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CLIMATE VARIABILITY AND CHANGE: FARMER PERCEPTIONS AND UNDERSTANDING OF INTRA-SEASONAL VARIABILITY IN RAINFALL AND ASSOCIATED RISK IN SEMI-ARID KENYA

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SUMMARY

This study examines farmers' perceptions of short- and long-term variability in climate, their ability to discern trends in climate and how the perceived trends converge with actual weather observations in five districts of Eastern Province in Kenya where the climate is semi-arid with high intra- and inter-annual variability in rainfall. Field surveys to elicit farmers' perceptions about climate variability and change were conducted in Machakos, Makueni, Kitui, Mwingi and Mutomo districts. Long-term rainfall records from five meteorological stations within a 10 km radius from the survey locations were obtained from the Kenya Meteorological Department and were analysed to compare with farmers' observations. Farmers' responses indicate that they are well aware of the general climate in their location, its variability, the probabilistic nature of the variability and the impacts of this variability on crop production. However, their ability to synthesize the knowledge they have gained from their observations and discern long-term trends in the probabilistic distribution of seasonal conditions is more subjective, mainly due to the compounding interactions between climate and other factors such as soil fertility, soil water and land use change that determine the climate's overall influence on crop productivity. There is a general tendency among the farmers to give greater weight to negative impacts leading to higher risk perception. In relation to long-term changes in the climate, farmer observations in our study that rainfall patterns are changing corroborated well with reported perceptions from other places across the African continent but were not supported by the observed trends in rainfall data from the five study locations. The main implication of our findings is the need to be aware of and account for the risk during the development and promotion of technologies involving significant investments by smallholder farmers and exercise caution in interpreting farmers' perceptions about long-term climate variability and change.

INTRODUCTION

Farming in the semi-arid tropics, where season-to-season variability in rainfall dictates productivity and profitability, is a risky endeavour especially for small and marginal farmers with limited land and financial resources. Farmers have to make several decisions such as which crop or variety to grow on how much land, what inputs to use, and what soil, water and crop management strategies to adopt. The outcome of such decisions is directly linked to the amount and distribution of rainfall during the season. Because of the high variability and uncertainty associated with seasonal rainfall, farmers make these decisions based on their knowledge and experience gained

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from several years of keen observation, experimentation and practice in the field. The role and value of this local indigenous knowledge in designing appropriate research, development and extension strategies that are relevant to the local conditions has long been recognized and is well documented (Agrawal 1995; Carswell and Jones 2004; Chambers 1983; Chambers *et al.* 1989; Richards 1985; Pretty *et al.* 1999).

A number of regional and national studies have highlighted the possible negative impacts of current climate variability and future change on agricultural productivity and the urgent need to develop improved coping and adaptation strategies. This is especially true in developing countries that are particularly vulnerable to the impacts of current variability and future changes in climate due to the high dependency of the population and economies on rainfed agriculture and their limited capacity to adapt (Adger *et al.*, 2007; Huq *et al.*, 2004; Kurukulasuriya *et al.*, 2006; Lobell *et al.*, 2008; Schlenker and Lobell, 2010; Sivakumar *et al.* 2005). Though there are uncertainties over the exact nature of changes in climate and their likely impacts on agriculture, important lessons can be learned from the experiences of farmers in semi-arid environments, for whom variability in rainfall and temperature at inter- and intra-seasonal and annual scales is not new and who have coped with it in their own way for many generations (Cooper *et al.*, 2008; Mertz *et al.*, 2009; Mortimore and Adams, 2001; Nunn *et al.*, 2007). Considering the important role local or indigenous knowledge can play in developing practical and realistic approaches that facilitate smallholder farmers in adapting to impacts of current and future climates, several studies were carried out to understand and assess farmer perceptions about climate variability and the mechanisms employed to cope with it across Africa and elsewhere (e.g. Bryan *et al.*, 2009; Mertz *et al.*, 2009; Nyong *et al.*, 2007; Sleggers, 2008; Thomas *et al.*, 2007). However, the main focus of these studies was sociological, documenting descriptive summaries from field surveys and semi-quantitative information generated through participatory processes with limited efforts to relate them to scientific measurements. Very few studies have tried to assess the accuracy of farmers' perceptions of current climate-induced risk and possible long-term changes in climate with observed data on rainfall and temperature (Meze-Hausken, 2004; Ovuka and Lindqvist, 2000; West *et al.*, 2008).

Understanding the trends in complex and variable phenomena such as rainfall is not straightforward and doubts have been expressed on the ability of farmers to accurately discern climate trends from their casual observations (Kempton *et al.*, 1997), the completeness of their assessment since they represent simplified versions of complex reality (Johnson-Laird, 1983) and the subjective nature of these perceptions (Beal, 1996; Marra *et al.*, 2003; Pannell *et al.*, 2006; Sattler and Nagel, 2010). Further, farmers' perceptions are also likely to be shaped by the agro-economic performance of crops and other farm enterprises that affect their livelihood where climate is only one of the many bio-physical and socio-economic factors that affect productivity. Farmers' perceptions are also expected to be influenced by a range of other factors such as gender, level of education and farm size.

Given the above, the objective of this paper is to understand how farmers perceive and interpret the nature of current climate-induced risk and possible changes in the nature of that risk due to climate change in their area and what influences their perceptions. This article is based on the results from a study conducted in the semi-arid areas of Eastern Province in Kenya, where climate is the dominant factor contributing to season-to-season variation in the productivity of rainfed agricultural systems. It analyses some of the challenges and potential pitfalls in farmer understanding, knowledge and attitudes towards climate variability and change, and their use by research and developmental agencies in developing well-targeted technologies and strategies that enable farmers to plan for and cope with current climate risks and adapt to future climate change.

MATERIALS AND METHODS

The study area

The study is focused on five Ukambani districts, the traditional home of the Akamba people in Eastern Kenya: Kitui, Mwingi, Mutomo, Machakos and Makueni in the southern part of Eastern Province, the second largest province in Kenya with an area of 153 472 km^2 and a population of 4 631 779 people. The districts are located between 0°03′ and 3°0′S and 37°45′ and 39°0′E (Figure 1) and together account for 27% of the area and 54% of the population of the province.

The agricultural potential of these areas is strongly linked to altitude. The districts are characterized by a major plateau, referred to as Yatta, which rises to an altitude of about 1100 m asl, but which is surmounted by ridges and hills that rise to 1900 m asl. The area is generally divided into lowland, lower mid-land and upper mid-land. The central area of the districts, mainly consisting of upper mid-land and highland, has higher potential for agriculture compared to lowland areas. Below 550 m, it is normally too dry and mainly inhabited by pastoralists. The population density reflects the agricultural potential and ranges from about 15 persons km^{-2} in the lowland to as high as 250 persons km^{-2} in the upper mid-land areas. The study is focused on the lower mid-land areas where dryland agriculture is practiced by smallholder farmers as the main source of livelihood.

Climate of the study area

The climate of the study area is predominantly semi-arid with characteristically erratic and unreliable rainfall. Mean total annual rainfall ranges from as low as 500 mm in the lowlands to over 1050 mm in the hilltops. The southward and northward movement of the inter-tropical convergence zone produces two rainy seasons a year near the equator where the study area is located. The first rainfall season is in March/April/May also referred to as 'long rains' (LR) and the second rainfall season occurs in October/November/December and is referred to as 'short rains' (SR) (see also Table 1). Temperature and evaporation rates are generally high with February and September being the hottest months of the year. Minimum mean annual temperatures vary from 14 °C to 22 °C while maximum mean annual temperatures vary from 26 °C to 34 °C.

