spreading information. They play a major role in putting rainwater harvesting in the limelight on a local level. Cooperation with NGOs, churches, and government agencies helps lift local water problems to the attention of regional and national levels. In Kenya, agencies have conducted pilot projects and workshops to promote rainwater harvesting at national and local levels as well as support the development in the private sector. The latter is in fact a growing sector in Kenya and instrumental through local manufacturing of components that are needed to implement rainwater harvesting projects such as gutters, roofing material, concrete, and water tanks. Nowadays there are several local providers that make the materials for rainwater harvesting easily accessible in every part of the country.

Next to the importance of local organizations is the notion of farmer-led research. Such research working not for but closely with the farmer is an important way to ensure their inclusion. Farmers are often excluded from agricultural research taking place at institutions like universities, research institutes, or government offices. If they are included at all, often they solely act as providers of information or informants in surveys. Research performed in the field with smallholder farmers brings in fact many challenges as accounting or standardized record keeping are not very common. Nevertheless, close research with smallholders, who are one of the main stakeholders in food security and climate change adaptation, has the advantage of integrating them explicitly in the learning process, building research capacity, and increasing the potential to develop technically feasible and economically viable solutions that are trialed, evaluated and further adapted by smallholders themselves.

8 Conclusions

The analysis of the GRP trial demonstrates how attractive this system can be, as it is an innovative, low-tech and low-cost irrigation technique for small-scale, and subsistence to semi-commercial farmers in semi-arid ACZ. It combines a simple way of construction, which is easy to understand and single-handedly replicable with low investment costs, low maintenance requirements, and in the same time water-saving and protecting the environment. The opportunity to adapt the system to individual needs and conditions like soil type, plot size, etc., generates a wide potential of adaptive flexibility to the farmer. Another important innovative insight is to combine such a water-smart low-tech irrigation system with other agronomic practices that are preventive in terms of water loss. These are, for example, mulching, agroforestry, terracing, composting, crop rotation, and intercropping. A combination of these techniques together with rainwater harvesting can foster successful economic productivity. All these methods help tap the full potential of a farm and have comparatively low investment costs.

In future, Kenyan policy makers are challenged to develop and establish a micro-credit system that enables smallholder farmers to integrate low-tech and micro-irrigation systems on their farms. Another option would be an agricultural subsidy program fostering such methods of climate change adaptation in small-scale farming systems, hence helping resource-poor smallholder farmers to adequately adapt to climate variability and change.

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