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Factors affecting smallholder adoption of adaptation and coping measures to deal with rainfall variability

Ylva Nyberg[a], Johanna Wetterlind[b], Mattias Jonsson[c] and Ingrid Öborn[a,d]

[a]Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden; [b]Department of Soil and Environment, SLU, Skara, Sweden; [c]Department of Ecology, SLU, Uppsala, Sweden; [d]World Agroforestry (ICRAF), Nairobi, Kenya

ABSTRACT

Rainfall variability is becoming more profound in East Africa. Smallholders relying on rainfed agriculture are particularly affected and need to adapt their farming systems accordingly. This study examined the measures small-scale farmers use to adapt to, or cope with rainfall variability and their rated perceived effectiveness. It also explored limitations to adoption of measures and sources of learning measures. Questionnaire-based interviews were held with 80 smallholder farmers, both female and male, living in Kisumu and Trans Nzoia counties in Kenya who had regular or sporadic access to advisory services (denoted trained and non-trained farmers). Trained farmers used more adaptation measures, especially of the measures perceived to be more effective, than non-trained farmers. Female farmers felt more limited by lack of knowledge than male farmers, while money, land and labour limited the smallholder farmers equally. Few measures were used to overcome limitations, but several limitations were covered within the advisory package used for trained farmers, and therefore large differences were seen not only in numbers of measures used, but also in the choice of measures and perceived effectiveness of use. Thus advisory services and policy interventions can play important roles in future efforts to improve adoption of measures.

KEYWORDS
Adaptation measures; advisory service; coping; Kenya; vulnerability

1. Introduction

Mitigation and adaptation efforts are currently not matching the rate of climate change. East Africa in particular is a region where rainfall variability (one aspect of climate change) is becoming more profound, greatly affecting smallholder farmers (Bekele et al., 2019; Bryan et al., 2013; Gebrechorkos et al., 2020). Rainfall variability is naturally high in the region, due to the El Nĩno Southern Oscillation (ENSO), but there has been an increasing trend for more extreme temperatures and rainfall patterns in recent years (Gebrechorkos et al., 2019, 2020; Saalu Faith et al., 2020). In order to adapt to climate change and variability, smallholder farmers can use more sustainable adaptation approaches that can buffer negative impacts, while at the same time being cost-effective and widely applicable (Jones et al., 2012). Practices that are beneficial for both climate adaptation and for sustainable production are included within e.g. soil and water management, nutrient management, crop management and agroforestry (Kalungu & Leal Filho, 2018; Kamau et al., 2014; Vitousek et al., 2009; Young, 1997). However currently, the adoption is low and therefore more drastic measures may be necessary to cope with extreme events (Vignola et al., 2015).

In Kenya, there is overall high awareness of climate variability (Saalu Faith et al., 2020), although some areas have limited awareness and use of adaptation options (Wetende et al., 2018). Many of the farmers in such areas, e.g. close to Lake Victoria, are trapped

CONTACT Ylva Nyberg ylva.nyberg@slu.se
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in vicious circles of low income leading to low investment and more pressure on resources, resulting in high environmental degradation. This cycle is hard to break and reverse without assistance in terms of e.g. credit opportunities, advisory services and/or payments for ecosystem services (de Janvry & Sadoulet, 2000; Swallow et al., 2009). Increasing maximum and minimum temperatures and more unreliable rainfall have been challenges for Kenyan smallholders for some time (Saalu Faith et al., 2020; Wetende et al., 2018). Smallholders who rely on rainfed agriculture are particularly affected and face the challenge of adapting their farming systems to this variability. Relatively simple adaptation measures (e.g. adding manure and mulch) may be enough for them to ensure continued food production (Bryan et al., 2011; Challinor et al., 2007; Nguyen et al., 2013). However, use of available and promoted adaptation measures is still not occurring at a broad scale (Öborn et al., 2017). Even if adoption of new practices is a process with diffusion in different stages with early and late adopters (Rogers, 1983), the critical mass needed to continue spreading the practices has not yet been reached, and adoption of more sustainable practices seem to be hindered in several ways among smallholders. Therefore, it is necessary to better understand the smallholder perspective, consider different types of adaptation measures and identify factors limiting the use of measures for different categories of farmers. This knowledge can assist the effectiveness of both extension services and smallholder farmers in large parts of the humid and sub-humid tropics.

Limitations to implementation and scaling up of adaptation measures include lack of capital, knowledge, time, technology, labour, social institutions, skilled and trained personnel, infrastructure and equity of resources (Thornton et al., 2006). Among these, knowledge has by several studies been found to be key to enable adoption of adaptation measures (Bedeke et al., 2019; Tambo, 2016). Confidence in the source of knowledge is crucial for adoption of practices (Bryan et al., 2009) and therefore it is important for the advisory agent to provide continuous, relevant and effective advise (Bedeke et al., 2019). In Kenya the role of government extension services has been questioned regarding both quality and frequency of advise (Nyberg et al., 2020a; Rees et al., 2000) and it is therefore necessary to differentiate between and consider several levels of access to knowledge. Also the role of horizontal (farmer-to-farmer) learning is important to consider among smallholders (Kiptot et al., 2006; Rosset et al., 2011). However, an individual's vulnerability to climate effects also affects their possibility to adopt different adaptation measures (Spence et al., 2011). Where people live, what they rely on for their livelihood, power structures, values and perceptions within a society and who they are (gender, education, profession etc.) greatly affect how vulnerable they are to climate variability (Adger et al., 2009; Mengistu, 2011; Mertz et al., 2009). The biophysical settings in terms of temperature and rainfall patterns, topography, altitude and soil types form the basis for smallholders' choices of adaptation strategies (Nelson et al., 2010). However, there is little information both regarding how the mixed farming systems typical for smallholders are affected by climate change and how interactions of components in the systems potentially can help to manage the risks (Thornton & Herrero, 2015). The unequal power over resources due to e.g. gender can enable or restrict farmers in their choices and adoption of farm practices although there are no clear patterns identified for specific measures yet (Jost et al., 2016; Ndiritu et al., 2014). Key knowledge gaps also concern the effectiveness of individual adaptation measures and key factors affecting decisions on their adoption (Mercer, 2004; Tongruksawattana & Wainaina, 2019).

The above mentioned factors affecting adoption of more sustainable farming practices can be fitted within the concept of the five capitals (natural, social, human, physical and financial) (DFID, 1999; Fang et al., 2014). In this study, we focus on three of these capitals; (i) human capital, represented by knowledge in terms of two levels of access to advisory services, (ii) social capital, characterized by social norms and traditions depending on the gender of the farmer, and (iii) natural capital, signified by two different biophysical settings of the farms. The overall aim of this study was to understand the adoption of measures to adapt to or cope with rainfall variability. Specific objectives were to evaluate how regular or sporadic access to advisory services, gender and the biophysical setting affect:

(1) Experienced rainfall variability challenges.
(2) Use of adaptation and coping measures.
(3) Perceived effectiveness of adaptation and coping measures.
(4) Main limitations for using adaptation and coping measures.
(5) Sources of knowledge about the measures.

The target audience of this research is therefore covering both researchers, policy makers, agricultural advisors and their agents as well as smallholder farmers themselves in sub-Saharan Africa. The paper is set out as follows. The Materials and Methods section describes the data collection, the three main factors considered in the analysis, i.e. selected regions, access to advisory services and gender related aspects. Then the results from quantitative statistical analyses are presented in regards to the main considered factors as well as other limitations or enabling learning sources. This is followed by a discussion of the results and how they compare with past studies on use of adaptation and coping measures to rainfall variability. Finally, conclusions and recommendations are presented.

2. Materials and methods

2.1. Experimental design

Structured questionnaire-based interviews (Hay, 2010) on the use of management measures were held individually with 80 smallholder farmers as a continuation of an earlier study on awareness of the same measures (Nyberg et al., 2020a). This quantitative approach (e.g. including counts and scores) enabled the study to be broader, involving a greater number of farmers, and also enhancing the generalization of the results. The study was designed to test for differences between farmers regarding regular or sporadic access to advisory services (trained or non-trained farmers), gender (male or female farmers) and biophysical setting (farming in Trans Nzoia or Kisumu). The study had 10 replicates of each of the eight factorial combinations (e.g. trained female farmer in Kisumu or non-trained male farmer in Trans Nzoia).

2.2. Questionnaire interviews

The questionnaire was developed to assess the use of a set of previously identified adaptation and coping measures in a quantitative way, created based on the outcomes of group interviews in the study areas (Nyberg et al., 2020a). This set of adaptation and coping measures was modified after an additional 10 individual interviews with advisory field staff representing the government (three men, one woman) and a non-governmental organization called Vi Agroforestry (four men, two women) in Kisumu and Trans Nzoia Counties. Measures for adaptation and coping were considered separately. Adaptation measures comprise preventive measures planned and used to avoid challenges, defined as 'initiatives to reduce the vulnerability of natural and human systems against actual or expected climate change effects' (Baede et al., 2007). Coping measures comprise immediate responses to challenges that have already occurred and are often short-term, survival-orientated solutions used because of lack of alternatives, such as selling property or reducing meals in a day (Dazé et al., 2009; Vincent et al., 2013). Coping measures are unsustainable, but with climate-related extremes predicted to increase in the future, there is need for more sustainable responses to climate stress among all farmers (Hisali et al., 2011).