Table 1. Selected meteorological stations within the five districts and their rainfall characteristics.

District	Meteorological station	Period	Missing data in months (% of total)	Rainfall (mm) (CV (%)) Annual	LR season (March–May)	SR season (October–December)
Kitui	Kitui Water office	1963–1995	2.7	1008 (33.1)	399 (49.9)	508 (40.9)
Mwingi	Mwingi Agricultural Office	1961–2006	3.1	774 (40.8)	250 (47.5)	426 (51.3)
Mutomo	Mutomo Agricultural Office	1959–2006	3.5	896 (55.6)	264 (68.7)	511 (72.3)
Machakos	Katumani Experimental Research Station	1957–2007	0	702 (28.4)	288 (41.5)	314 (50.7)
Makueni	Makindu Meteorological Station	1959–2004	0	595 (40.6)	172 (53.3)	306 (58.0)

CV: coefficient of variation; LR: long rains; SR: short rains.

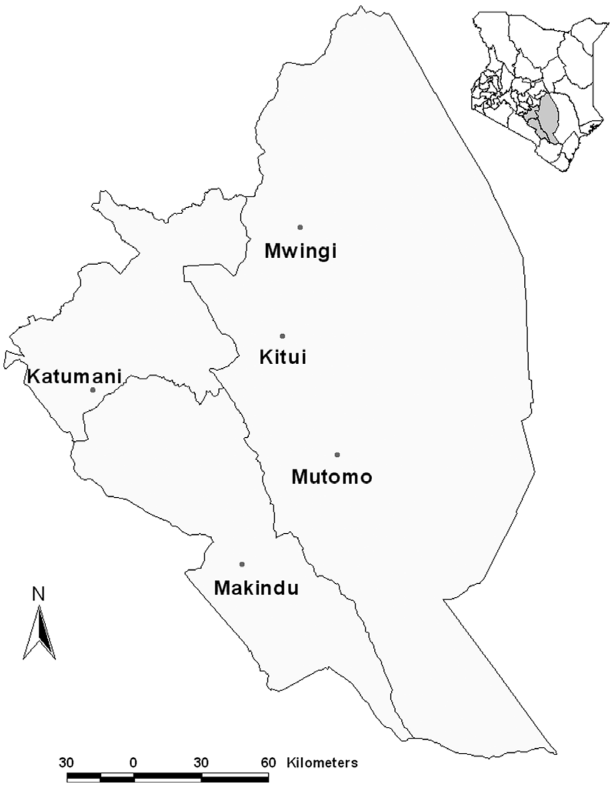

Figure 1. Map of Kenya with study districts and locations of climate data source indicated.

Soils and land use at study location

In the eastern and southeastern drylands, where the study area is located, strongly weathered soils (Ferralsols, Acrisols and Luvisols) dominate on basement rocks (as in the Machakos and Kitui Hills) and on the tertiary peneplains. In general, the soils are very old, low in organic matter and very infertile. Most farmers grow maize,

Table 2. Distribution of farmers covered by the survey across the locations.

		Number of farmers		
District	Location	Women	Men	Total
Kitui	Kyangwithya East	17	11	28
Mwingi	Mwingi	39	7	46
Mutomo	Nguutani	39	11	50
Machakos	Mwala	22	19	41
Makueni	Makindu	16	14	30
Total		133	62	195

beans, cowpea, pigeonpea, and sometimes green gram and cotton. Sorghum and millet, once the staple grains, are found in small patches in croplands but have been largely replaced by maize. Farmers in the highland areas grow coffee while cabbages, tomatoes, onions, red peppers and greens are usually limited to river flood plains or poorly drained valley sites.

Selection of survey sites within study area

The main criterion used in selecting the study sites was the availability of long-term daily weather data. Daily weather data for more than 25 stations located within Ukambani region were collected and analysed for data quality, length of record and distribution of rainfall during the LR and SR seasons. From the available data, five stations with data for all or part of the 1957–2006 period and with minimal missing data (<5%) especially for the months that fall within the main LR and SR seasons (Table 1) were selected. Of the five locations selected, Katumani and Makindu stations have the longest records with no missing data. These two stations are synoptic stations of the Kenya Meteorological Department and the quality of data is good. The other three stations are rainfall recording stations, with missing values, fortunately mostly outside the main cropping seasons. Among the stations selected, Kitui has the shortest record of observations (33 years) with no data available after 1995. Data for Mwingi and Mutomo showed some abnormally high rainfall records for a few days and these were corrected by extrapolating the data from nearby stations.

Field surveys

Field surveys were conducted during August and September 2008 at one selected ‘location’ in each of the five districts. In Kenya, a ‘location’ is the fourth level administrative subdivision below provinces, districts and divisions. The target location was selected randomly from all the locations that were within a 10 km radius from the identified meteorological station. Within each location 50 farmers, selected randomly from a list of households available at the district office, were interviewed. Overall the survey yielded 195 usable responses of which 68% are from women farmers (Table 2).

The survey questionnaire (available from the corresponding author) included simple questions aimed at eliciting farmers’ understanding and knowledge of the season-to-season variability, especially about rainfall, and how they classify seasons and criteria they use to do so. In addition, it assessed the ability and accuracy with which farmers can recollect the seasonal conditions that occurred during the past 10 seasons and the impact of variable rainfall conditions on crop productivity. The questionnaire was also designed to capture the farmers' perceived probability distribution of different types of seasons and long-term changes in the climate observed at their respective locations.

Climate data analysis

Data from the five selected meteorological stations were analysed to characterize the variability and trends in the amount and distribution of rainfall and temperature. While all the stations have rainfall records, temperature records are available for only Katumani Experimental Research Station and Makindu Meteorological Station. The temperature record for Katumani Experimental Research Station started in 1987 while Makindu has records from 1959 onwards. Weekly, monthly and decadal totals, coefficients of variation (CV) and anomalies for rainfall were computed using spreadsheet-based tools. Inter-annual variability in rainfall and temperature was evaluated by calculating the standardized anomalies for rainfall (SRA) and temperature (STA) using the following equation (Oliver, 1980):

$$\text{SRA} = P_t - P_m/\sigma$$

Where P*t* is annual rainfall in year *t*, P*m* is long-term mean annual rainfall over the period of observation and σ is standard deviation of rainfall. For calculation of STA, rainfall in the above equation was replaced with temperature.

Evaluation of farmer perceptions

To contrast the perceptions of farmers with scientific data, we tried to classify the seasons using three different criteria. The first is based on the deviation from the long-term mean, which meteorologists use to classify the seasons. According to this criterion, seasons with a rainfall in excess of 25% of the long-term mean are classified as good and those with rainfall less than 25% below the long-term mean as poor. The second is based on the adequacy of average seasonal rainfall to grow the region's main staple crop maize using the criterion developed by Stewart and Faught (1984). According to this, good seasons are the seasons with a rainfall of more than 350 mm, poor seasons are the ones with a rainfall of less than 220 mm and average seasons will have a rainfall between 221 and 349 mm. The final classification is based on maize yields simulated by the crop simulation model Agricultural Production System Simulator (APSIM), which is driven by long-term daily climate data. The seasons at different locations were also classified using the average yields of maize expected by farmers as threshold limits.

