

Comparison of measured multi-decadal rainfall variability with farmers' perceptions of and responses to seasonal changes in western Uganda

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Abstract Smallholder farmers in Sub-Saharan Africa (SSA) are not only dealing with decreased production from land degradation, but are also impacted heavily by climate variability. Farmers perceive decreased rainfall or shortened rainy seasons throughout SSA; however, the link between perceptions and climate variability is complex, especially in areas with increasing land degradation. Moreover, little is known about climate variability and farmers' perceptions in central equatorial Africa. The purpose of this study is to quantify interannual rainfall variability from 1983 to 2014 in western Uganda and to relate the rainfall variability and associated changes in soil moisture to perceptions and coping strategies of local farmers. Surveys of 308 farming households and 14 group interviews were conducted near Kibale National Park, and daily satellite-based rainfall data for the region were extracted from the African Rainfall Climatology version 2 database. Results indicate a decrease in the long rains by approximately 3 weeks throughout much of the region; thus, soil-water deficits have intensified. Farmers perceived later onsets of both the short rains and long rains, while

also reporting decreasing soil fertility and crop yields. Therefore, farmers' perceptions of rainfall variability in the Kibale region may reflect more the decrease in soil fertility than the shortened rainy seasons and decreased soil moisture. Expanding croplands has been the farmers' most prevalent coping strategy to decreased yields; however, nearly all the unfarmed land in western Uganda is now in protected areas. Consequently, western Uganda is facing a crisis at the nexus of population growth, land use change, and climate change.

Keywords Climate variability · Tropical rainfall · Africa · Smallholder agriculture · Perceptions

Introduction

Maintaining food security continues to be a central challenge facing farming households in Sub-Saharan Africa (SSA). SSA is the only remaining region of the world where per capita food production has remained stagnant over the past several decades (Sanchez 2002; Chauvin et al. 2012), and it is estimated that approximately 220 million people in SSA, mostly in farming households, are undernourished (FAO 2015). In addition to social, economic, and political factors, two key environmental factors that constrain smallholders' food production are climate variability and declines in soil fertility and potential productivity associated with land degradation (Andersson and Gabriellsson 2012).

Given that nearly 90 % of staple food production in SSA comes from rain-fed farming systems (Rosegrant et al. 2002), climate variability strongly influences productivity. There is a major need for research on connections between interannual rainfall variation and smallholder agriculture in central equatorial Africa (CEA), a relatively wet region of

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SSA that includes much of the Democratic Republic of Congo and extends eastward into western Uganda. Mean rainfall over CEA is approximately 1500 mm annually with peaks in the transition seasons of October–December and March–May when the Intertropical Convergence Zone (ITCZ) and the associated rainbelt is over the region (Nicholson and Grist 2003; Todd and Washington 2004; Jackson et al. 2009). Over the past several decades, there have been insufficient ground-based measurements for nearly all of CEA to determine rainfall trends (Trenberth et al. 2007; Hartmann et al. 2013). The lack of multi-decadal data, and thus poor understanding of the controls of interannual rainfall variability in the region, makes the potential predictability of seasonal rainfall in CEA low (Washington et al. 2006, 2013). Satellite-based rainfall data provide a mixed picture: satellite-only data show a positive trend in rainfall (Maidment et al. 2015), while a merged satellite-gauge dataset shows a drying trend over CEA (Diem et al. 2014a). In addition, it is likely that rainfall in CEA is not correlated with the El Niño Southern Oscillation (ENSO), which is dramatically different than the strong correlations in eastern equatorial Africa (e.g., Kenya) (Diem et al. 2014a).

A second major challenge to food production in SSA is soil productivity, which is impossible to sustain without sufficient nutrient inputs (e.g., those from inorganic fertilizer, legumes, and manure) and is also strongly influenced by climate. In most SSA farming systems, nutrient outflows far exceed inflows (Sanchez et al. 1997), leading to widespread declines in soil fertility which is the fundamental biophysical cause of food insecurity on smallholder farms (Rowe et al. 2006). Declines in soil fertility may be exacerbated by soil erosion or changes in cropping intensity and fallow period (Grandy et al. 2012; Turinawe et al. 2015). Further, declines in soil fertility are likely already enhanced by changes in rainfall patterns, which could impact net primary productivity, soil nutrient and organic matter dynamics, and ultimately soil erosion. For example, microbial activity, organic matter decomposition dynamics, and the mineralization of nitrogen (N) are strongly related to soil moisture and wetting–drying cycles, and all three are suppressed during extended dry periods (Desureault-Rompré et al. 2015; Sierra et al. 2015).

Perceptions by farmers of decreased rainfall or shortened rainy seasons are widespread throughout SSA (Ovuka and Lindqvist 2000; Meze-Hausken 2004; Thomas et al. 2007; West et al. 2008; Osbahr et al. 2011; Rao et al. 2011; Ogalleh et al. 2012; Kassie et al. 2013; Simelton et al. 2013; Tambo and Abdoulaye 2013; Antwi-Agyei et al. 2014; Below et al. 2015); however, the link between perceptions and climate variability is complex. Farmers' climate-variability perceptions are influenced by past biophysical, socioeconomic, and agronomic conditions

(Meze-Hausken 2004; Rao et al. 2011; Below et al. 2015), and farmers' perceptions may be more affected by recent events and extreme events than by long-term trends (Bryan et al. 2009; Osbahr et al. 2011). Moreover, there are different aspects of rainfall that farmers perceive, and the perception of changing rainfall is more driven by a change in seasonality or in the frequency of extremes rather than a change in total rainfall for a season (Roncoli et al. 2002; Kosmowski et al. 2015). Therefore, farmers' perceptions in SSA do not always corroborate the findings from the analyses of rainfall data: farmers often perceive rainfall decreases or shortened seasons when neither has changed (Meze-Hausken 2004; Bryan et al. 2009; Kassie et al. 2013; Simelton et al. 2013). Farmers' perceptions of rainfall variability may reflect more the variability in food production than in rainfall itself (Bryan et al. 2009; Osbahr et al. 2011; Rao et al. 2011).