The individual interviews followed the same structure as the group interviews in Nyberg et al. (2020a) and were held in English or Swahili, depending on the preference of the interviewee. An additional 13 adaptation and two coping measures were identified by advisors and added to the list used in the questionnaire (Table 1 and Table A1). The final questionnaire covered background parameters, including age of respondent, farm size, family size and number of crop, livestock and tree products. It also covered perceived rainfall variability challenges, use of adaptation and coping measures, the effectiveness of measures used (by scoring), factors limiting adoption of measures not used, and sources of inspiration and knowledge for adoption of measures used (Table S1 in Supplementary Material (SM)). If a farmer had used a measure during the past three years, the perceived effectiveness was scored on a scale from 0 to 5, where: 0 indicated no positive effect to adapt to or cope with rainfall variability; 1 = small positive effect, but never enough to adapt to or cope with rainfall variability alone; 2 = visible positive effect, but rarely enough to adapt to or cope with rainfall variability alone; 3 = visible positive effect, sometimes enough to adapt to or cope with rainfall variability alone; 4 = strong positive effect, often enough to adapt to or cope with rainfall variability alone; and 5 = enough to adapt to or cope with rainfall variability alone. The questionnaire also provided interviewees with the possibility to add measures that were missing, but none did so. Interviewees were also asked to compare themselves to their neighbours, in terms of being less, more or equally vulnerable to the rainfall variability challenges identified. In addition, interviewees were asked about the mixed farm combination (in terms of having crops, livestock

Table 1. Adaptation (A) and coping measures (C) used in the individual farmer questionnaire organized into 12 categories depending on the nature and aim of the measure.

Type of measure	Name of measure	A/C	Use %[a]	Mean score[b]	±SD[c]
Erosion control	Early ploughing, Early planting, Raised beds, Soil ridges,[d] Add manure, Dig cut-off drain, Dig ditches, Plough/plant along contours, Double digging (incorporating manure by digging deep and cover with soil), Add mulch, Dig terraces, Grass strips, Add compost, Dry planting (planting before rain), Soil in sacks, Stone lines, Plant without ploughing, Use greenhouse	A	61 (8–95)	3.3	1.3
Crop production	New/short-term crop varieties, Plant traditional crops, Drought-resistant crops, Plant perennial crops, Water-tolerant crops, Plant cover crops, Plant 'under-ground' crops (root and tuber crops, groundnuts), Bananas in ditches, Relay cropping,[d] Crops in nursery, Mushroom production[d]	A	62 (3–80)	3.3	1.3
	Early harvesting, Sell harvest at 'throw-away' price,[d] Chemical on leaves to reduce moisture	C	53 (13–81)	2.5	1.5
Tree production	Have tree nursery instead of direct sowing,[d] Plant trees for micro-climate/more rain,[d] Plant trees as windbreak, Plant trees for soil fertility, Sell fruit from trees, Plant trees for erosion control, Sell timber, Plant trees to absorb water, Sell firewood or charcoal, Sell tree seedlings,[d] Sell fodder from trees, Sell medicine from trees[d]	A	51 (1–95)	3.4	1.2
Livestock production	Focus on livestock, Fence the farm,[d] Take livestock to greener pasture, Rotational grazing, Plant fodder, Build raised cattle shed, Dry/store fodder, Reduce number of livestock and upgrade,[d] Zero grazing system, Beekeeping, Establish fish pond	A	43 (6–76)	3.2	1.4
	Sell livestock	C	76	2.9	1.4
Irrigation	Timely watering, Roof catchment, Hand irrigation, Reuse of water,[d] Micro-catchments on farm, Dig a water pan, Dig a well, Pump irrigation, Gravity irrigation, Drip irrigation	A	43 (0–96)	3.1	1.3
Off-farm	Keep a shop, Make and sell baskets, ropes, pots, Make and sell bricks, Go fishing in lake/river	A	27 (11–50)	3.2	1.2
	Trading, Sell labour, Sell land,[d] Mine and sell stones	C	37 (9–65)	2.4	1.3
Food and cooking	Preserve food, Use raised energy-saving stoves	A	47 (28–66)	3.8	1.1
	Change eating habits, Less meals per day	C	75 (71–79)	2.2	1.4
External	Government build dikes	A	15	3.0	1.4
	Help from relatives, Relief food, Migration	C	30 (13–49)	2.3	1.4
Group related	Knowledge, exposure through group,[d] Saving/loaning/marketing through group, Labour, encouragement from group[d]	A	79 (71–88)	3.5	1.1
Vegetable growing	Kitchen garden, Grow tomatoes off-season, Grow vegetables in a sack	A	49 (21–73)	3.1	1.3
Opportun-istic	Sell river water, Sell fish from flooded area, Harvest and sell sand	A	10 (5–13)	2.8	1.2
Other	Lease land, Visit agricultural training centre,[d] Plant other area	A	60 (48–66)	3.2	1.2

Data modified from Nyberg et al. (2020a).
[a]Mean percentage of farmers ($n = 80$) using a measure from that category and, in brackets, the range of percentage of farmers using single measures within the category (Use).
[b]Mean score.
[c]Standard deviation (±SD) of score.
[d]Measure only identified by advisors.

and/or trees) they considered to be least vulnerable to rainfall variability challenges.

During the interviews, adaptation measures were explained as measures that farmers plan for and choose to carry out, while coping measures were explained as measures that farmers are forced to carry out due to urgent circumstances. In many cases, but not all, the same measures were used to meet the challenges of too much and too little rainfall. Of the 94 adaptation and coping measures included in the questionnaire (Table 1), 81 were categorized as adaptation measures and 13 as coping measures. This categorization followed how the majority of farmer groups defined the measures (Nyberg et al., 2020a). Depending on the aim and nature of the measures, they were divided into 12 groups and three levels of implementation and decision making (field, farm or landscape) (Table A1). The concept of field, farm and landscape level measures is based on where decisions are taken in a household and also related to the power structures for taking decisions and was first used in Nyberg et al. (2020a). Examples of measures decided upon and applied at field level were digging ditches or using mulch. Farm-level measures included fencing the farm or roof water capture, which needed a decision on farm/household level. Examples of landscape measures, which needed decisions both by the farm and outside the farm, included saving money through a group or selling timber products. Five test interviews were carried out to finalize and improve the questionnaire and to test the duration of interviews and translation. The corresponding author carried out the interviews and took notes, assisted by the same translator for all respondents. Each interview was carried out on the farm of the interviewee and lasted for 1.5 to 2 hours.

The 80 individual farmers selected for structured questionnaire interviews were chosen based on the following selection criteria: (1) Farm size ≤2 ha; (2) the majority of income from farming; (3) a mix of farms on both flat land and sloping land (where water does not lie, reducing the risk of fields flooding); and (4) not part of the focus group discussions reported in our previous study (Nyberg et al., 2020a). The interviewees were randomly selected while walking together with a village resource person through the area. Farms were included as long as there was a respondent available, willing to participate and all selection criteria were fulfilled. The interviewees were not necessarily household heads. All data was based on quantitative information from the respondents' self-assessment in questionnaires in the study. Ground-truthing was not carried out, which potentially can mean that the definitions of different measures differed among farmers.

2.3. Selected regions

Field work was carried out in Kisumu (KI) and Trans Nzoia (TN) counties in Kenya (Figure 1), which were the same areas studied in Nyberg et al. (2020a). They were selected due to their similar high dependence on agricultural production, but key differences in natural capital, such as climate and soil features and in their history of agriculture, which can be assumed to lead to adoption of different measures depending on the challenges experienced. Kisumu County is a relatively flat area with rapidly decreasing farm sizes due to a long history of subdivision and inheritance of land. Vertisols and Planosols are the main soil types, which are characterized by poor infiltration capacity (Government, 1985). Historically, people in Kisumu are dependent on fishing, with agriculture as a lower priority. Trans Nzoia, on the other hand, is known as the 'bread basket' of Kenya, where people moved in after independence (earlier large-scale colonial farms) to get agricultural land. The area is relatively undulating and Trans Nzoia has mainly Ferralsols soils (Government, 1985). Further, Kisumu is a hotter area than Trans Nzoia due to its lower altitude (1100 compared with 1800–2000 m asl), with mean minimum and maximum temperature of 17 and 30°C, respectively, while mean annual rainfall is 1362 mm (Kisumu meteorological station). The climate is cooler in Trans Nzoia, with mean annual minimum and maximum temperatures of 12 and 26°C, respectively, because of the higher altitude and closeness to Mt Elgon and Cherangani hills (Trans Nzoia meteorological station). Mean annual rainfall (1267 mm) is similar to that in Kisumu. The inter-annual variability in rainfall is large in both counties, with total annual long-term precipitation (28 and 44 years, respectively) ranging between 919 and 1829 mm in Trans Nzoia and 1029 and 1791 mm in Kisumu (Kisumu and Trans Nzoia meteorological stations).

2.4. Access to advisory service

Human capital in terms of knowledge was in this study indirectly studied via the access to advisory services. The farmers classified as trained had received continuous access to agricultural advisory services through a non-government organization (NGO) called Vi Agroforestry for several years. Vi Agroforestry provided advisory services and training on the concept of agroforestry, but also on aspects of farming business, village saving and loaning associations, nutrient, water and soil management and sustainable energy, to both women and men in the targeted households. Vi Agroforestry had 77 advisory staff in Kisumu between 2002 and 2010, while in Trans Nzoia it had 100–250 field advisors in total between 1990 and 2004 and a declining number of advisors until 2008, when the scheme was phased out (Nyariwo, personal communication, 2014). Apart from this NGO, all farmers in the two areas had also more or less sporadic advisory services through government advisors and other local and international actors.