Crop simulation modelling with APSIM

We used the APSIM v7.1 (Keating *et al.*, 2003) model to simulate maize yield response to weather inputs. A number of studies have evaluated APSIM's ability to simulate observed maize yield response to climate and management at several locations across Eastern and Southern Africa including one of our study sites Katumani. Using the data from a maize trial conducted over 19 seasons (i.e. short- and long-rains, 1990–1999) and comparing different plant populations (2.2 and 5.3 plants m^{-2}), rates of fertilizer application (0, 70 and 100 kg N ha^{-1}) and mulch treatments, Okwach and Simiyu (1999) assessed the ability of APSIM to simulate observed variability in maize yields (0 to 5.5 t ha^{-1}), in response to daily weather and treatments. APSIM simulated weather and management impacts on maize yield (root mean square error = 0.3 Mg ha^{-1}, $R^2 = 0.96$) quite well. The input data requirements of the model include daily weather data (minimum and maximum temperature, precipitation and solar radiation), soil properties, crop cultivar characteristics and management practices employed. Temperature and solar radiation were available for Makindu for the whole period and for Katumani since 1986. Missing temperature and solar radiation observations were estimated using a stochastic weather generator MARKSIM (Jones and Thornton, 2000).

The simulation runs were set up using farmer-specified management practices. We used the Katumani maize variety which is widely grown in the target districts. Maize was planted at a density of three plants m^{-2} on a soil that is 1.5 m deep with a plant available water capacity of 163 mm. The curve number for runoff was set to 87 and crop residues were removed after harvest. Fertilizer nitrogen was applied at a rate of 20 kg N ha^{-1} at the time of sowing to account the nitrogen contributions from legume rotation and application of 2.5 t ha^{-1} manure every alternate year. The simulation runs were made allowing the accumulated effects of crop growth and hence accounted for the nitrogen depletion.

RESULTS

Characteristics of the respondents

The survey covered different age, education, sex and land holding groups. Such factors are generally considered to influence an individual's perception about short- and long-term variability in climate. The majority of the respondents interviewed were women (68%) reflecting the fact that more women actively practice agriculture in the survey areas. The mean age of the sample was 44.6 years with respondents spread equally in the younger and older age groups (Table 3). No major difference was observed in the average age of the respondents between districts, except for Kitui where the average age of the group was higher by 10 years. The age profiles of men and women (data not presented) showed 13% more men in the age groups of 45 years and above. With respect to education, 82% of the farmers interviewed had at least primary education. In general women are less educated than men. Nearly 85% of the respondents having no formal education are women.

Average farm size of all farmers interviewed is 2.87 ha with 17% of them holding less than 1 ha and the rest distributed equally in the groups 1–2.5 ha and more than 2.5 ha. The proportion of men and women farmers in different farm size groups (data not presented) is very similar. However, at Makueni, the mean farm size of women farmers is 0.7 ha larger than that held by men farmers while at Mwingi the mean size

Table 3. General characteristics of the survey population.

Category	Kitui	Mwingi	Mutomo	Machakos	Makueni	Total
Age groups						
Mean age (years)	54.5	44.3	41.8	43.2	42.5	44.6
Aged <24	0	1	8	5	0	14
Aged 25–44	4	25	16	14	20	79
Aged 45–64	19	18	23	18	7	85
Aged >65	5	2	3	4	3	17
Education level						
None						
Women	2	11	9	6	2	30
Men	0	0	3	2	0	5
Primary						
Women	10	21	24	9	6	70
Men	4	2	4	10	8	28
Secondary						
Women	5	6	6	7	5	29
Men	7	4	4	6	5	26
College						
Women	0	1	0	0	3	4
Men	0	1	0	1	1	3
Farm and household size						
Average farm size (ha)	1.62	2.93	3.53	2.73	3.03	2.87
<1.0	8	6	8	8	3	33
1.0–2.5	17	21	17	15	12	82
>2.5	3	19	25	18	15	80
Cropped area						
Area cropped during SR (%)	75.9	84.6	82.7	92.0	66.4	81.8
Area cropped during LR (%)	65.9	71.6	60.5	81.0	45.3	65.9

LR: long rains; SR: short rains.

of the farms held by men is 1 ha larger than that held by women farmers. Despite the small size of holding, there are very few years during which the whole farm is planted. On average, 18% of the farm is left fallow during SR season and 34% during LR season reflecting the general perception that rainfall during the LR season is more variable and unreliable than that during SR season and that the duration of the season is shorter. In addition, farmers also cited lack of inputs and an inability to undertake farm operations in a timely manner due to lack of available labour.

Crops grown and major constraints

Maize and beans are the common food crops grown by most farmers in the study districts. However, maize is the only crop grown at all the five locations by all the farmers (Table 4) both in SR and LR seasons. The area planted to maize during SR season tends to be higher than that during LR season mainly due to greater reliability of rains during the SR season and also to ensure adequate supplies to meet the household food needs. Beans, cowpea and green gram are planted either

Table 4. Commonly grown crops in the districts.

District	Maize	Beans	Cowpea	Pigeonpea	Green gram	Sorghum
			Farmers growing various crops (%)			
Kitui	100	96	4	71	7	7
Mwingi	100	100	78	70	54	44
Mutomo	100	43	80	43	90	67
Machakos	100	98	73	68	7	22
Makueni	100	83	57	83	43	17
All locations	100	82	65	64	45	36

Table 5. Farmer ranking of various constraints to crop production (% farmers).

District	Input costs	Climate	Soil fertility	Varieties	Output price	Do not know
Kitui	48	21	20	4	7	0
Machakos	15	41	26	6	5	7
Makueni	32	42	18	2	3	3
Mutomo	37	18	18	6	4	17
Mwingi	35	28	22	3	2	10
Total	33	29	21	4	4	9

as an intercrop or in rotation with maize while pigeonpea is always grown as an intercrop. Beans are the most preferred legume crop at all locations except Mutomo where farmers showed preference for green gram due to its high tolerance to moisture stress and shorter duration. At all locations, preference for cultivating pigeonpea is very similar. Despite the great suitability of sorghum and millet crops for these dry locations (they are more tolerant to drought than maize) very few farmers are involved with their cultivation. Only 36% of all farmers interviewed are growing sorghum, most of them from Mutomo and Mwingi districts.

When asked to identify major constraints to farming in their area and rank them in order of their importance, most farmers ranked high cost of inputs especially fertilizers, high variability in the amount and distribution of rainfall during and between the seasons, and low soil fertility as the major constraints limiting their ability to realize higher yields (Table 5). One of the reasons cited by farmers for not considering climate variability as the most important constraint is the belief that climate is an 'act of God' over which they have no control. The relatively low rank given to soil fertility is partly due to the high rank given to input costs which mainly reflects the investments in soil fertility enhancement. Overall, the perceptions of men and women were found to be very similar.