Rainfall-perceptions research also can be hindered by the use of data from just a single rain gauge. Over a period of decades, gauges are sometimes moved, undergo different recording practices, and may undergo changes in instrumentation (Dai et al. 1997). Consequently, inhomogeneities (i.e., variations not caused by variations in the regional climate) in the rainfall record will exist and thus artificial changes in the rainfall record may mask actual changes in regional rainfall. If using rain-gauge data, then it is best to pool data from multiple stations to minimize the impact of station-specific inhomogeneities (Easterling and Peterson 1995).

Our study addresses the need to obtain and match reliable local-scale rainfall measurements with local perceptions of change and variability in a critical geography of extremely dense human population within a biodiversity hotspot in CEA. The purpose of this study is to quantify interannual precipitation variability from 1983 to 2014 in western Uganda and to relate the precipitation variability and associated changes in soil moisture to perceptions and coping strategies of local farmers. The objectives of the study are to (1) determine spatial variations in onset, cessation, duration, and cumulative rainfall during the rainy and dry seasons using satellite-based rainfall estimates, (2) assess trends in rainfall-related variables over the 32-yr period, (3) estimate differences in soil-water availability between the early 1980s and the present, and (4) compare the rainfall and soil-water analyses with farmers' perceptions and coping strategies obtained from household surveys and group interviews.

Study area

Kibale National Park (795 km²) in western Uganda (Fig. 1) is an important, climatically representative case of the understudied CEA region. A major advantage of having

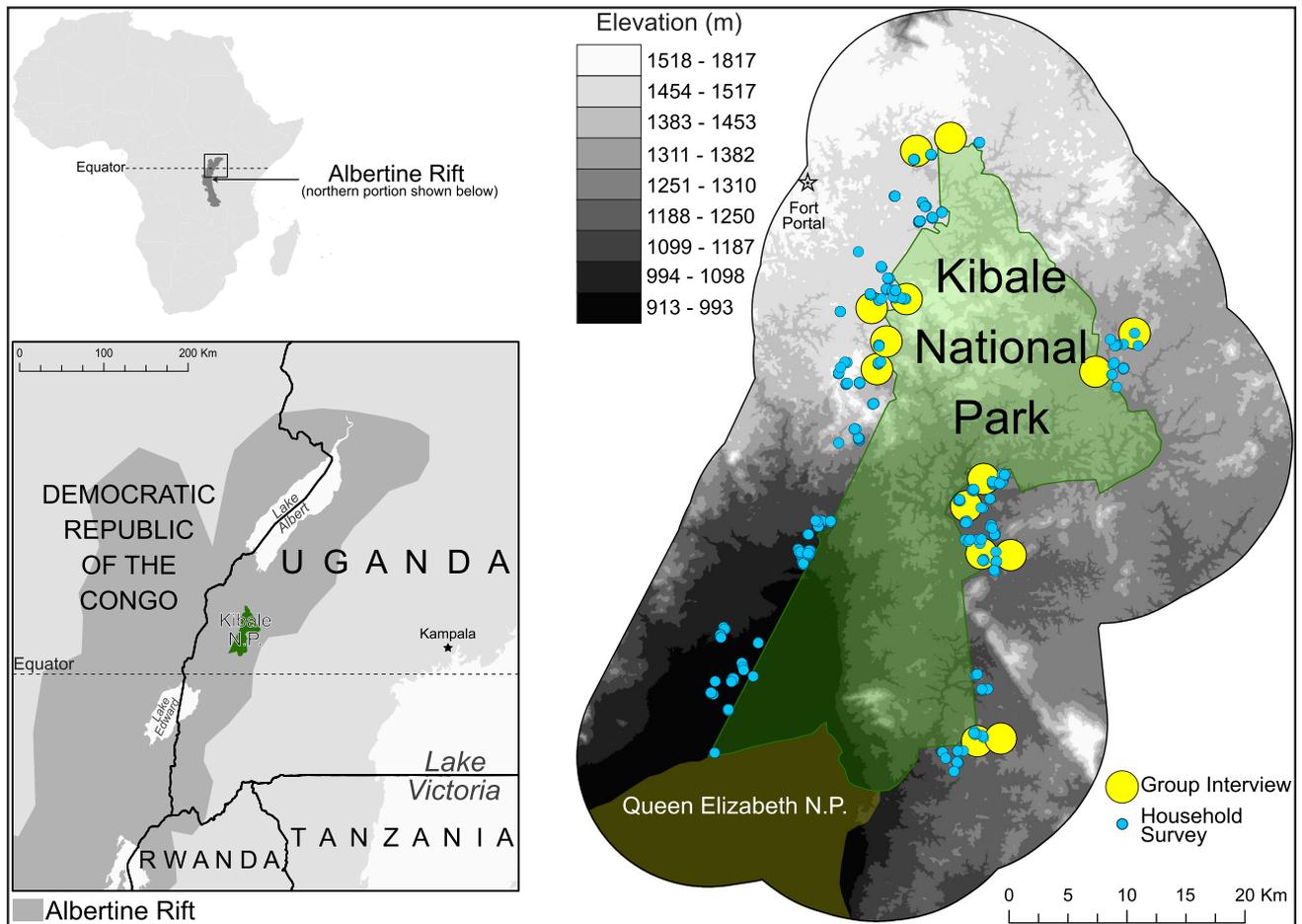


Fig. 1 Location of the Albertine Rift in central equatorial Africa, the northern portion of the Albertine Rift, and Kibale National Park in the Uganda portion of the Albertine Rift. The study domain is the park

and zone within 10 km of the park boundary. Elevation is given as shading (m MSL)