2.5. Gender aspects

Gender aspects are important to consider in relation to lack of adoption of more sustainable measures. Gender may be considered part of the human capital. But in many smallholder communities, social interaction, norms and traditions are strongly connected to gender and therefore it rather serves as an indicator of social capital in this context. Traditionally, women in sub-Saharan Africa are responsible for the home

Figure 1. Map showing the two geographical areas of the study (bold border); Kisumu and Trans Nzoia Counties in western Kenya.

and the children, while men are responsible for income generation (Kiptot & Franzel, 2012; Laszlo Ambjörnsson, 2011). Also in terms of farm work, the responsibilities of men and women differ. Men have a larger responsibility of cash crops, large livestock, long-term trees and land, while women are left to ensure food on the table from food crops and small livestock such as poultry (Manzanera-Ruiz et al., 2016). However, there is a close link between social and human capitals in terms of knowledge and information since women in sub-Saharan Africa in most cases have lower education, less access to extension and advisory services, networks and decision making bodies within the community (Farnworth & Colverson, 2015).

2.6. Data analysis

The data collection was carried out to enable the quantitative data analysis described below. Two groups, comprising the perceived most and least effective measures, were identified. Measures were scored by farmers but, to avoid individual scores having too large an effect, only measures used by at least 10 farmers (12.5% of respondents) were included in the groups. One group of 22 measures with score >3.4 were identified as the most effective measures, while another group of 17 measures with score <3.0 were identified as the least effective measures (Table A1). The use and scoring of total number, categories and levels of adaptation measures, total number of coping measures, and proportions of the most and least effective measures used among only adaptation measures and all measures respectively were analysed using a full-factorial three-way ANOVA, including F-tests, with training, gender and site as factors. Gaussian error structures were assumed and checked using residual plots. Different learning sources and limitations were tested using logistic regression for the binary data (McCullagh & Nelder, 1989), with training, gender and site as explanatory variables. Interactions between explanatory variables were dropped if they were non-significant in a chi-square test based on the full-factorial model. Differences between factor levels in the different tests were compared and tested using estimated marginal means (emmeans package in R) (Lenth et al., 2019). The goodness-of-fit of the Anova model was assessed using R-squared for the overall model and F tests for individual factors (Table 2). For the logistic models, goodness-of-fit was assessed using McFadden's pseudo-R^2 (calculated in R package pscl). All analyses were made in R 3.4.2 (R Core Team, 2019). Results were deemed significant for p-values below 0.05.

3. Results

3.1. General information on interviewees

The characteristics of the participants are presented in Table S2 in SM. Interviewed farmers had 0.9 ± 0.6 (area ± standard deviation) ha of mostly flat land, were 41 ± 14 years old, had a family with 7 ± 3 members and most commonly primary education background. They were members of on average two local groups, e.g. farmer groups to exchange information or groups for saving money. Most often the farmers had no own off-farm income, but had someone within the household who had off-farm income. Further, the farmers had 5 ± 1 different types of crops and 2 ± 1 types of livestock, and had trees on the farm for 4 ± 2 different purposes. They had used 41 ± 10 different adaptation strategies and 6 ± 2 coping measures to manage rainfall-related challenges. Kisumu farmers had on average lower education, flatter land and more off-farm income than Trans Nzoia farmers. Female farmers had on average lower education than male farmers. All trained farmers were members of some kind of farmer or savings group (Table S2). Female farmers in Kisumu had the lowest education and male farmers in Trans Nzoia the highest, followed by female farmers in Trans Nzoia. There was no difference in education level between trained and non-trained farmers.

3.2. Rainfall variability challenges

Kisumu farmers mentioned both more, and more severe, rainfall variability challenges than Trans Nzoia farmers (Table S3 in SM). An average of three challenges was reported in Kisumu and two in Trans Nzoia. In Kisumu, drought, too little rain, too much rain and floods were the most common and unanimously experienced challenges. Farmers in Trans Nzoia experienced less extreme challenges and were mainly concerned about too much rain and sometimes too little rain, and to some extent floods. Related challenges to the excess rain in Trans Nzoia were strong winds and hailstones that could destroy crops instantly. Farmers had experienced all these challenges for a long time, but they believed that the frequency and scale of the problems had increased since the 1980s. Several farmers also described rainfall as being unreliable nowadays in both Kisumu and Trans Nzoia. Only one farmer in Trans Nzoia said that he had encountered no rainfall variability challenges.

3.3. Use of adaptation and coping measures

Most of the interviewees were aware of nearly all of the measures listed (Table 1), either through other people's practices or through their own experience. Most of the measures were related to a change in current production, but some were related to new types of

Table 2 . Significant results from a linear model testing the effects of gender (G), site (S) and access to training (T) on different types of measures used.

Measures analysed	Adjusted R^2	Factors	Parameter	Estimate	SE[a]	F[b]	Pr(>F)[c]
Total number of adaptation measures	0.37	Intercept		41.7	2.54		
		T	Trained	6.0	3.59	31.6	<0.0001
		G × S	Female farmer × Trans Nzoia	18.8	5.08	12.5	0.0007
Total number of coping measures	0.14	Intercept		6.0	0.61		
		S	Trans Nzoia	−0.4	0.87	12.4	0.0007
Proportion[d] of most effective adaptation measures used	0.29	Intercept		31.0	1.71		
		S	Trans Nzoia	2.2	2.43	12.0	0.0009
		T	Trained	3.4	2.43	11.9	0.001
		S × T	Trans Nzoia × Trained	−0.7	3.44	5.7	0.02
		G × S × T	Female farmer × Trans Nzoia × Trained	−10.3	4.86	4.5	0.04
Proportion[d] of least effective measures used (coping or adaptation)	0.17	Intercept		23.4	1.58		
		T	Trained	−0.6	2.23	8.7	0.004
		G × S	Female farmer × Trans Nzoia	−8.5	3.16	7.0	0.01
Average score for most effective adaptation measures	0.05	Intercept		3.4	0.20		
		T	Trained	0.5	0.29	8.4	0.005
Average score for least effective measures (coping or adaptation)	0.07	Intercept		3.1	0.22		
		S	Trans Nzoia	−0.9	0.31	4.6	0.04
Erosion control measures	0.23	Intercept		10.9	0.78		
		T	Trained	2.3	1.11	11.7	0.001
		G × S	Female farmer × Trans Nzoia	3.8	1.57	11.1	0.001
Crop production measures	0.32	Intercept		6.9	0.59		
		S	Trans Nzoia	−1.4	0.84	8.2	0.0055
		T	Trained	0.8	0.84	16.5	0.0001
		G × S	Female farmer × Trans Nzoia	4.5	1.18	12.8	0.0006
Irrigation measures	0.11	Intercept		4.9	0.43		
		G	Female farmer	−2.1	0.61	5.3	0.024
Tree production measures	0.27	Intercept		5.3	0.68		
		T	Trained	1.8	0.96	24.4	<0.0001
Off-farm measures	0.03	Intercept		1.1	0.25		
		G	Female farmer	−0.3	0.35	5.8	0.018
Food measures	0.21	Intercept		1.2	0.20		
		T	Trained	0.1	0.28	17.2	<0.0001

[a]Standard error of parameter estimates (SE).
[b]F-value testing whether the parameter estimate is significantly different from zero (F).
[c]Probability of the observed F-value being greater than the critical value (Pr(>F)).
[d]The proportions (%) of adaptation measures scored to have high (>3.4) or low (<3.0) perceived effectiveness.

production or off-farm alternatives for income. Of the 81 adaptation measures, an average of 36 measures were used by non-trained households. Trained farmers used significantly more adaptation measures than non-trained farmers, with an average of 48 measures ($P <$ 0.0001) (Figure 2(a), Table 2). Female farmers in Kisumu used fewer adaptation measures than male farmers, while female farmers in Trans Nzoia used slightly more measures than male farmers (gender × site: $P = 0.0007$) (Figure 2(b)). For coping measures, there was a difference between the areas, with Kisumu farmers using more coping measures than Trans Nzoia farmers ($P = 0.0007$) (Figure 2(c)). However, all interviewees had used between one and 12 of the 13 coping measures during the past three years.

Among categories of measures, erosion control measures were most commonly used. These measures were used more by trained farmers (Figure 3(a)), as were crop measures (Figure 3(c)), tree measures (Figure 3(e)) and food measures (Table 2). Female farmers in Trans Nzoia used more erosion control measures than female farmers in Kisumu, whereas male farmers in Kisumu used more than male farmers in Trans Nzoia men (gender × site: $P = 0.001$) (Figure 3 (b))). In general, the use of crop measures was less frequent among Trans Nzoia farmers (Table 2) and among Kisumu female farmers (Figure 3(d)). Irrigation measures were used less by female farmers, especially in Kisumu, and female farmers also used fewer off-farm measures (Table 2, Figure 3(f)). No differences between

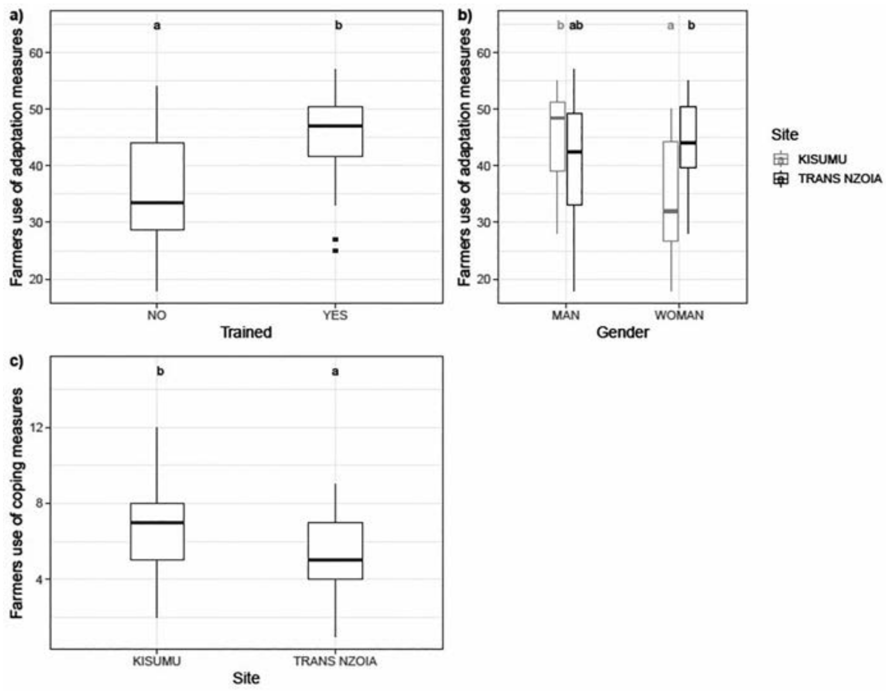

Figure 2. Number of adaptation and coping measures self-reported to be used by individual farmers, divided between (a) adaptation measures for trained (YES) and non-trained (NO) farmers and (b) adaptation measures used by male and female farmers in Kisumu and Trans Nzoia and (c) coping measures used in Kisumu and Trans Nzoia. Boxplots indicate the number of measures used for 25, 50 and 75% of respondents.

the groups were found for livestock production measures. All field, farm and landscape adaptation measures were more commonly used by trained farmers ($P < 0.0001$). Female farmers used less adaptation measures on farm level than male farmers ($P = 0.007$) and Kisumu female farmers, especially the non-trained, lagged behind in terms of using both field- and farm-level adaptation measures.