Farmer understanding of climate variability

Farmers are well aware of the season-to-season weather variability and have generally classified the seasons as good, not so good or average, and very dry or poor based on criteria that included factors such as crop yields, early and late onset

Table 6. Criteria used by farmers to evaluate the seasons.

Season type	Criteria
Good	High yield, early onset, good rain at onset, good rainfall during January and June, short breaks, high temperature, moderate sunshine
Average	Yields which are about half of what they get in good seasons, low rainfall at onset, good rainfall but with breaks or poor distribution, poor rainfall after November, cloudy with cool temperatures and drizzles, good yield with investments, late onset starts in November, poor spatial distribution
Poor	Very low or no yield, late onset and long dry period after onset making replanting a necessity or poor crop stand, long breaks, rains stop early, some heavy damaging rainfalls

Table 7. Farmers ability to recollect the seasons (% farmers) (figures in parentheses are total number of respondents at each location).

Season	Kitui (28)	Mwingi (46)	Mutomo (49)	Machakos (40)	Makueni (30)	All locations (193)
2008LR	100	100	100	100	100	100
2007SR	100	96	94	95	97	96
2007LR	86	85	92	95	77	87
2006SR	86	83	90	95	67	79
2006LR	46	72	82	73	33	65
2005SR	46	72	82	63	33	63
2005LR	39	50	82	55	27	54
2004SR	39	50	82	53	27	53
2004LR	39	46	80	45	17	49
2003SR	39	46	80	45	17	49

LR: long rains; SR: short rains.

of rain season, amount and distribution of rainfall (Table 6). The most commonly used measure is crop yield and climatic factors affecting it. The climatic factors identified by farmers not only include amount and distribution of rainfall but also others such as onset of season, cloudiness, temperature and rainfall during critical stages such as January and June coinciding with the grain-filling stage of the maize crop during SR and LR seasons. The variables identified by farmers clearly indicate the fairly good understanding they have about the effects of climate on crop growth and performance.

After eliciting information about different seasons and the rationale used in classifying the seasons, farmers were asked to recollect and describe the seasonal conditions over the past 10 seasons (Table 7) to assess their ability to remember and chart the events. The respondents were first asked to describe the season that preceded the survey followed by the season prior to that up to 10 seasons. No effort was made by the enumerators to assist farmers by providing clues that link the season with an important or landmark event. While all farmers were able to recollect how the season that preceded the survey was, only 49% of the interviewed farmers were able to recollect the conditions that existed during all 10 seasons over the past 5 years. Across the locations, at Mutomo 80% of the farmers were able to describe the

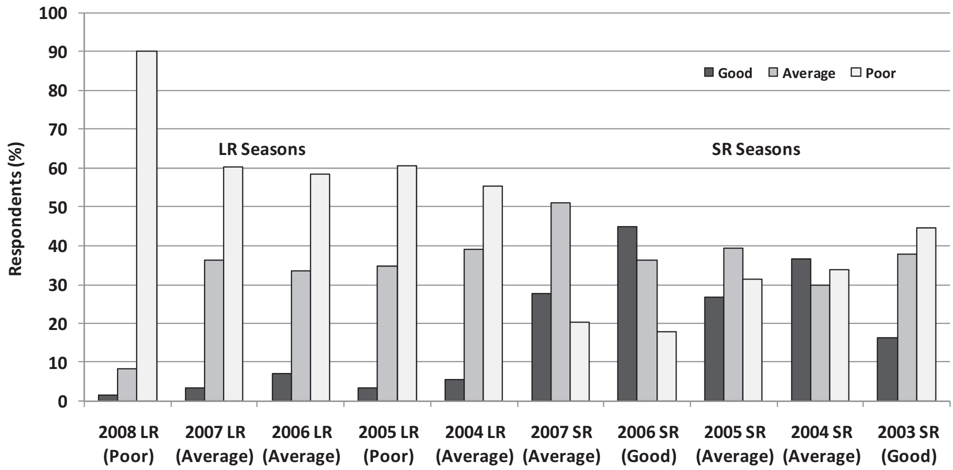

Figure 2. Variability in the rating of seasonal conditions by farmers across all locations (description in parentheses indicate the actual condition based on the amount of rainfall received).

conditions over all the 10 seasons while only 17% of the Makueni farmers remember the conditions that existed during all 10 seasons. It is interesting to note that Mutomo is the location where climate was ranked as the most important constraint by only 18% of the respondents. We found no special reason to explain this anomaly.

Though farmers were able to recollect the conditions during the past 10 seasons fairly well, there are differences in the way different farmers classified the same season (Figure 2). In general, there is a good agreement between farmers' rating and the observed conditions for seasons that are either 'good' or 'poor' except for 2003 SR season which many respondents rated as an average to poor season despite having a good rainfall. This being the tenth season, it could be partly attributed to the failure to recollect the seasonal conditions accurately. Farmers showed a tendency to rate LR seasons as poor and SR seasons average to good, which also reflects the general understanding that LR seasons are less reliable than SR seasons. Further, crop performance during average seasons is more sensitive to management practices employed, and it is likely that farmers' perceptions reflect more the variability in resource endowment and in management between the farmers than rainfall itself.

Farmers were then asked to identify the frequency of occurrence of different season types out of 10 seasons, and Table 8 summarizes their responses by gender, age and educational background. The seasons included both LR and SR seasons. In general, the farmer perceived frequency of occurrence of different season types at different locations reflected the differences in the amount of rainfall received at these locations. For example, at the wetter location Kitui, 34% of all seasons were rated as good and 29% as poor seasons while at the drier location Makueni only 8% of the seasons were considered as good and as many as 63% as poor. No significant differences were observed in the perceptions due to gender, age or level of education except where indicated (Table 8). One possible explanation for the general lack of differences

Table 8. Farmer perceived frequency distribution of good, average and poor seasons out of 10 seasons by sex, age and educational group.

Location	Good seasons		Average seasons		Poor seasons	
	By gender					
	Men	Women	Men	Women	Men	Women
Kitui	3.2	3.6	3.8	3.6	3.0	2.8
Mwingi	3.1	2.4	3.4	3.2	3.4*	4.4*
Mutomo	2.1	2.1	3.0	3.4	5.1	4.5
Machakos	2.4	2.2	3.6	3.3	4.1	4.5
Makueni	0.7	0.9	2.8	2.9	6.5	6.2
All	2.2	2.3	3.3	3.3	4.5	4.4
	By age					
	44 yrs or less	45 yrs or more	44 yrs or less	45 yrs or more	44 yrs or less	45 yrs or more
Kitui	3.3	3.5	4.3	3.6	2.5	2.9
Mwingi	2.5	2.7	3.1	3.3	4.4	4.1
Mutomo	1.9	2.4	3.3	3.3	4.8	4.4
Machakos	2.4	2.2	3.4	3.5	4.2	4.3
Makueni	0.9	0.7	3.0	2.7	6.6	6.2
All	2.0**	2.5**	3.2	3.4	4.8**	4.2**
	By education					
	Primary or lower	Secondary or higher	Primary or lower	Secondary or higher	Primary or lower	Secondary or higher
Kitui	3.7	3.1	3.5	4.0	2.8	2.9
Mwingi	2.5	2.8	3.1	3.4	4.4*	3.8*
Mutomo	2.2	2.0	3.2	3.7	4.7	4.3
Machakos	2.1*	2.6*	3.5	3.4	4.4	4.1
Makueni	0.6	1.0	3.0	2.7	6.4	6.3
All	2.2	2.3	3.3	3.4	4.5	4.3

*Significant at 5% level; ** significant at 1% level.

between groups may be due to the relatively small sample size and also the increased awareness about climate issues resulting from the ongoing campaigns on climate change and coverage in media.