Kibale as the study region is the presence of three ground-based rain gauges within and near the park to supplement the satellite-based data (Fig. 2). The range in annual rainfall is relatively large for such a small region: a minimum of 900 mm occurs in the southern portion, and a maximum of 1500 mm occurs in the northern portion (Diem et al. 2014b). The region has two rainy seasons: the short rains begin in late February and end in early June, and the long rains begin in early to mid-August and end in mid-December in the northern part of the region (Harterter et al. 2012). Kibale and much of western Uganda lie within the Albertine Rift, which is a biodiversity hotspot and one of the most important conservation regions in Africa (Plumptre et al. 2007). Conservation areas in the Albertine Rift are severely threatened due to extremely high human population growth, intensive smallholder agriculture, and high rates of habitat loss and agricultural conversion (Brooks et al. 2001). Kibale is a remnant of a transitional forest between savannah and mid-altitude tropical forest

now surrounded by agriculture resulting from dramatic human population growth over the past several decades; the rural population density near the park's boundaries is now roughly 300 people km² (Harterter et al. 2015). The majority of the 40 million people living in the Albertine Rift are smallholder farmers who rely completely on rainfall and soil fertility to sustain their livelihoods (Plumptre et al. 2007). We define smallholder farmers in western Uganda as predominately subsistence farmers who farm mostly food crops on small plots of land and keep livestock; additional income-generating activities include wage labor off farm, sale of surplus crops, and trades such as carpentry, managing small shops, and selling charcoal. Farms near Kibale are relatively small (i.e., less than five hectares), and more than 20 species of crops are planted in two cropping cycles (Harterter et al. 2012). In addition, previous research in western Uganda indicates that there are probably several months in a typical year when households have insufficient food (Kristjanson et al. 2012).

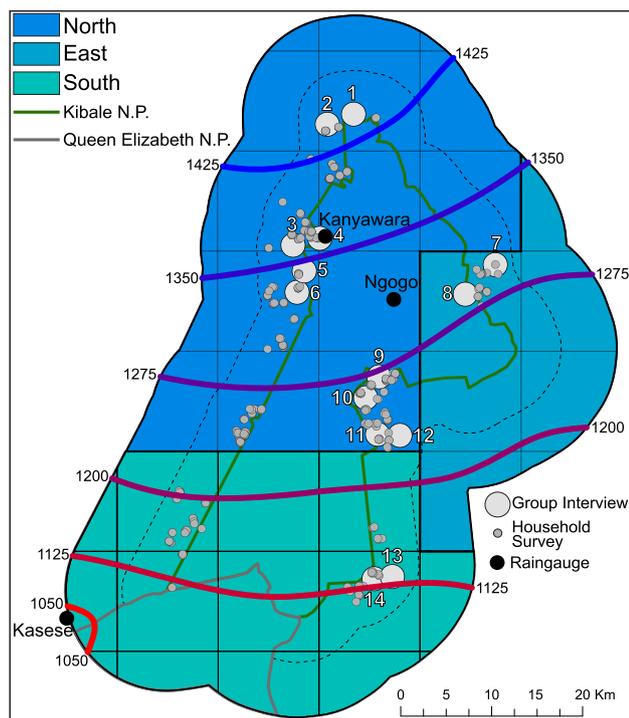


Fig. 2 North, East, and South zones within the Kibale region along with annual rainfall totals and locations of rain gauges within and proximate to the region, and the 14 group interviews (denoted by numbers) and the 308 surveys within 5 km of Kibale National Park. ARC2 cells (10-km resolution) are shown

Materials and methods

Rainfall zones

The Kibale region was divided into rainfall zones based on gridded, three-month (January–March, April–June, July–August, and September–December) rainfall totals from 1983 to 2014. The rainfall totals were extracted from the ARC2 (African Rainfall Climatology, version 2) dataset (Novella and Thiaw 2013), which has a daily temporal resolution and a 10-km spatial resolution. Daily ARC2 data were acquired from the International Research Institute for Climate and Society at Columbia University. ARC2 data are developed by the Climate Prediction Center of the National Oceanic and Atmospheric Administration for the Famine Early Warning Systems Network (FEWS NET) and were deemed satisfactory at identifying rainfall days and estimating three-month rainfall totals in the Kibale region in our previous work (Diem et al. 2014b). The dataset was missing rainfall totals for 340 out of 11,348 days. The three-month totals were summed monthly totals: months with 90 % or more days with valid rainfall totals were retained and rainfall totals were upwardly adjusted if necessary using the ratio of total days per month by the number of days with valid rainfall totals;

if a month was missing more than 10 % of the rainfall totals, then the 3-month period containing that particular month was removed from the analysis. There were a total of 37 ARC2 cells that existed partially or wholly within a 10-km buffer of the park. Using an S-mode input matrix consisting of 110 rows (one row for each 3-month period over 32 years) and 37 columns (i.e., grid cells), standardized principal components analysis was used to determine the rainfall zones. A scree plot of log-transformed eigenvalues was used to determine the number of components to retain, with the components representing the rainfall zones. The loadings matrix was orthogonally rotated using the VARIMAX technique to enable a proper examination of the loadings, and each cell was assigned to the component on which it had the highest loading; thus, the maximum-loading rule was used (Diem and Brown 2006). Each component represents a unique rainfall zone (i.e., rainfall regionalization).