Among all farmers, the most and least used individual measures were identified. Thirteen measures were used by 80% or more of the interviewees and 14 measures were used by less than 12.5% (Table A1). Commonly used measures were adaptation measures such as early ploughing and planting, roof water capture and application of manure to crops. Rarely used measures included both coping and adaptation measures, e.g. beekeeping, greenhouse growing, selling land or selling fodder. Drip irrigation was the only measure not used by any interviewee. During analysis of the most and least effective measures, it was noticed that apart from trained farmers using more adaptation measures, they also used a larger share of the perceived more effective measures ($P < 0.001$) (Table 2, Figure 4(a)) and a smaller share of the perceived least effective measures ($P < 0.004$) (Figure 4(c)). The five measures showing the largest difference between trained and non-trained farmers were: (1) visit an agricultural training centre; (2) have trees to improve soil fertility; (3) have trees for rain or to improve the micro-climate; (4) get knowledge through a group (saving or farming group); and (5) sell firewood/charcoal. Trans Nzoia farmers used more of the more effective measures than Kisumu farmers (Table 2, Figure 4(b)). Non-trained female farmers in Kisumu used the fewest perceived effective measures of all farmers, while they also used more of the less effective measures than female farmers in Trans Nzoia (Figure 4(d)).

3.4. Scoring the effectiveness of adaptation and coping measures

Adaptation measures were generally scored higher than coping measures, with few exceptions. Adaptation measures where actions and decisions were taken on field level were mainly among the most effective measures, compared with farm- or landscape-level measures. The highest average perceived

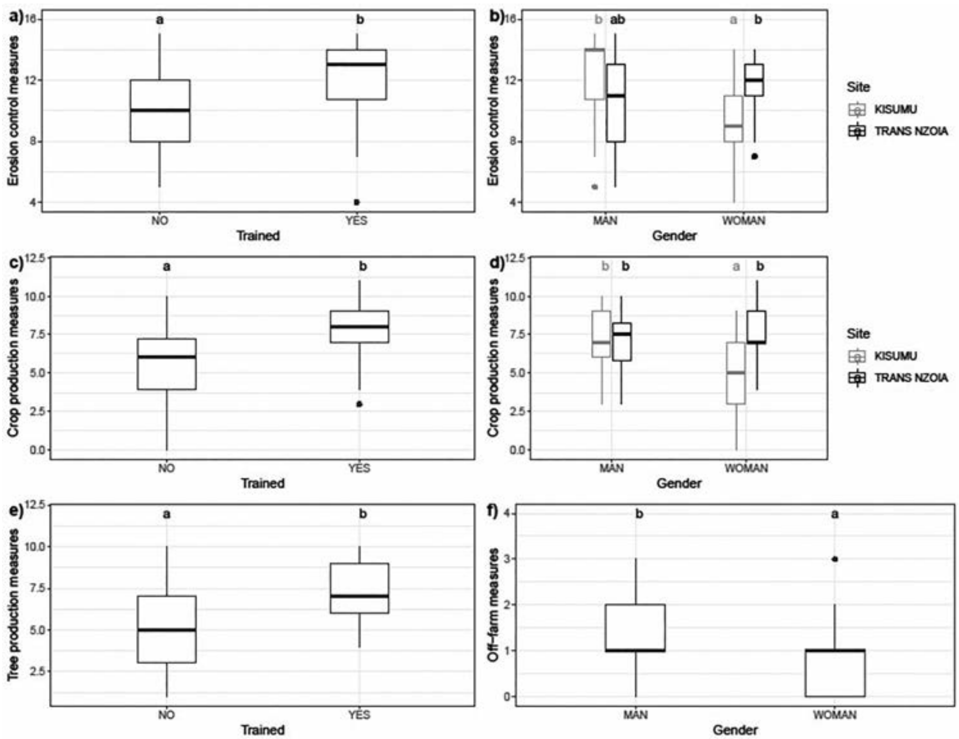

Figure 3. Number of adaptation and coping measures self-reported to be used by individual farmers, divided between different categories of measures. (a–b) Erosion control measures, (c–d) crop production measures, (e) tree production measures and (f) off-farm measures. Boxplots indicate the number of measures used by 25, 50 and 75% of respondents.

effectiveness score was for energy-saving stoves (Table A1) and the lowest average score was for selling products at a 'throwaway price'. All three levels of adaptation measures (field, farm, landscape) were scored higher by trained farmers than by non-trained farmers. Trained farmers also scored the most effective measures higher than non-trained farmers, while the least effective measures were scored lower by Trans Nzoia farmers (Table 2).

Farmers in Kisumu scored energy-saving stoves highest, whereas raised animal sheds were scored highest in Trans Nzoia. In general, Kisumu farmers seemed to value firewood (trees) and group assistance highly and included five tree-related measures among the most effective measures. Several Kisumu farmers reported that during floods, they may have food but no firewood to cook food with.

Mulching was scored highest among the trained farmers, followed by leguminous trees and labour from the group (possibly since the use of adaptation measures often needs more labour input). A trained male farmer in Kisumu commented 'We learnt to harvest trees from our parents and to plant them from Vi Agroforestry'. Some trained farmers also saw 'selling firewood' as an opportunity (adaptation), instead of a threat (coping). The most effective measure to adapt to rainfall-related challenges according to scoring by female farmers was to visit an agricultural training centre.

3.5. Limitations and sources of knowledge to adopting measures

The six most used sources of knowledge among the farmers were neighbour/friends, government, parents, groups, education and international NGOs (Figure 5(a)). Trained farmers to a larger extent obtained knowledge through Vi Agroforestry ($P < 0.0001$, McFadden's pseudo $R^2 = 0.68$) (expected through the selection criteria) and other international NGOs ($P = 0.0008$, McFadden's pseudo $R^2 = 0.38$), and to a smaller extent from neighbours/friends ($P = 0.0007$, McFadden's pseudo $R^2 = 0.13$) or government ($P < 0.0001$, McFadden's pseudo $R^2 = 0.26$), compared with non-trained farmers. Female farmers in Trans Nzoia received less of their knowledge from the

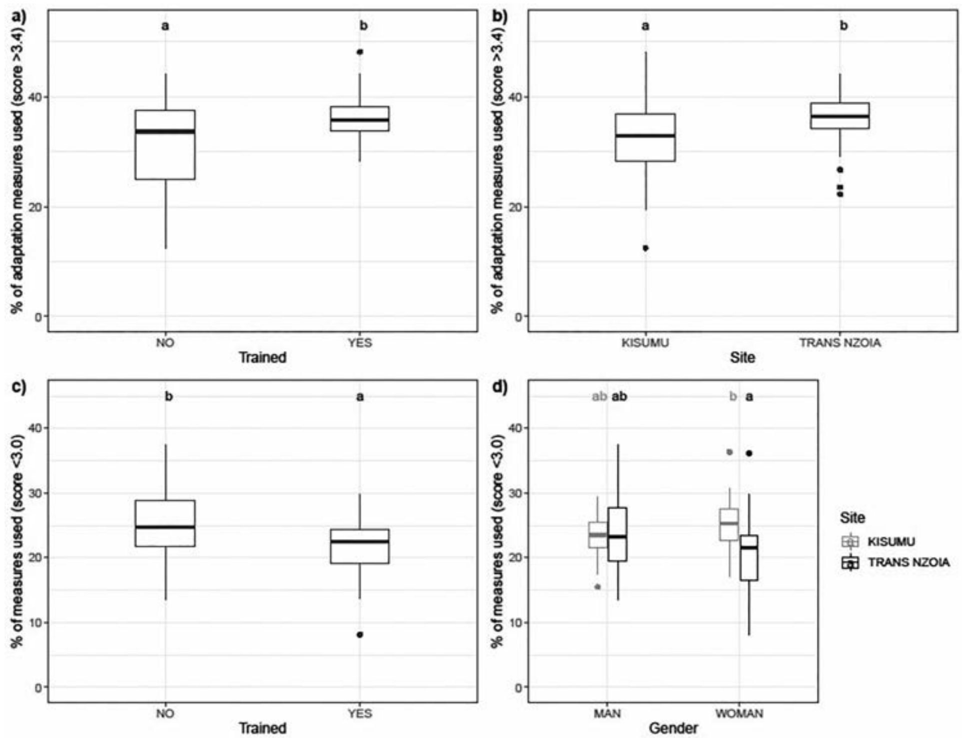

Figure 4. Proportion (%) of (a–b) adaptation measures scored to have high (≥3,4) perceived effectiveness, and (c–d) adaptation and coping measures scored to have low (<3.0) perceived effectiveness. Average score between 0-5, where 0 is least effective and 5 is most effective. Only measures used and scored by more than 10 farmers are included. Boxplots indicate the average score for 25, 50 and 75% of respondents.

government than male farmers, while the opposite applied in Kisumu ($P = 0.01$). Trans Nzoia farmers more commonly had education as a source of knowledge than farmers in Kisumu ($P = 0.008$, McFadden's pseudo $R^2 = 0.18$).