Since farmer assessment of seasons is strongly influenced by the performance of their main crops, farmers were asked to indicate the yields of maize that they normally expect in good, average and poor seasons. Maize was chosen as an indicator crop since it is grown by all farmers in all the seasons. Farmer perceived yields showed large differences across locations and generally followed the climatic potential of the location (Table 9).The yields match well with the reported average yields for these districts by the Ministry of Agriculture.

Observed variability in rainfall

The three criteria used gave very different distributions of good, average and poor seasons at all the locations (Table 10). Since the meteorological criterion is statistical in nature with no consideration to crop requirements, distribution of different types of season reflects the distribution of rainfall around the mean. This leads to an

Table 9. Farmer perceived maize yields in good, average and poor seasons.

Location	Average annual rainfall (mm)	Maize yield (kg ha^{-1})		
		Good seasons	Average seasons	Poor seasons
Kitui	1008	2163	1131	307
Mwingi	774	2119	889	235
Mutomo	896	1623	643	141
Machakos	702	1846	914	316
Makueni	595	1385	667	200
All locations	–	1876	828	228

Table 10. Number of good, average and poor rainfall seasons out of 10 seasons at the 5 meteorological stations close to the survey areas.

Location	Short rains seasons			Long rains seasons			All seasons		
	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor
Based on meteorological criteria									
Kitui	2.4	4.5	3.0	3.9	2.1	3.9	3.2	3.3	3.5
Mwingi	2.6	3.5	3.9	2.6	4.1	3.3	2.6	3.8	3.6
Mutomo	2.7	3.1	4.2	3.1	2.5	4.4	2.9	2.8	4.3
Machakos	2.2	4.5	3.3	2.4	4.3	3.3	2.3	4.4	3.3
Makueni	3.3	2.8	3.9	2.4	4.1	3.5	2.8	3.5	3.7
Based on rainfall adequacy to grow maize									
Kitui	7.6	1.5	0.9	5.5	1.8	2.7	6.5	1.7	1.8
Mwingi	5.9	3.0	1.1	2.4	3.0	4.6	4.1	3.0	2.8
Mutomo	5.8	2.7	1.5	2.5	2.7	4.8	4.2	2.7	3.1
Machakos	2.2	3.9	3.9	3.5	3.3	3.1	2.8	3.6	3.5
Makueni	3.3	2.8	3.9	0.4	1.7	7.8	1.8	2.3	5.9
Based on APSIM simulated maize yields									
Kitui	5.5	4.5	0.0	6.2	3.5	0.3	5.8	4.0	0.1
Mwingi	6.6	2.7	0.7	5.2	4.6	0.2	5.9	3.7	0.4
Mutomo	6.2	3.2	0.6	4.6	3.5	1.9	5.4	3.4	1.3
Machakos	6.4	2.8	0.8	6.7	1.4	2.0	6.5	2.1	1.4
Makueni	5.8	2.4	1.8	3.6	4.0	2.4	4.7	3.2	2.1
Farmer perception									
Kitui							3.4	3.7	2.9
Mwingi							2.6	3.2	4.2
Mutomo							2.1	3.3	4.6
Machakos							2.3	3.4	4.3
Makueni							0.8	2.9	6.3

underestimate of good seasons at locations where the mean rainfall is more than adequate to grow maize crop and overestimate at locations where mean rainfall is lower than that required. The Stewart and Faught (1984) criterion is again based on the amount of rainfall received during the season and does not account for the distribution of rainfall during the season or the buffering effect of moisture stored in the soil. The distribution of various seasons derived from this criterion followed the observed variation in rainfall and matched better with farmer assessment than the

Table 11. Farmers' perceived changes in long-term climate.

Observed change	Number	%
Sample size	195	100
Rainfall	122	63
Reduced	87	45
High variability and unreliable	27	14
Increased and more reliable	8	4
Seasons/onset	90	46
Delayed/variable/unpredictable	68	35
Early	2	1
Reduced/shortened	8	4
Reduced LR	12	6
Temperature	68	35
High variability	6	3
Increased	40	29
Decreased in cool dry period	22	11

other two criteria. The classification of seasons based on APSIM simulated yields gave a very different distribution of seasons compared to the other two methods.

However, we consider APSIM simulated yields as more realistic since they take into consideration water and nitrogen stresses and the management practices commonly used by farmers in the target locations. Compared to the other two criteria, the classification of seasons based on APSIM simulated yields identified fewer seasons as having poor seasonal conditions to grow maize. When compared with farmer assessment, these assessments, which are based on the use of observed daily climatic data, clearly indicate that farmers at all locations underestimated the number of good seasons and overestimated the number of dry seasons.

Farmer perceptions about long-term changes in climate

Almost all farmers interviewed believe that the climate is changing and that today's climate is very different from that existing some years ago. During the interviews farmers were specifically asked to compare present day conditions with conditions that existed during their childhood to make sure that the changes identified have occurred in the longer term and not the short-term variation that is commonly observed from season to season. According to them, major changes have taken place in the amount and distribution of rainfall and temperature as well as in the onset and length of wet and dry seasons (Table 11). About 45% of the 195 farmers interviewed felt that the amount of rainfall received over the years has declined, and another 14% felt that the rainfall has become more variable and unreliable making agriculture more risky. The eight respondents that indicated an increase in amount and reliability of rainfall were all from Machakos. About 35% of the farmers interviewed are of the opinion that the onset of the rainy season was either delayed or has become highly variable and unpredictable. Eleven of the twelve farmers who felt that the changes in onset are more pronounced during the LR season were from Machakos.

Changes in temperature were mentioned by about 35% of the farmers. The majority (59%) perceived a general increase in temperature in all months while 32% noted a decrease in temperature during the cool dry period of June to August. Farmers cited reduced crop yields and inability to grow some crops that they were growing before, early flowering, drying up of streams, increased pest/disease outbreaks, disappearance of some trees and reduced pastures as major evidence on which their observations were based.

Observed changes in rainfall

Long-term rainfall data for the selected meteorological stations were analysed for broad trends and cyclic variations in LR and SR season rainfall by constructing standardized rainfall anomalies (Figure 3). In general, rainfall at all locations showed very high year-to-year variation with seasonal rainfall varying from less than a fourth to three times the long-term average. The trends in temporal variability of seasonal rainfall at all locations are very similar. Rainfall showed mostly positive anomalies during 1960s and negative anomalies during the 1970s. After the 1970s, the fluctuations in rainfall are dominated by short period cycles of about five years duration that normally coincide with the swings in the El Niño/La Niña-Southern Oscillation. No discernable increasing or decreasing trend either in the annual or seasonal rainfall has been observed over the period of study. During the period for which data is analysed, the proportion of negative anomalies ranged from 49% in Kitui to 59% at Katumani indicating fairly equal distribution of positive and negative anomalies.