Intra-annual variations in biases of the ARC2 estimates were estimated by comparing the mean daily ARC2 estimates with ground-measured daily rainfall totals at weather stations within or proximate to the rainfall zones. Data from 2002 to 2011 for Kanyawara and Ngogo, which are located inside Kibale National Park, and data from 2001 to 2010 for Kasese, which is located approximately 12 km from the park boundary, were used (Fig. 2). Kanyawara data were collected by Dr. Colin Chapman of McGill University and Drs. Patrick Omeja and Dennis Twino-mugisha of the Kibale Fish and Monkey Project. Ngogo data were collected by Drs. Jeremiah Lwanga, David Watts, and John Mitani of the Ngogo Chimpanzee Project. Kasese data were acquired directly from the Uganda Department of Meteorology.

Rainy season onset and cessation

Daily ARC2 estimates were used to determine rainy-season onset based on the methods in Osbahr et al. (2011) and Stern et al. (1982); both studies focus on rainy-season onset in Uganda. Season onset was assumed to occur after February 1 for the short rains and after July 1 for the long rains. Three-day rainfall totals were calculated, and five different rainfall thresholds (18, 19, 20, 21, and 22 mm) were used to determine season-onset day, which was the mean day of the resulting days from the five thresholds. A single threshold of 20 mm was used in Osbahr et al. (2011).

Few methods have been published regarding determination of cessation of rainy season in Uganda or equatorial Africa. Marengo et al. (2001) define rainy-season cessation date for the Amazon basin as that pentad with daily mean rainfall <4.0 mm, provided that six of the eight preceding pentads had rainfall totals exceeding 4.5 mm day⁻¹ and six

of the eight subsequent pentads had rainfall totals $<3.5 \text{ mm day}^{-1}$. Hartter et al. (2012) define dry-season onset, as opposed to rainy-season cessation, in the Kibale region as the first of five or more consecutive days with no rain followed by four or fewer consecutive rain days. Derived from the above criteria, the initial season-cessation day for the Kibale region was that pentad with daily mean rainfall $<4.0 \text{ mm day}^{-1}$, provided that four of the six preceding pentads had rainfall totals greater than or equal to 4.0 mm day^{-1} and four of the six subsequent pentads had rainfall totals $<4.0 \text{ mm day}^{-1}$. The final season-cessation days were determined from a joint analysis of the above results and visual examination of charts of pentad rainfall totals for each year.

Testing for trends

Trends in rainfall variables (i.e., rainfall total, onset day, cessation day, and season duration) over 1983–2014 were assessed using one-tailed Kendall-Tau correlation tests with a significance level of 0.01. The Kendall–Theil robust line, which is affected minimally by outliers, was used to estimate changes over the 32-year period; the robust line is the median of the slopes between all combinations of two points in the data (Helsel and Hirsch 2002).

Current and historical soil-water budgets

Soil-water budgets were calculated for the early 1980s and the present day for each of the rainfall zones using the WebWimp water-budget model (<http://climate.geog.udel.edu/~wimp/>) (Willmott et al. 1985). The key input data are monthly temperatures, precipitation totals, and the soil water-storage capacity. Modeled mean monthly temperatures at 1-km resolution for 1950–2000 were acquired from WorldCLIM (Hijmans et al. 2005); gridded, high-resolution temperature data specific to the early 1980s and the present time were not available. Monthly rainfall totals for the earlier period and the current climate were the estimated 1983 and 2014 values, respectively, from monthly Kendall–Theil robust lines from 1983 to 2014; the values were derived from ARC2 estimates. The Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC 2012) shows the dominant soils in the Kibale region to be nitosols, acrisols, fluvisols, luvisols, and andosols, and those soils all have a soil water-storage capacity of 150 mm m^{-1} of the soil unit.

Group interviews

To better understand perceptions and coping strategies among farmers regarding rainfall variability, group interviews were conducted in 14 communities near Kibale

between June and August 2011. Since women do the majority of the on-farm work with planting and harvesting, only female participants were included in these interviews. Permission to conduct the interviews was granted by the local chairman, and he organized and invited participants. Group interviews included five to 30 individuals, with a total of 232 individuals participating. Each interview was co-facilitated by EM and a Ugandan field assistant using local languages (Rutoro, Rukiga, Rukonjo, and Runyankole). No identifying information was recorded for participants.

During interviews, participants were asked a series of questions that compared current weather and general agricultural conditions and outcomes to those of the past (i.e., 10 years ago or longer). To elicit perceptions of seasonal changes in rainfall, respondents were asked about the onset, cessation, duration, and amount of rainfall for all seasons. To determine whether farmers were altering their agricultural practices in response to perceived changes, they were asked about planting time, crop choices, and land management. Although the questions were predetermined, farmers frequently brought up other relevant issues during discussion. Following discussion of predetermined questions, participants were asked open-ended questions about other concerns they may have, in order to assess general perceptions of risk.