The top limitations preventing farmers from adopting measures were money, knowledge, land and labour (Figure 5(b)). Water was the fifth most limiting factor, regarding limitations in terms of adaptation to rainfall variability. Non-trained farmers were more limited by knowledge than trained farmers ($P = 0.009$), and female farmers perceived themselves as being limited by knowledge to a larger extent than male farmers ($P = 0.04$, McFadden's pseudo $R^2 = 0.19$). Interactions showed that trained farmers in Trans Nzoia were least limited by knowledge ($P = 0.02$) and farmers in Kisumu were more limited by land ($P = 0.02$, McFadden's pseudo $R^2 = 0.13$) and water ($P = 0.004$, McFadden's pseudo $R^2 = 0.16$) than farmers in Trans Nzoia.

In terms of vulnerability, the majority of farmers saw themselves as being neither more nor less vulnerable than their neighbours (Table 3). Characteristics of farmers considering themselves more vulnerable were often lack of knowledge, money, land or animals (Table 3). Those who felt less vulnerable explained that they were knowledgeable, had livestock (especially dairy cows), had the farm in a beneficial location and had trees on their farms (Table 3). Trained male farmers in Trans Nzoia appeared least vulnerable, whereas female farmers in Kisumu appeared most vulnerable (Table 3). Farmers were also asked about the farm components making them less vulnerable to rainfall variability challenges, and almost all farmers (74 out of 80) believed that a mix of crops, trees and livestock was the best combination to reduce vulnerability, compared with having just one or two of these.

4. Discussion

The discussion is comparing the results with earlier research findings in regards to rainfall related challenges in the two areas, use of adaptation measures and the perceived effectiveness of the measures. Further, the limitations to the use of measures, also

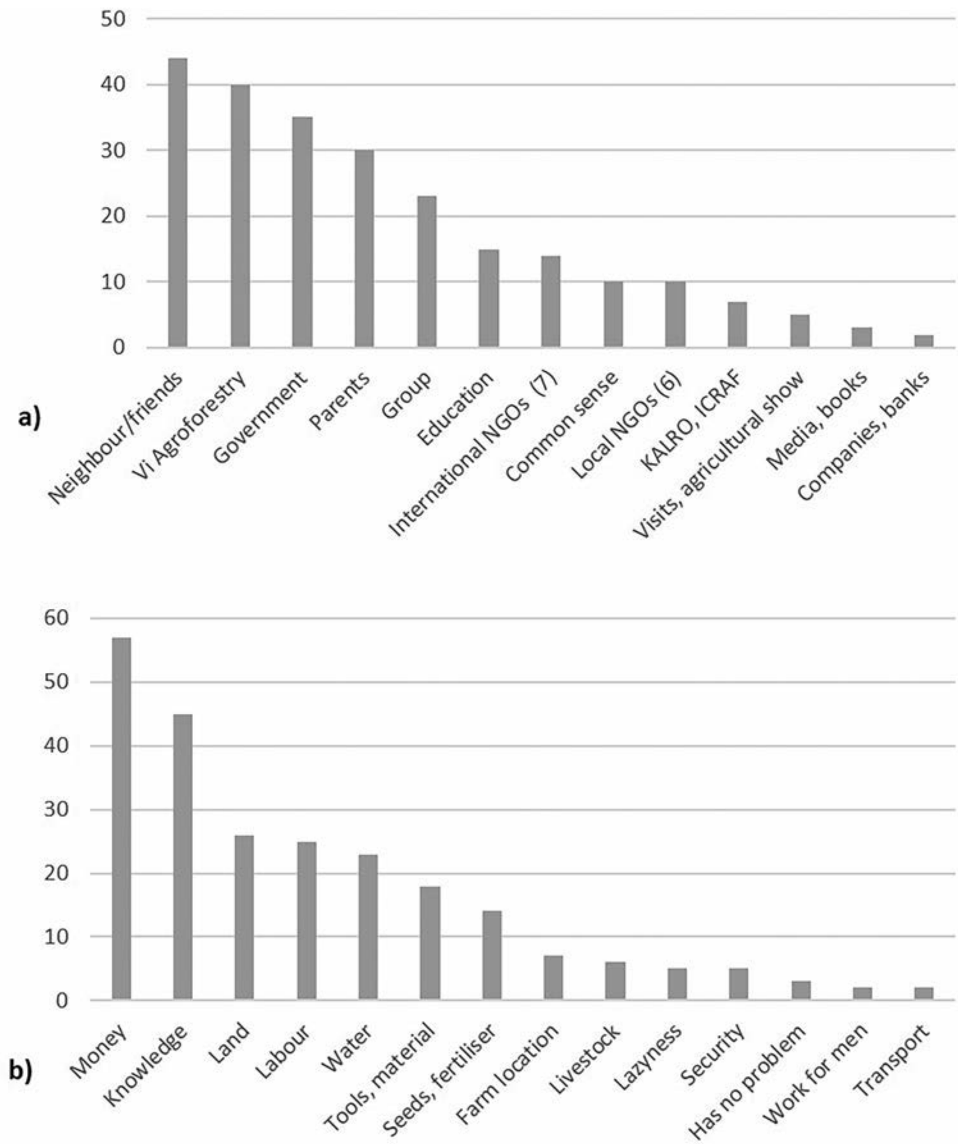

Figure 5. (a) Sources of knowledge about adaptation and coping measures and (b) limitations to farmers not using the measures, as self-reported by farmers. The bars show the number of farmers reporting the knowledge source or limitation.

in terms of the concept of the five capitals, factors affecting vulnerability of farmers, together with several sources of knowledge to learn adaptation measures are discussed.

4.1. Perceived and observed rainfall variability challenges

Farmers in Kisumu experienced more extreme rainfall-related challenges in terms of both droughts and floods, which was expected due to the higher temperatures and impermeable soils in this region. It has been found earlier that farmers living in more humid areas of sub-Saharan Africa have better welfare than those living in drier areas (Azzarri & Signorelli, 2020). Farmers in both Kisumu and Trans Nzoia perceived that rainfall had become more unreliable and that the frequency and scale of extreme weather events had increased. These perceptions among farmers are supported by studies of the local climate in neighbouring counties and trends in East Africa, where rainfall patterns have changed

Table 3. Data on number of farmers (a) that felt less or more vulnerable to rainfall variability than their neighbours, and the most common reasons for being (b) less or (c) more vulnerable than neighbours.

	Non-trained ($n = 40$)	Trained ($n = 40$)	Male ($n = 40$)	Female ($n = 40$)	Kisumu ($n = 40$)	Trans Nzoia ($n = 40$)
(a) Vulnerable compared with neighbours						
Less vulnerable	4	14	8	10	4	14
Neither more or less vulnerable	31	22	31	22	28	25
More vulnerable	5	4	1	8	8	1
(b) Reasons for being less vulnerable						
Knowledgeable	11	24	19	15	12	22
Has cow/livestock	13	11	10	14	12	12
Farm location	7	7	6	8	6	8
Has trees	4	8	6	6	2	10
None	5	4	1	8	8	1
Has terraces/ditches	3	4	3	4	1	6
(c) Reasons for being more vulnerable						
Lack of knowledge	16	3	8	11	13	6
No reason	4	14	8	10	4	14
Lack of money	5	10	11	4	11	4
Lack of land	5	6	8	3	6	5
No cow/livestock	6	3	3	6	4	5
Farm location	6	3	5	4	2	7

between the seasons and made the rainy seasons more diffuse and with higher maximum and minimum temperatures (Gebrechorkos et al., 2019; Saalu Faith et al., 2020; Wetende et al., 2018). It is important that farmers have recognized a change in rainfall patterns, since such awareness can make them more motivated to find and use adaptation measures for the changing situation (Deressa et al., 2011; Maddison, 2007). Extreme rainfall events such as floods are associated with lower food consumption among the affected people and an increased poverty level (Azzarri & Signorelli, 2020). These effects are directly related to coping measures evaluated in this study, where farmers changed eating habits or had less meals per day or had to sell off property like livestock, crops or land, or even leave the farm and migrate.

Even though the total number of measures (94) was high, the measures related to savings and loan options, diversification of produce and ways of acquiring knowledge were few, as found in other studies (Bedeke et al., 2019; Kalungu & Leal Filho, 2018). However, these factors seemed to be of high importance, according to responses on limitations to using measures, for farmers being more or less vulnerable than their neighbour. Timing of ploughing, planting, watering and harvesting were commonly used measures (Table A1) to adapt production to rainfall variability and can in some cases be the difference between success and failure. However, timing demands knowledge and experience and sometimes involves taking risks, which few smallholders can afford (Bedeke et al., 2018). The key to adoption of adaptation measures and positive changes that could benefit overall farm management may therefore include savings and loan opportunities, access to knowledge and diversification of production.