Since most farmers have identified a decline in the amount and increase in the variability of rainfall as major changes, we analysed the rainfall data for its variability over decadal timescales. The start and end periods of the decade were selected such that each decade includes one wet and one dry cycle. No major differences are noticeable in the amount of annual and seasonal rainfall, CV or number of dry years between different decades (Table 12). Rainfall during the past two decades (1986–2005) is equal or slightly higher than the rainfall during the preceding two decades (1966–1985). However, at Katumani and Makindu the number of LR seasons during which rainfall is less than the long-term average has been high during the last two decades.

Another variable to which farmers attach great significance is the date of onset of rainy season since the selection of the optimum time to plant largely is dictated by this factor, and often good yields are realized when the crop is planted early. At these locations, maize is normally harvested in the month of January/February when the dry season is already set. Hence, delay in the onset of rainy season results in a delay in planting the crop and thereby increases the probability of the crop experiencing increased moisture stress during anthesis and grain-filling. We have computed the date of onset by setting 1 March for LR season and 1 October for SR season as the start of the rain periods. The onset date is the first day after the season start date during which at least 20 mm rainfall is received over three consecutive days. As would be

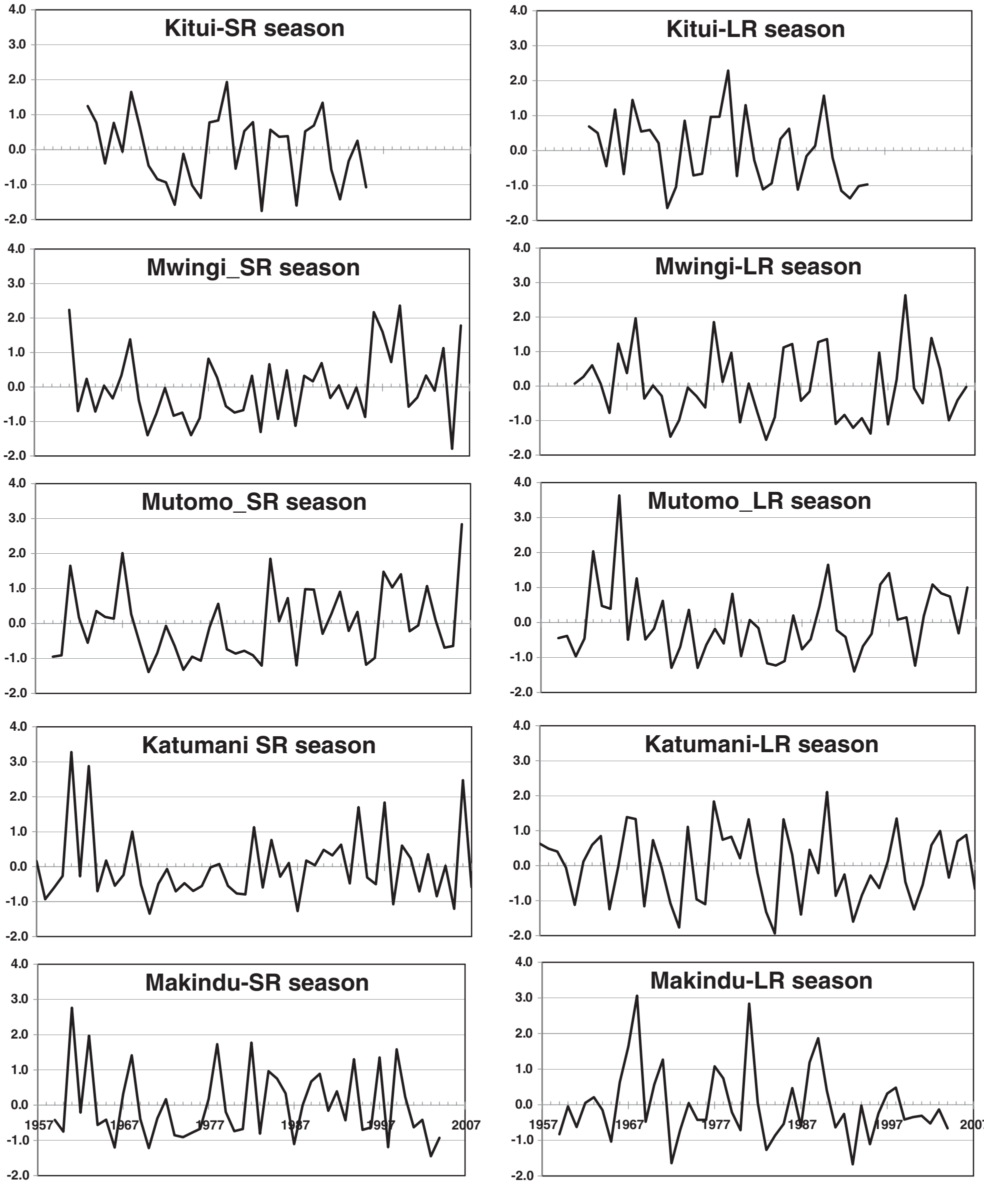

Figure 3. Standardized long rains (LR) and short rains (SR) seasonal rainfall anomalies at the five study locations.

expected, there is considerable variability in the date of onset of both the LR and SR across years with early onset of the rains usually occurring in the wetter seasons and later onset in the drier seasons (see Figure 3), with the same pattern occurring both at Katumani and Makindu (Figure 4). For the LR season, Figure 4 suggests a tendency towards an earlier start, whilst the same is not apparent for the SR.

Table 12. Decade-wise distribution of annual and long rains and short rains season rainfall amounts (RF) and associated coefficient of variation (CV).

	Katumani			Kitui[†]			Makindu[‡]			Mutomo[§]			Mwingi[§]		
Decade	RF (mm)	CV (%)	Years <long term average	RF (mm)	CV (%)	Years <long term avg.	RF (mm)	CV (%)	Years <long term average	RF (mm)	CV (%)	Years <long term average	RF (mm)	CV (%)	Years <long term average
							Long rains season								
1956–1965	293	30.7	4	449	27.0	2	140	31.3	5	281	64.4	5	256	23.7	1
1966–1975	279	49.0	6	414	49.6	4	208	59.4	5	290	91.9	8	252	47.0	7
1976–1985	305	49.5	3	442	51.2	6	178	62.0	6	171	69.6	7	241	54.2	6
1986–1995	254	49.6	8	327	57.5	6	168	57.6	6	228	65.7	5	225	58.1	6
1996–2005	291	33.8	4				153	22.5	8	337	42.7	3	281	48.9	6
							Short rains season								
1956–1965	356	65.3	6	613	21.7	1	367	68.5	5	509	53.4	3	474	55.6	3
1966–1975	234	38.2	9	436	41.8	7	239	61.2	7	410	73.2	9	334	54.7	7
1976–1985	271	36.1	5	528	47.0	4	348	51.9	5	416	68.1	6	360	45.6	6
1986–1995	316	36.7	4	530	39.9	5	328	40.3	5	550	45.3	4	399	32.7	3
1996–2005	276	50.6	4				266	72.1	6	586	47.3	4	547	52.1	5

[†]Kitui the data for decade 1957–1965 are for three years and there is no data available for the decade 1996–2005.

[‡]Makindu the data for the decade 1956–1995 are for seven years and for 1996–2005 are for nine years.

[§]Mwingi and Mutomo data for the decade 1956–1965 are for seven years.