During the interview, EM took detailed notes (audio or video recordings are culturally inappropriate), and after each meeting, EM verified her notes with the field assistant to reduce translation errors. Post-processing of interview notes involved assigning statements to emic categories related to rainfall- and climate-associated farming practices. This coding identified ten statements that appeared in three or more of the group transcripts. As an organization step useful in understanding climate changes in human–environment systems, we present these responses following components of vulnerability: exposure, sensitivity, and response or adaptation (Turner et al. 2003; Adger 2006).

Household surveys

During 2011 and 2012, a total of 308 household surveys were conducted in communities within five kilometers of the Kibale boundary. We used the geographic sampling strategy of designating “superpixels,” as done in previous work in agricultural communities near parks in Uganda (e.g., Goldman et al. 2008). Ranger stations and entrance gates served as anchor points for 5-km buffers, and within each of those buffered areas, ten superpixels were randomly generated (9-ha circle areas, with radii of 170 m) outside the park boundary. Five households were selected for surveys from among all landholders in each of the superpixels.

The survey instrument had two parts. The first part was a series of fixed-choice questions to characterize demographics, farming, rainfall variability, and change (amount, season onset and cessation, duration), and planting cycles for crops. The second part focused on perceptions where respondents were asked to comment on changes in weather patterns, population growth, and food security. Survey location was recorded using a handheld global positioning system receiver. All surveys were conducted in one or a mixture of local languages by a Ugandan field assistant. No study authors or other westerners were present during the surveys in order to limit respondent bias.

Results

General characteristics of the rainfall zones

The Kibale region is comprised of three rainfall zones (i.e., North, East, and South) that have the expected two rainy seasons and two dry seasons, but the zones vary markedly in rainfall totals (Figs. 2, 3). The North zone, which has a mean altitude of 1400 m a.s.l., receives at least 20 % more rainfall than the South zone (mean altitude 1120 m a.s.l.) receives. Much of the South zone is in a rain shadow from the nearby Rwenzori Mountains (Diem et al. 2014b). The gradient in rainfall from north to south exceeds 6.5 mm km^{-1} . The East zone (mean altitude 1320 m a.s.l.) is much smaller in area and appears to be transitional in rainfall between the two other zones.

The North and East have longer rainy seasons and receive much more rainfall than the South (Fig. 3). The short rains in the North and East typically begin in late February and end in late May, while in the South the onset and cessation dates are in early March and mid-May, respectively. The second dry season occurs between the short rains and long rains, and this season is nearly 90 days long in the South; the season is at least 3 weeks shorter in the East and possibly 4 weeks shorter in the North. ARC2 appears to underestimate rainfall from mid-May to mid-June; thus, the cessation dates of the short rains and the onset dates of the second dry season might be underestimated (i.e., the short rains might be longer than estimated). The long rains, which begin in late July in the North and East and in early in August in the South, are approximately 6–7 weeks longer than the short rains in the North and East and between 3 and 4 weeks longer in the South. The long rains in all three zones typically end in early December. Ground-based measurements show that the long rains should have substantially more rainfall than the short rains in the North (Diem et al. 2014b); however, the ARC2 satellite-based product seems to underestimate October–November rainfall in the North by approximately 40 %.

Similar to the North, the East probably also has an underestimate of long-rains rainfall and an underestimate of the duration of the short rains, but the severity of the underestimate may not be as large as it is for the North. The ARC2 product does not underestimate rainfall in the South during either of the rainy seasons.

Variability in seasons and rainfall

Over the 32-year study period, the short rains were more variable than the long rains, and both seasons were more variable in the South than in the other zones (Fig. 4). For all four variables (i.e., onset, cessation, duration, and seasonal rainfall total) at the three zones, the short rains had larger coefficients of variation than the long rains. The South zone had considerably larger coefficients of variation for season duration and rainfall compared to the other two zones.

The short-rains season weakened significantly over time only in the East zone. The season onset increased by 17 days, the season duration decreased by 29 days, and the rainfall decreased by 128 mm (i.e., 29 %) over the 32 years. The North and South zones did not have definitive changes in season onset, cessation, and duration, but the zones did have nonsignificant decreases in rainfall.

The long rains weakened significantly over time at all three zones, with the largest impacts in the East and South. Season onset increased by 18 and 28 days in the East and South, respectively. Season duration decreased by 20 and 25 days in the East and South, respectively. Rainfall in all three zones decreased, but it was only significant in the North and East, where the rainfall decreased by 176 mm (i.e., 28 %) and 134 mm (i.e., 23 %), respectively, over the 32 years.

The dry seasons got longer in the three zones, with the significant changes occurring in the East and South. There was a significant increase in duration of the first dry season in the East: the season lengthened by 31 days. The duration of the second dry season increased significantly in both the East and South, and the duration increased by 26 and 28 days, respectively. These increases were dictated primarily by delayed onset dates of the second rains. The East had a significant increase in second-dry rainfall, and this is a result of the second dry extending into both the short rains and long rains.