4.2. Adoption of measures by farmers

Overall adoption of adaptation measures was high in the two regions compared with in earlier studies (Kalungu & Leal Filho, 2018; Kamau et al., 2014). One explanation can be the relatively high confidence in the advisory agent that has been found in nearby areas (Lee, 2017), which plays an important role for adoption (Bedeke et al., 2019). Among all interviewees, the most commonly used measures were those considered to represent common sense or learnt from parents, such as timely watering, early ploughing and planting, using a tree nursery instead of direct sowing of trees and ridging soil when growing potatoes (Table A1). These measures were likely commonly used because they are cheap or effective compared with the alternatives. Application of livestock manure to crops was among both the most used and the perceived most effective measures, but was practised by only 84% of farmers although livestock were present on almost all farms (Table A1 and Table S2). The least used measures were those that were either new (mushroom production), required specialist knowledge (e.g. beekeeping, fishpond or greenhouse), were not very well known or too expensive (drip and gravity irrigation) or the last option to survive (e.g. migration and selling land).

The results demonstrated a strong positive effect on adoption of adaptation measures from having regular access to training, not only in terms of number of adaptation measures, but also the ability to choose more effective measures. This is good news, since several studies suggest that better access to advisory services can assist smallholders in responding to climate change effects (Bedeke et al., 2019; Deressa et al., 2009; Farnworth & Colverson, 2015). Focusing on horizontal learning in farmer-to-farmer networks or associations may play an important role in scaling up the use of measures (Rosset et al., 2011). However, the results in this study clearly showed the importance of external sources (advisory services) in order to increase the use of adaptation measures and especially the measures perceived more effective.

Among the non-trained farmers, there was a clear difference between non-trained female farmers in Kisumu and Trans Nzoia, with the Kisumu women lagging behind in use of adaptation measures. This was possibly due to female farmers in Kisumu having the lowest education, while male farmers in Trans Nzoia had the highest, followed by female farmers in Trans Nzoia. Lower education levels can have a significant negative effect on adoption of adaptation measures, as can being female (Deressa et al., 2009). Farming women in sub-Saharan Africa are also known to have less access to agricultural advisory services (Kiptot & Franzel, 2012), which can explain why e.g. male farmers in this study used more irrigation measures in general than female farmers. Women should therefore be targeted specifically according to their needs. An Ethiopian study found off-farm measures to be as common as on-farm measures (Bedeke et al., 2018). Off-farm diversification measures were included in this study, but were not among the most used or those perceived as most effective. It is possible that farmers in this study saw off-farm measures more as a complement to farming activities that could be intensified when needed. The higher use of off-farm measures among male than female farmers was probably a consequence of the cultural tradition of women being responsible for the home and children and needing permission from their husband to perform measures such as study visits, selling trees or off-farm income opportunities (Laszlo Ambjörnsson, 2011; Momsen, 2019). Farm-level adaptation measures were also used less by female farmers. Those are again measures that need some kind of strategic decision at household level regarding timing of production (e.g. early ploughing) or construction of e.g. a zero-grazing system, well or energy-saving stove, which can limit their use by female farmers. In addition, some measures are traditionally not carried out by women (e.g. fencing the farm, planting long-term trees or roof water capture) (Kiptot & Franzel, 2012; Laszlo Ambjörnsson, 2011). African women still have limited ownership and access to land and on-farm resources (Kiptot & Franzel, 2012), which makes them fall behind in terms of use of adaptation measures and especially measures needing strategic decisions at farm level. However, even if the differences between men and women in terms of decision making on-farm have long been known (Alkire et al., 2013; Padmaja & Kondapi, 2018), analyses of adoption of adaptation measures according to the level of decision making have not been studied. It would further enrich the knowledge base with separate studies of women within a household compared with women as household heads, since the power over resources and labour would differ. Several earlier studies have shown that when programmes consider gendered constraints and power over resources, farmers are more likely to succeed in improving production (Crist et al., 2017; Doss, 2018). Empowering women through directed extension services has been found to increase farm productivity (Diiro et al., 2018).

Higher adoption rates have been found in drier compared with wetter areas of Kenya and in hotter compared with cooler areas (Deressa et al., 2009; Kalungu & Leal Filho, 2018). The same pattern was expected in this study, where Kisumu is hotter and therefore drier than Trans Nzoia (though still semi-humid) (Braun, 1980) and awareness of measures is higher in Kisumu (Nyberg et al., 2020a). Kisumu farmers used more coping measures than Trans Nzoia farmers, but there was no difference in adaptation measures. Using coping measures like reduced consumption or selling livestock, land or labour increases the vulnerability of smallholders (Hisali et al., 2011). The use of adaptation measures (often labour- or capital-intensive) is less likely among more vulnerable farmers, which could lead to a vicious circle of declining yields and increasing vulnerability (Hisali et al., 2011).

4.3. Perceived effectiveness of different measures according to farmers

The individual measures with the highest average scores were using energy-saving stoves, planting leguminous trees for soil fertility and preserving/storing food. The two latter measures were included amongst the top scored measures for all groups, and all three measures are confirmed to be effective in the literature (Devereux, 2016; Dresen et al., 2014; Droppelmann et al., 2017; Sapkota et al., 2014). These measures were considered the most effective since as long as a household has food and firewood to prepare the food, it can handle rainfall variations. Having food, but lacking firewood to prepare it, was mentioned as a challenge, especially in Kisumu. The lowest scored measures (selling at a 'throwaway price', food aid and selling labour) were seen by many as measures costing either money or labour, which is often the case (Hisali et al., 2011). It was not uncommon for interviewees to score a measure 0, even if they ended up realizing that the measures helped even if they led to negative consequences. Early harvest and selling livestock, on the other hand, were perceived as better coping measures and were considered to be adaptation measures by some farmers.

It was also interesting that early ploughing (the second most used measure) was among the lowest scored measures. This could be because the measure is only beneficial if the rainy season is consistent and long enough (Mkuhlani et al., 2019).

Few previous studies have considered differences in the effectiveness of measures, differences in the effect depending on who is implementing or sample selection bias regarding which farmers tend to adopt practices (Abdulai & Huffman, 2014; Posthumus et al., 2010). However, since trained farmers in this study scored the most effective measures higher than non-trained farmers, this suggests that trained farmers were able to use the measures in a more effective way. This is perhaps because they have more detailed knowledge about them, access to credit in case of emergencies or a supportive social network that gives them the confidence to try the measures (Abdulai & Huffman, 2014). No measure was scored higher than 3.9 on average, which indicates a need for a combination of measures in order to manage rainfall-related challenges. Many adaptation measures have already been found to be more effective when adopted in combination with other adaptation measures, indicating that promotion of packages of measures can be more effective than promotion of individual measures (Bedeke et al., 2019; Di Falco, 2014). Changing crop variety to drought-resistant varieties, together with soil and water conservation measures or terracing, are examples of measures found to give synergies when combined (Bedeke et al., 2019; Di Falco, 2014). Such packages can then be designed to fit different groups of farmers that have different preconditions.

Few of the most effective measures were related to irrigation or specific varieties of crops, which are often discussed as possible solutions for Africa (Bryan et al., 2013; Fox et al., 2005; Ndambiri et al., 2013). Irrigation may be more relevant for Kisumu, since the main challenges in Trans Nzoia were linked to too much rain. Irrigation may be effective during droughts, but other important attributes are needed for an adaptation measure to be successful, e.g. low cost vs. benefit, a reasonable timeframe, ease of implementation and acceptability to the local community (Furlow et al., 2011). When adaptation or coping measures that are locally perceived to be more effective than others are identified, these should be incentivized in government and NGO activities and through horizontal farmer networks to widen their success (Rosset & Martínez-Torres, 2012; Stigter et al., 2005). The finding that field-level measures were perceived to be more effective than farm- or landscape-level measures confirms findings in our previous study in the same areas (Nyberg et al., 2020a). The reason may be that the effect is often directly related to production (e.g. through choosing special types of crops or erosion control measures) and also easy to identify compared with indirect effects on production from farm-level measures such as planting fodder, roof water capture or fencing fields.

4.4. Factors affecting adoption of measures and limitations to their use

This study confirmed that human capital in terms of regular advisory services is highly important for adoption of adaptation measures (Bryan et al., 2011; Challinor et al., 2007; Erenstein, 2003). Social capital through gender (Bedeke et al., 2019) and natural capital in terms of biophysical settings (Azzarri &

Signorelli, 2020) seemed to play smaller, but still significant, roles. The results confirmed that male farmers attended more off-farm advisory events and also received more visits by advisors (Kiptot & Franzel, 2012; Laszlo Ambjörnsson, 2011). To include gender aspects better in advisory services, a more multi-disciplinary and holistic approach is needed both among advisory services and researchers (Challinor et al., 2007). This study confirmed that relatively well-known technologies like terraces, reduced tillage, mulching, water harvesting and use of chemical fertilizer and organic manure (Kalungu & Leal Filho, 2018) are still often not used. However, access to regular advisory services resulted in both higher use and better ability to choose the adaptation measures perceived more effective.