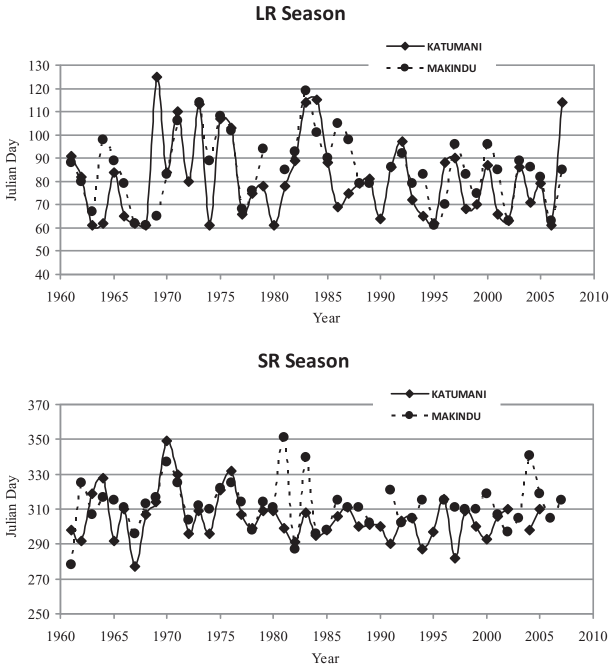

Figure 4. Onset day of long rains and short rains seasons at Katumani and Makindu.

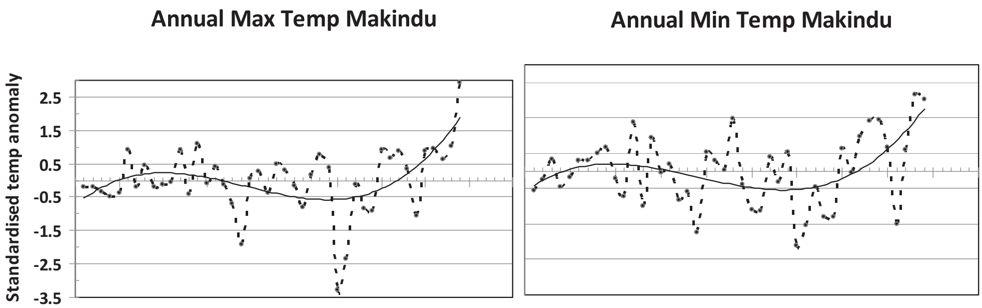

Figure 5. Standardized annual minimum and maximum temperature anomalies at Makindu and Katumani stations.

Observed changes in temperature

The trends observed for maximum and minimum temperature during the SR and the LR seasons were sufficiently similar at both locations to allow us to present just the annual values (Figure 5). The standardized temperature anomalies for Makindu station show a clear increasing trend since 1990, but the same is not so clear in case of Katumani where the length of the record is only 20 years. At both locations, the years 1989 and 1990 are the coolest years. Out of the last 10 years on record, 8 years at Makindu and 7 years at Katumani have shown positive anomalies.

DISCUSSION

The analysis of long-term rainfall data showed large season-to-season variation in the amount and distribution of rainfall at all the study locations. However, the general trends observed in the variability of annual and seasonal rainfall across locations are very similar mainly because the climate in the region is strongly influenced by large-scale phenomena that are common to all locations in the study area (Ogallo, 1994). One of the issues that our study focused is on understanding how well farmers operating in these environments have understood and appreciated the nature of this variability. The results indicate that farmers, in general, have a good understanding of this variability, the probabilistic nature of this variability and its implications for crop productivity. Though farmers do not have a quantitative measure of the amount of rainfall received during various seasons, they do have a good grasp of general climatic conditions especially in relation to the variables that have significant impact on performance of crops. The ability of the farmers and pastoralists in understanding and appreciating the probabilistic nature of climate was also highlighted in the studies conducted by Ingram *et al.* (2002) in Burkina Faso and Luseno *et al.* (2003) in northern Kenya and southern Ethiopia. Working with pastoralists, Luseno *et al.* (2003) demonstrated the ability of the pastoralists to comprehend the variability in climate by asking them to allocate 12 stones into piles representing 'below-normal', 'normal' and 'above-normal' in proportion to their expectations of the seasonal conditions during the forthcoming season. More than 90% of the pastoralists allocated the stones to more than one category.

Whilst there is overwhelming evidence in support of farmers' ability to understand the variability in climate, it is not clear what criteria they use to distinguish different seasons and how well their perceptions corroborate with observed rainfall events and amounts. Our study examined this aspect first by understanding how they classify the seasons and criteria used and then by evaluating the ability and accuracy with which farmers recollect the events that have happened in the recent past. Farmers classified the seasons into three groups based on criteria that include a complex mix of factors that impact on the outcome of their activities. These include rainfall, onset and cessation of the rainy season, and distribution of rainfall especially in relation to critical stages of growth. The near uniformity among the farmers in defining the criteria is clear indication of their good understanding of the climate. Farmers were also able to recollect the past seasons fairly accurately especially the 'good' and 'poor' seasons which corroborated well with the meteorological records. This can be expected considering the high impact these events have on overall performance of the farming system (Mertz *et al.*, 2009; Meze-Hausken, 2004). The differences in their assessment of 'average' seasons are understandable given the variable impact of these events depending on the status of their resource base and crop and soil management practices employed.

Though farmers were able to recollect the climatic events that have occurred in recent years fairly well, their assessment about the frequency distribution of these events is not well supported by the trends in observed data. The differences in the assessment of distribution of different seasons by farmers in Kitui and Makueni districts, the wettest and driest locations within the present study, indicate that farmers are referring to the experiences at their specific location. The perceived distribution of seasons is also broadly in agreement with the observed distribution. While there is no single criterion that mimics farmers' thinking, the three different criteria used in the study have highlighted the general tendency of farmers to overestimate the dry seasons and underestimate the wet seasons. Sherrick *et al.* (2000) found similar overestimation of probabilities associated with conditions adverse for production while comparing the subjective probability estimates by 54 large-scale grain producers near Urbana, Illinois, with the actual rainfall distributions that were observed. These distortions in probability estimates by farmers are often attributed to a phenomenon known as 'negativity bias' widely documented in psychological research as a human tendency to pay more attention to and give more weight to negative than positive impacts (Hansen *et al.*, 2004). The overestimation of poor seasons is a clear indication that farmers perceive higher risk than is actually present in their environments, and this can influence their decisions on adoption of new technologies, especially the decisions that involve cash investments such as purchase of seeds and fertilizers. Studies on risk behaviour of smallholder farmers suggest that farmers generally tend to be risk-averse and prefer to adopt risk minimization strategies (Binswanger, 1980; Dillon and Scandizzo, 1978).

Farmers across the study locations believe that the climate has changed. This response of farmers is consistent with results reported from surveys conducted at other locations in Africa (Bryan *et al.*, 2009; Mertz *et al.*, 2009, Nyong *et al.*, 2007; Sleggers, 2008; Thomas *et al.*, 2007). In all these studies the majority of the farmers have identified declining rainfall and increased variability in the distribution of rainfall within and across the seasons as major problems. However, the changes that farmers have identified are not obvious from available rainfall records. Detailed analysis of long-term daily and monthly records from the five sites indicated no major detectable change in the rainfall during the past four to five decades. In fact, the longest dry period that the region has ever experienced was between 1966 and 1975 during which the annual and seasonal rainfall was below the long-term average in at least seven out of ten years. Considering the strong belief among the farmers that the climate has changed for the worse and clear lack of evidence in the climatic data to support the same, we looked at other changes in the system that are possibly attributed by farmers as being due to changes in climate.