Changes in soil-water availability

All three zones were estimated to have experienced an increase in soil-water stress from 1983 to 2014, with soil-water deficits present and becoming more severe in the South (Fig. 5). Monthly ARC2 estimates of rainfall in the North were adjusted based on comparisons with data from

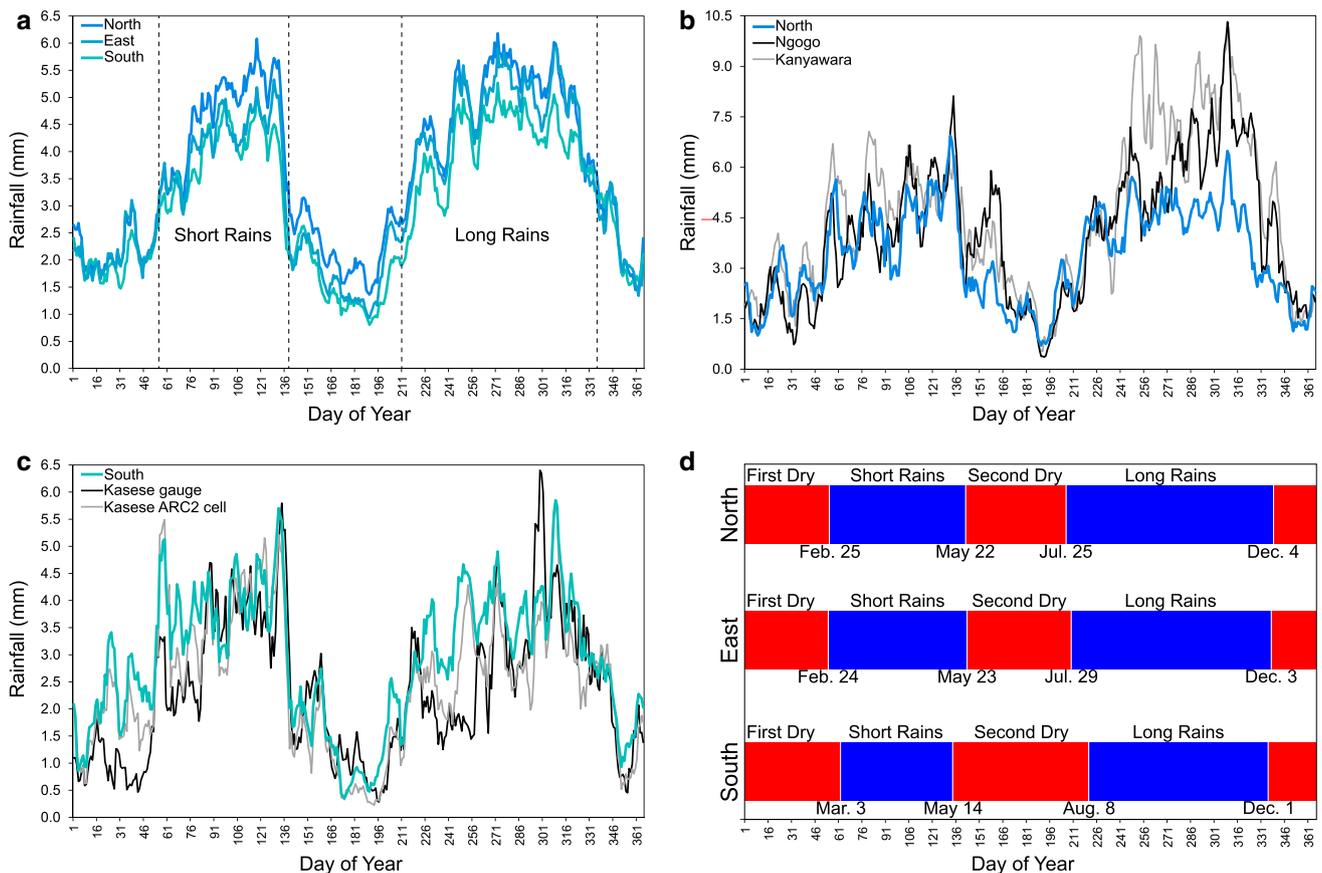


Fig. 3 Mean rainfall totals per day of year for **a** 1983–2014 for the North, East, and South zones, **b** 2002–2011 for the North zone and the mean of the Kanyawara and Ngogo gauges, and **c** 2001–2010 for the South zone, the Kasese gauge, and the ARC2 cell corresponding to

the Kasese gauge. A 7-day moving-mean filter was applied to all data sets. **d** Mean date of onset and cessation and mean duration of the two dry seasons and the two rainy seasons for the three rainfall zones