Low perceived effectiveness (score = 2.3) could explain the low use of reduced tillage observed in this study, while lack of capital and knowledge could explain why only 22 of 80 farmers had tried the perceived most effective measure, using energy-saving stoves. The results confirmed that more than 25% of farmers believed that money, knowledge, land, labour and water all limited their use of adaptation measures, as reported previously (Hisali et al., 2011). However, trained farmers were less limited by knowledge, and male farmers less so than female farmers. Context also mattered, with smallholders in Kisumu being more limited by land and water compared with Trans Nzoia farmers. In a few cases, female farmers stated that they could not perform adaptation measures because it was men's work, which shows the role of traditions and gender norms (Laszlo Ambjörnsson, 2011; Rietveld, 2017). Diversity, not only among crops but also including e.g. trees and livestock, is also important in improving the resilience of subsistence farmers (Yoshimura et al., 2018). Our study confirmed the claim that smallholders consider diversification of farming systems to reduce vulnerability to rainfall variability (Droppelmann et al., 2017; Sagastuy & Krause, 2019). The importance of trees and livestock was demonstrated in this study, with tree and livestock production measures receiving high scores. Livestock and trees were also rated high in the descriptions of less vulnerable farmers. In addition, a majority of interviewees regarded a combination of crops, trees and livestock as being the best option for improved resilience, allowing the farm to withstand different climate conditions and acting as savings or insurances (Ogada et al., 2020). The advisory concept used by Vi Agroforestry was multi-disciplinary, emphasizing a diversified farming system (agroforestry), targeting both women and men and including concepts of village saving and loans and farming business in their advisory portfolio. This approach covers several of the limiting factors reported by farmers, such as risk spreading with more diversified production, gender inequalities, credit opportunities and income generation. This concept was perhaps one contributing factor to the clear differences between trained and non-trained farmers in this study. Labour remains an important challenge, especially with more diversified farming systems (Descheemaeker et al., 2016; Nyberg et al., 2020b).

Poor smallholder farmers seem to be highly aware of the reasons for increasing rainfall variability and measures for adapting to changes (Ngugi, 2002). However, they are still not implementing measures, since their priority is current food access and they may lack knowledge and capital to invest in measures to sustain and increase their production (Agesa et al., 2019). Larger farm size can also inhibit adoption of adaptation measures, due to lack of labour. Better-off households with other job opportunities due to higher education may see the farm as a secondary priority and thereby not perceive the need for investing in more sustainable production, since they are not reliant on the farm alone (Tongruksawattana & Wainaina, 2019). An increasingly common way of assisting poor households to adapt to climate change is through aid in terms of cash transfers via government or NGOs (Lawlor et al., 2019; Wood, 2011). However, questions remain regarding selection of households (Robles et al., 2019), corruption, transparency and actual adaptation achieved (Daidone et al., 2019). Money in a desperate situation may not be used for farm investments or agricultural advice. Instead, this study clearly confirmed that money and knowledge both limit farmers in improving their adaptive capacity. Therefore, cash transfers should be combined with e.g. efficient initial and regular advisory services on suitable adaptation measures (Ambler et al., 2017; Maddison, 2007), which could later be scaled up through horizontal learning using farmer-to-farmer networks (Posthumus et al., 2010; Rosset et al., 2011). Social networks, e.g. membership of a farmers' group or association for sharing knowledge or saving money, has been found to strengthen resilience for smallholders (Yoshimura et al., 2018). In this study, the majority of farmers (86%) were members of at least one such group. Continuous access to knowledge and information is key for smallholders' ability to adapt to, or cope with, future rainfall variability (Challinor et al., 2007). Local experience within communities should also be documented and best practices spread, while new knowledge should be tested and the results shared through farmer networks and advisory systems.

4.5. Farmers are learning the measures from different sources

The most common ways to learn about adaptation measures were through neighbours/friends, government and parents, as found earlier (Hughes et al., 2018; Krishnan & Patnam, 2014). Considering the combined role of neighbours/friends, parents and group members, local knowledge sharing seems to be important. With substantial horizontal learning (farmer-to-farmer), one can expect a blurred picture when comparing trained and non-trained farmers. However, significant differences were still found in this study, pointing to the importance of regular access to advisory services. One way of scaling up certain measures could be to encourage horizontal learning and formalize it in ways tested in other parts of the world (Rosset et al., 2011). Neighbours have been found to be the most common learning source in the long run, although government officers and NGO advisors are important sources of information especially in early stages of adoption (Kalungu & Leal Filho, 2018; Krishnan & Patnam, 2014). The fact that farmers targeted by one international NGO were more likely to be targeted by other international NGOs can be explained by NGOs using the same criteria to target farmers (e.g. membership of formal groups) or by some farmers being more proactive in attracting the attention of NGOs. In any case, it is probably not the resource-poorest farmers that benefit most from NGOs (Duchoslav & Kenamu, 2018; Kidd et al., 2000). According to this study, non-trained farmers and female farmers perceived themselves as being more limited by lack of knowledge. Overall, Kisumu farmers were limited to a larger extent by several factors (e.g. too small land holdings, water) than Trans Nzoia farmers, most likely due to the higher temperatures, more severe rainfall-related challenges and less favourable soils in Kisumu (Government, 1985). Female farmers in Kisumu also viewed themselves as more vulnerable than their neighbours due to lack of knowledge, money, land or livestock, which confirms that female farmers are more restricted in agricultural development (Diiro et al., 2018; Kiptot & Franzel, 2012). Female farmers in Kisumu also had the least education among all farmers interviewed. Trans Nzoia farmers had learned more through their education than Kisumu farmers, which can be explained by farmers having higher education in Trans Nzoia. In this study, media played a small role in information sharing, even though this technique is becoming more available (Fabregas et al., 2019).

4.6. Limitations of the study

During the interviews, the interviewees were not always heads of households. If heads of households had been selected, the results might have been different since female household heads can have more power over resources but perhaps less available labour. The choice of using a quantitative approach allowed for a greater number of farmers, and also enabled generalization of the results. However, a deeper understanding of e.g. limitations and learning sources could have been achieved with a more qualitative approach to the analysis of the data. Qualitative methods are better to understand views and perceptions in order to develop concepts or theories for potential future research.

5. Conclusions

Adoption of adaptation and coping measures to adapt to or cope with rainfall variability was found to be relatively high among smallholder farmers interviewed in Kisumu and Trans Nzoia counties, Kenya. A more challenging biophysical setting increased the use of coping measures even if almost all interviewees had used one or several coping measures during the past three years. Access to regular advisory services resulted in a higher number of adaptation measures used. Regular agricultural advise also enabled farmers to use a larger proportion of the perceived more effective adaptation measures at the same time as trained farmers experienced the measures as being more effective compared to non-trained farmers. However, interviewees confirmed that the main reasons for not using adaptation measures were lack of money, knowledge, land and labour. Female farmers felt more limited by lack of knowledge than male farmers, which was explained by lower access to advisory services and education.

Farmers in both areas perceived an increase in rainfall-related challenges, but the challenges were more extreme in Kisumu with its impermeable soils and higher temperatures. Extreme challenges like drought and flood led to higher use of coping measures (as opposed to adaptation measures), which increased the vulnerability of smallholders and probably prevented some from using as many adaptation measures as farmers in the more favourable Trans Nzoia area. Horizontal learning on measures (farmer-to-farmer) was equally important as external learning sources, but less effective than learning through regular advisory services that is an external source.

Apart from regular advisory services, other key factors for increased adoption of adaptation measures among smallholders were access to credit, access to more labour or simple mechanization, and more diversified farming systems including trees and livestock together with crops. Several of these factors were included in the advisory package used for trained farmers in this study, who displayed greater adoption of measures and also more effective choices of measures and more effective use.

6. Recommendations

Regular access to advisory services is enabling farmers to adopt more adaptation measures and should therefore be promoted. However, no individual measure was in itself found to solve the region's rainfall-related challenges, and therefore packages of effective and synergistic measures should be promoted through a more holistic approach to advisory services. Few measures were directed at overcoming limitations and thus more effort is needed, in which advisory services and policy interventions can play a role. Women e.g. need to be targeted specifically in order to get the same access to knowledge as men. Agricultural advice should also cover risk spreading through more diverse farming systems (including crops, trees and livestock) and target the main limitations of farmers, e.g. by promoting suitable saving and credit opportunities, leasing of simple machinery, and mainstreaming gender discussions. It can also be suitable to promote relatively simple adaptation measures in the beginning of advising farmers, measures that do not need much capital, labour, land or special knowledge, but still give both short-term and long-term benefits.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Ylva Nyberg holds a PhD in Crop Production Science with an international profile from the Swedish University of Agricultural Sciences (SLU). She is currently working within aspects of food security, sustainable farming systems and resilience as a post-doc at SLU. Her focus areas include small-scale tropical agriculture, agroforestry and climate change adaptation.

Johanna Wetterlind is Associate Professor in Soil Science at the Department of Soil and Environment, Swedish University of Agricultural Sciences (SLU). She holds a PhD in Soil Science and has carried out post-doc work at the French National Institute for Agricultural Research (INRA), France. Focus areas include plant nutrition, precision agriculture, proximal sensing and soil spectroscopy.

Mattias Jonsson is Senior lecturer in terrestrial ecology at the Department of Ecology, Swedish University of Agricultural Sciences (SLU). He has a part-time assignment at the Centre for Biological Control, SLU. He holds a PhD in entomology and has carried out post-doc work at Lincoln University, New Zeeland. Focus areas include plant protection, food-web and landscape ecology, and ecosystem service management.

Ingrid Öborn is Professor of Agricultural Cropping Systems at the Swedish University of Agricultural Sciences (SLU) and a senior research fellow of World Agroforestry (ICRAF). She holds a PhD in Soil Science from SLU. She has extensive experience of interdisciplinary international research using systems and multi-actor approaches linking research to policy and practice. Her research focuses on sustainable intensification and diversification of farming systems, ecosystem services, agroforestry and nutrient cycling.

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Appendix

Table A1. Adaptation and coping measures used in the individual farmer questionnaire (81 and 13, respectively) organized into 12 categories depending on the nature and aim of the measure, and separated into different spatial scales.