From the evidence cited by farmers the decline in yields is a major driving factor contributing to this perception. We analysed the long-term maize yields from Machakos and Makueni districts to assess the trends in maize yields. The data sources include published papers and district annual reports from the Ministry of Agriculture. The data clearly indicate a sharp decline in maize yields from 1990 (Figure 6) and confirms the farmer observation of declining yields. However, the period 1992 to 2006 during which the decline in yields was observed was not dry compared to the long-term average or the 15-year period prior to 1992. For example at Katumani, the average SR season rainfall recorded during the 15-year period between 1992 and 2006

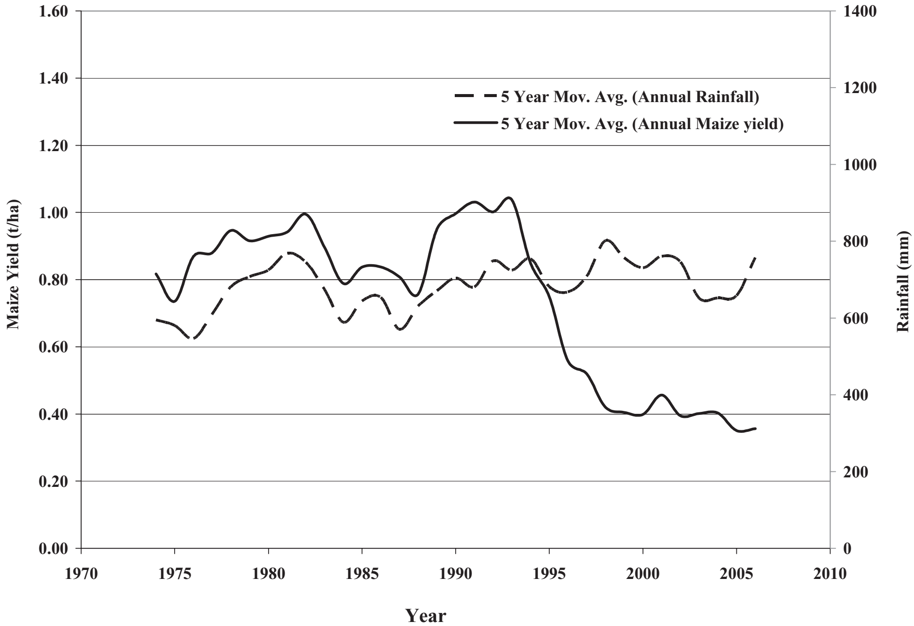

Figure 6. Trends in annual maize yield (t ha^{-1}) (based on total area and production during long rains and short rains seasons) and annual rainfall (mm) in Machakos district.

is higher (322 mm) than the preceding 15-year period (283 mm), and no difference was observed in the distribution of poor (<220 mm) and good seasons (>350 mm) during these two periods. Also no difference was observed in the distribution of dry spells between the two periods. Hence, we conclude that the observed decline in yields is not related to changes in the amount and distribution of rainfall.

Machakos district is well known for the large-scale efforts to transform eroding hillsides into productive, intensively farmed terraces (Tiffen *et al.*, 1994), and the historical changes in demography and land use are well documented. Important among the changes noted are: a rapid increase in cultivated area from 15% in the 1930s to between 50% and 80% in 1978, population growth from about 240 000 in the 1930s to an estimated 2 million in 2009 and extension of agriculture into more marginal lands (Mortimore and Tiffen, 1994; Tiffen *et al.* 1995). While terracing helped in controlling soil erosion, intensive cultivation of the terraces with low use of fertilizers has contributed to a serious decline in soil fertility (De Jager *et al.*, 2001; Gachimbi *et al.*, 2005; Siedenburg, 2006; Smalling *et al.*, 1997). There are several reasons for low use of fertilizers but the most important is the high cost, especially in 1990s, following the structural adjustments and market liberalization policies adopted by the Government of Kenya (Nyangito and Kimenye, 1995). The policy changes have resulted in a sharp increase in fertilizer prices; e.g. the price of 1 kg N, applied as DAP, increased from less than 50 KSh before 1990 to nearly 150 Ksh in 1996 leading to a decline in the amount of nutrients applied per hectare (Hassan *et al.* 1998; Omiti *et al.* 1999). Hence the decline in yields, which is real and happening, is more due to a combination of decline in soil fertility, intensive cultivation with low inputs and increased use of marginal lands, rather than the decline in rainfall as perceived by farmers.

Another important finding of our work is near unanimity in the perceptions of men and women, young and aged, and educated and uneducated groups of farmers. This apparent lack of differences between groups on how they perceive climate variability and change indicates a deeply ingrained belief and attitude of respondents towards these issues despite the lack of support by the observed climatic data. It is unclear whether the mismatch between farmer perceptions and the scientific observations is due to the failure of data and analytical methods employed in capturing and measuring the real experiences of farmers on which their perceptions are based, or due to the subjectivity, biases and generalization in farmer observations and understanding.

CONCLUSIONS

Our study has analysed farmers' knowledge and understanding of both short-term and long-term variability in climate, their ability to discern trends in climate and how the perceived trends converge with actual observations. Farmers in the study area demonstrated a good understanding and knowledge of the general climate at their location, its variability and the probabilistic nature of variability, but their ability to estimate the frequency distribution of different events and discern long-term trends are more subjective. Our results indicate that farmers tend to attach higher significance to negative events or impacts leading to a biased estimation in the frequency of occurrence of negative events. This has important implications in the assessment of risk and in subsequent decision-making. Their perception of higher risk results in them preferring techniques requiring low levels of cash investment and acts as a major deterrent in optimizing input use and taking advantage of improved technologies. We consider this as one of the primary reasons for low levels of adoption of improved technologies in the drier areas. An important implication is that making a uniform recommendation (such as application of fertilizer) based on performance under mean conditions may not be appropriate in environments where climate variability results in high season-to-season variability in production. The recommended technologies should include adequate information on the risk and return profile of the proposed technology so the end user can make informed decisions depending on their ability to take risks. There is also a need for increased attention to risk management options in order to deal effectively with year-to-year fluctuations in seasonal rainfall.

The results of our study, as well as those conducted in other parts of the continent, clearly indicate that majority of the farmers subscribe to the theory that the climate is changing for the worse. Despite this near unanimity in perception about climate across the countries, across environments, across the gender groups and across the levels of education, the available meteorological records do not show any significant change in the amount and distribution of rainfall. Our analysis has strongly suggested that farmers' perceptions about climate are a combination of various factors that affect production and are not entirely based on climatic observations. Despite the fact that rural communities have developed a wealth of knowledge from their experiences on climate, there are limitations in their understanding especially in perceiving long-term trends in climate. These limitations need to be understood and overcome through a parallel and more objective analysis of recorded climatic data from nearby stations before utilizing such farmer-based assessments of climate change as the sole basis for future research and development action.

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