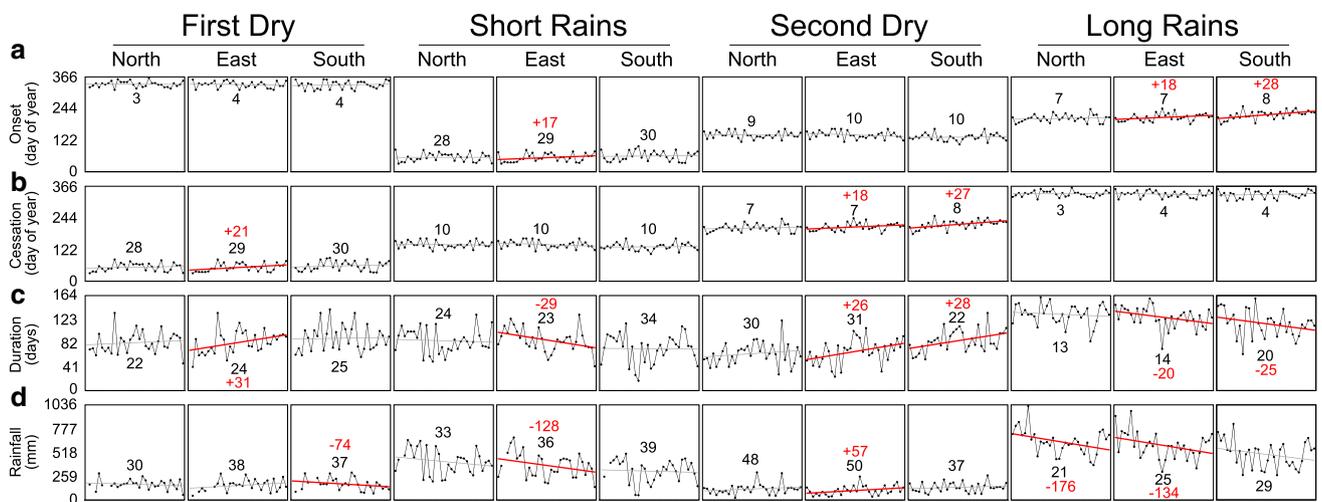


Fig. 4 Means, variability, and trends for 1983–2014 for **a** onset, **b** cessation, **c** duration, and **d** rainfall totals of the two dry seasons and two rainy seasons at the three zones (North, East, and South) of the Kibale region. Coefficients of variation (in %), which are the black numbers in the panels, are used to show the interannual variability.

Red lines indicate significant ($\alpha = 0.05$; one-tailed) trends, and gray lines indicate nonsignificant trends. The red numbers in select panels are 1983–2014 differences calculated with Kendall–Theil robust lines (color figure online)

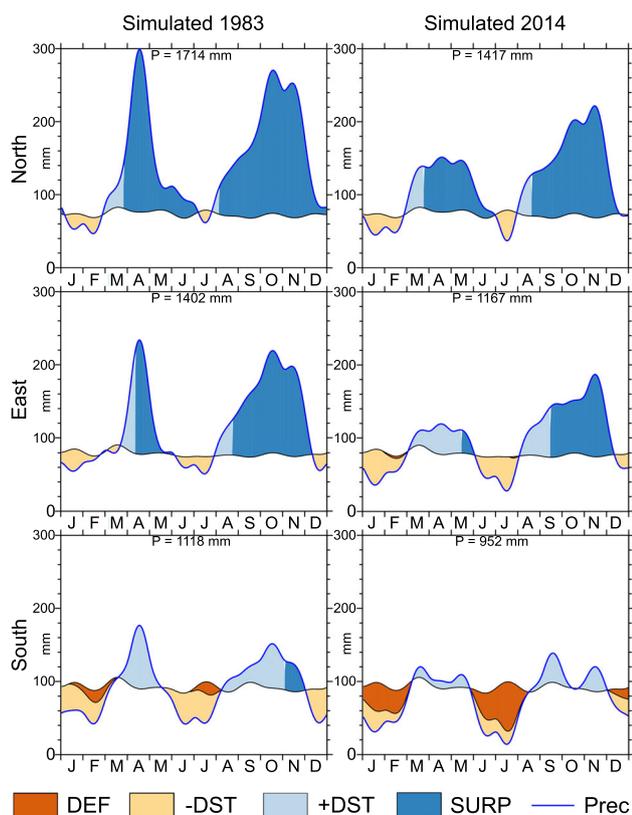


Fig. 5 Soil-water budgets for the North, East, and South zones for simulated first (1983) and last (2014) years based on linear trends in monthly rainfall from 1983 to 2014 and modeled mean temperatures for 1950–2000. Annual precipitation (P) totals are shown at the top of each panel. DEF is the deficit or unmet atmospheric demand for moisture. DST is the estimated change in soil moisture from the end of the previous month to the end of the current month. SURP is surplus (i.e., surface runoff plus percolation below the plant root zone). Prec is the monthly total precipitation. All units are mm. Model output and base graphs are from WebWIMP

the Kanyawara and Ngogo stations, and rainfall estimates in the South were adjusted based on a comparison with data from the Kasese station (Fig. 2). Rainfall adjustments in the East were the means of the adjustments made for the North and South. The equatorial location of the zones causes a minimum range in monthly temperatures: Mean monthly temperatures range from 19.5 to 20.8 °C in the North, from 20.3 to 21.7 °C in the East, and from 21.8 to 23.2 °C in the South. The South is at least 1.2 °C warmer than the other zones during each month. The South also has much less rainfall than the other zones (i.e., 33 % less than the North and 19 % less than East); therefore, there is much more soil-water stress in the South. The South has soil-water deficits during the dry seasons and at the start of the rainy seasons, whereas the North never reaches a deficit and the East probably has small deficits in February and July under the present-day scenario. The largest deficits in the South in the early 1980s occurred in February and July,

and in the present scenario the deficits have become more severe and now encompass January–February and June–July, with July having the largest deficit.

Perceptions of the weather and changing seasons

The household surveys revealed that nearly all farmers worried about the weather, especially dry conditions, with southern farmers worrying more than the rest of the farmers. Overall, most farmers (94 %) worried to some degree about the weather, and 72 % worried “a lot.” Most southern farmers (85 %) worried a lot about the weather, compared to 69 % of the rest of the farmers. Farmers in the South had five weather-related concerns (i.e., too much sun, not knowing when to plant, changing seasons, drying of crops, and drying of pasture) reported in at least 20 % of household surveys, while farmers in the North only had three concerns (i.e., low yields, too much sun, and not knowing when to plant) reported in at least 20 % of surveys. There were only 19 survey respondents in the East, which makes generalizing about farmers in that rainfall zone difficult. The two weather-related concerns shared by both the northern and southern farmers were too much sun (i.e., long dry periods or dry intervals within rainy seasons) and not knowing when to plant crops. The southern farmers also were much more likely to list famine or hunger as a concern compared to the northern farmers.