Type of measure	Name of measure	A[a]	C[b]	Scale[c]	Use %[d]	Mean score[e]	±SD[e]	Explanation and reason to use measure
Erosion control	Early ploughing	✓		FA	95	2.8	1.3	To utilize a shorter rainy season
	Early planting	✓		FA	93	3.4	1.3	To utilize a shorter rainy season
	Raised beds	✓		FI	88	3.4	1.3	To prevent flooding of crops
	Soil ridges[f]	✓		FI	88	3.6	1.3	Heap soil around plant for improved water infiltration
	Add manure	✓		FI	84	3.5	1.3	To promote water infiltration
	Dig cut-off drain	✓		FI	80	3.0	1.3	Drain ditches to prevent flooding
	Dig ditches	✓		FI	73	3.2	1.3	To promote water infiltration and prevent flooding
	Plough/plant along contours	✓		FI	71	3.6	1.2	Across slope to improve water infiltration
	Double digging	✓		FI	70	3.6	1.3	To get better root conditions to survive drought
	Add mulch	✓		FI	69	3.7	1.2	To promote water infiltration
	Dig terraces	✓		FI	65	3.2	1.3	To promote water infiltration
	Grass strips	✓		FI	60	3.2	1.5	Across slope to improve water infiltration
	Add compost	✓		FI	60	3.5	1.3	To promote water infiltration
	Dry planting	✓		FA	45	2.7	1.5	Plant before rain to utilize a shorter rainy season
	Soil in sacks	✓		FI	28	3.0	1.6	Building ridges to prevent flooding
	Stone lines	✓		FI	11	3.6	1.5	Across slope to improve water infiltration
	Plant without ploughing	✓		FI	10	2.3	1.3	No tillage to improve water infiltration
	Use greenhouse	✓		FA	8	3.0	2.0	To not depend on rainfall
Crop production	Early harvesting		✓	FI	81	3.3	1.4	To get something at least
	New/short-term crop varieties	✓		FI	80	3.5	1.5	To be sure to harvest
	Plant traditional crops	✓		FI	79	2.8	1.3	Better adapted to this area, watermelon, butternut, pumpkin, millet, cow pea etc.
	Drought resistant crops	✓		FI	76	3.2	1.3	Cassava, sweet potato, sorghum, millet, cow pea, pigeon pea, local vegetables etc.

(*Continued*)

Table A1. Continued.

Type of measure	Name of measure	A[a]	C[b]	Scale[c]	Use %[d]	Mean score[e]	±SD[e]	Explanation and reason to use measure
	Plant perennial crops	✓		FI	73	3.4	1.2	Can withstand more rainfall variability, sugarcane, banana, coffee, tea, macadamia etc.
	Water-tolerant crops	✓		FI	71	3.5	1.2	Rice, banana, yam, vegetables, sweet potato, cassava etc.
	Plant cover crops	✓		FI	68	3.3	1.2	To promote water infiltration, sweet potato, desmodium etc.
	Plant under-ground crops	✓		FI	66	3.2	1.4	Not affected by hailstorms, cassava, yam, sweet potato, groundnut etc.
	Bananas in ditches	✓		FI	65	3.6	1.2	To collect water for better performance
	Sell harvest at 'throwaway' price[f]		✓	LA	65	1.5	1.2	To get money
	Relay cropping[f]	✓		FI	60	3.3	1.2	Crops 'overlapping' each other in the field to utilize rainy season
	Crops in nursery	✓		FI	38	3.5	1.1	For survival, then transplant
	Chemical on leaves to reduce moisture		✓	FI	13	2.8	1.0	Did not know name
	Mushroom production[f]	✓		FA	3	3.5	0.7	To not depend on rainfall
Tree production	Have tree nursery instead of direct sowing[f]	✓		FA	95	3.3	1.4	For survival and easy watering, then transplant
	Plant trees for micro-climate/more rain[f]	✓		FA	81	3.6	1.2	To keep humidity/to attract rainfall
	Plant trees as windbreak	✓		FI	79	3.6	1.2	To prevent strong wind destroying crops
	Plant trees for soil fertility	✓		FI	71	3.9	1.2	To improve water infiltration
	Sell fruit from trees	✓		LA	66	3.2	1.1	To get money
	Plant trees for erosion control	✓		FI	59	3.4	1.4	To improve water infiltration
	Sell timber	✓		LA	58	3.2	1.2	To get money
	Plant trees to absorb water	✓		FI	34	3.4	1.3	To prevent flood
	Sell firewood or charcoal	✓		LA	33	3.4	1.0	To get money
	Sell tree seedlings[f]	✓		LA	26	3.3	1.1	To get money
	Sell fodder from trees	✓		LA	6	3.4	1.1	To get money
	Sell medicine from trees[f]	✓		LA	1	4.0	-	To get money
Livestock production	Focus on livestock	✓		FA	76	3.0	1.4	If crops failed, pay more attention to livestock
	Sell livestock		✓	LA	76	2.9	1.4	To get money to survive
	Fence the farm[f]	✓		FA	69	3.3	1.4	To prevent free-grazing animals from entering
	Take livestock to greener pasture	✓		LA	61	2.9	1.4	Walk with livestock to other area to graze
	Rotational grazing	✓		FA	55	3.2	1.4	Graze one area at the time to make grass last
	Plant fodder	✓		FA	51	3.2	1.4	To not depend on rainfall
	Build raised cattle shed	✓		FA	48	3.4	1.2	To protect hooves from water when flooding
	Dry/store fodder	✓		FA	35	3.6	1.5	To not depend on rainfall
	Reduce number of livestock and upgrade[f]	✓		FA	34	3.3	1.2	To improve fodder efficiency
	Zero grazing system	✓		FA	24	3.5	1.2	To control grazing and improve fodder efficiency
	Beekeeping	✓		FA	11	2.7	1.7	To not depend on rainfall
	Establish fish pond	✓		FA	6	2.8	1.1	To not depend on rainfall
Irrigation	Timely watering	✓		FA	96	3.3	1.2	Morning and evening to utilize water better
	Roof capture	✓		FA	86	3.3	1.3	To utilize water better
	Hand irrigation	✓		FI	64	2.9	1.3	For crops to survive when drought
	Reuse of water[f]	✓		FA	54	2.8	1.3	From household to farm to utilize water better
	Micro-catchments on farm	✓		FI	39	2.9	1.4	For improved water infiltration
	Dig a water pan	✓		FA	33	3.1	1.5	Small pond to store water
	Dig a well	✓		FA	31	3.1	1.4	To get water when drought
	Pump irrigation	✓		FI	25	3.5	1.2	For crops to survive when drought
	Gravity irrigation	✓		FI	3	2.5	0.7	For crops to survive when drought

(*Continued*)

Table A1. Continued.

Type of measure	Name of measure	A[a]	C[b]	Scale[c]	Use %[d]	Mean score[e]	±SD[e]	Explanation and reason to use measure
	Drip irrigation	✓		FI	0	-	-	For crops to survive when drought
Off-farm	Trading		✓	LA	65	2.8	1.3	Buy and sell goods to not depend on rainfall
	Sell labour		✓	LA	64	2.0	1.2	To not depend on rainfall
	Keep a shop	✓		LA	50	3.3	1.2	Craftsman, hairdresser, bicycle taxi, shoe polisher
	Make and sell baskets, ropes, pots	✓		LA	31	3.3	1.3	To not depend on rainfall
	Make and sell bricks	✓		LA	16	3.2	1.7	To not depend on rainfall
	Go fishing in lake/river	✓		LA	11	2.6	1.3	To not depend on rainfall
	Sell land[f]		✓	LA	9	1.4	1.0	To get money to survive
	Mine and sell stones		✓	LA	9	2.6	1.3	To not depend on rainfall
Food and cooking	Change eating habits		✓	FA	79	2.2	1.3	Eat less preferred food to make food last
	Less meals per day		✓	FA	71	2.2	1.4	From three meals to two to make food last
	Preserve food	✓		FA	66	3.8	1.2	E.g. with solar dryer to always have food
	Use raised energy-saving stoves	✓		FA	28	3.9	1.0	To use less firewood and avoid flooding
External	Help from relatives		✓	LA	49	2.6	1.3	To survive
	Relief food		✓	LA	29	2.0	1.3	To survive
	Government dikes	✓		LA	15	3.0	1.4	To prevent flooding
	Migration		✓	FA	13	2.1	1.7	To survive
Group related	Knowledge, exposure through group[f]	✓		LA	88	3.5	1.1	To get knowledge
	Saving/loaning/marketing through group	✓		LA	78	3.5	1.2	To be able to invest or save for future
	Labour, encouragement from group[f]	✓		LA	71	3.5	1.1	To get enough labour
Vegetable growing	Kitchen garden	✓		FA	73	2.9	1.3	Possible to irrigate and have emergency food
	Grow tomatoes off-season	✓		FA	53	3.3	1.2	To get better price and not depend on rainfall
	Grow vegetables in a sack	✓		FA	21	3.1	1.3	Possible to irrigate and have emergency food
Opportun-istic	Sell river water	✓		LA	13	2.8	1.3	To get money
	Sell fish from flooded area	✓		LA	13	2.9	1.3	Try to fish from flooded area to get money/ food
	Harvest and sell sand	✓		LA	5	2.5	1.0	Sand comes with water during flooding
Other	Lease land	✓		LA	66	2.8	1.2	Plant crops in another place to spread risks
	Visit agricultural training centre[f]	✓		LA	65	3.6	1.1	To get knowledge
	Plant other area	✓		FA	48	3.1	1.2	Swampy, sloping, drier depending on challenge to at least get some harvest

The table is modified from Nyberg et al. (2020a).
[a]A = adaptation measure.
[b]C = coping measure.
[c]Different spatial scale; field (FI), farm (FA) or landscape (LA), depending on which level the measure was decided upon and practised.
[d]Percentage of farmers ($n = 80$) using the measure in the last three years.
[e]Mean score of perceived effectiveness and standard deviation (±SD) of score. Farmers only scored measures that they had used during the last three years.
[f]The measure was uniquely identified by advisors.