The southern farmers were more likely to report changes in the onset and cessation dates of the rainy seasons than were the northern farmers (Table 1). Substantial percentages of southern farmers reported that the short rains have been starting later (53 %) and ending earlier (48 %) than in the past, while the percentages for the northern farmers for later onset and earlier cessation were only 31 and 17 %, respectively. The overall view from the group interviews was that the short rains have become shorter, with a later onset (e.g., February rains keep disappearing) and an earlier cessation (e.g., the rains no longer last through May). Farmers also reported that the long rains have a delayed onset, with 50 % of northern farmers and 73 % of southern farmers reporting that the long rains have been starting later. However, unlike for the short rains, few farmers noticed an earlier cessation of the long rains. In addition, participants in half the groups interviewed stated that long rains have become shorter resulting from a delayed onset; the remaining groups did not report that the length of the long rains had changed much from the past.

Changes in agricultural practices and outcomes

In addition to stating that the rainy seasons are starting later than in the past, the farmers also report decreasing agricultural productivity, and in response the dominant coping

Table 1 Farmers' perceptions of current onset and cessation of growing seasons compared to how onset and cessation were in the past

Zone	Earlier	Later	Same	Different every year	Unsure/ no response
<i>(A) Short-rains start</i>					
North	7	31	2	56	4
South	2	53	2	38	5
<i>(B) Short-rains end</i>					
North	7	17	2	59	15
South	48	3	2	38	8
<i>(C) Long-rains start</i>					
North	7	50	4	34	3
South	3	73	3	15	5
<i>(D) Long-rains end</i>					
North	3	28	8	52	9
South	5	35	2	48	10

Values are the percentages of surveyed farmers in the North and South zones. The number of respondents in the North and South are 229 and 60, respectively. The East zone is not included due to the small sample size of 19 farmers

strategy has been to acquire more land for planting (Table 2; Fig. 6). Nearly all the 14 group interviews reported an aspect of decreasing agricultural productivity by noting one of the following: It has become harder to fallow the land, soils are losing fertility, or crop yields are decreasing. Multiple group-interview participants in both the North and South reported a substantial decrease in crop yields from the past until the present time. Large percentages (65 %) of individual farmers either do not do anything to increase yields or they try to purchase, rent, or borrow more land. The focus groups noted

that cropland is expanding into wetland areas: "In cooler parts, closer to the swamp, you can plant before the soils are wet (because there is more water in the soils making it cooler), but in the drier parts you have to wait for soils to be wet enough (Respondent from group 7)," "Those that are getting good yields today are those that are planting in wetlands (Respondent from group 9)." Out of 308 farmers, only eight and three used manure and fertilizers, respectively, to increase yields. Finally, fallowing is not a common practice in Kibale; therefore, only 4 % of farmers state that increasing fallowing times is something they do to increase yields.

Discussion

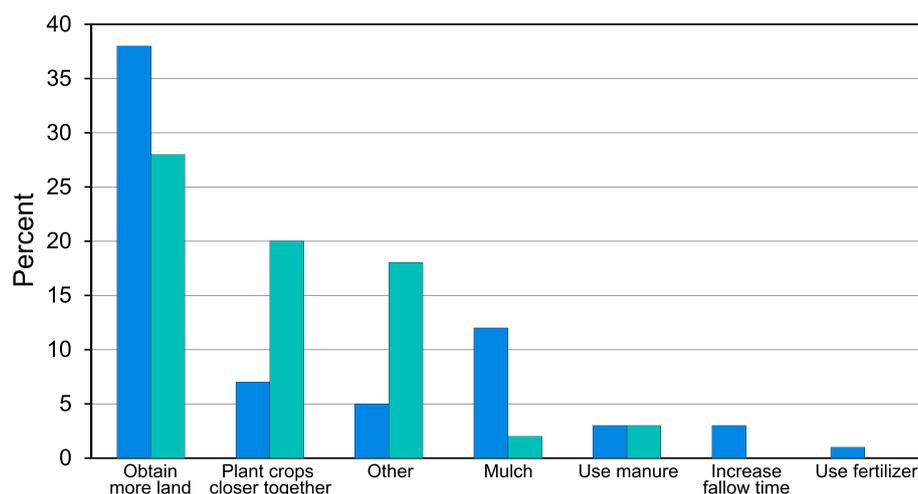
Satellite-based findings of a shortening of rainy seasons in the Kibale region from 1983 to 2014 supports the finding of a drying trend for CEA as whole (Diem et al. 2014a). There are three plausible atmospheric mechanisms that would cause a drying trend over western Uganda (Diem et al. 2014a). First, boreal-summer rainfall in the western and central parts of equatorial Africa as well as in western Uganda is negatively correlated with North Atlantic Ocean sea-surface temperatures (Knight et al. 2006; Zhang and Delworth 2006; Balas et al. 2007; Diem et al. 2014a). The Atlantic ITCZ shifts northward during the warm phase of the Atlantic Multidecadal Oscillation (AMO), an index of sea-surface temperatures centered on the North Atlantic Ocean, and during recent decades the AMO transitioned to a warm phase in the 1990s from a cold phase that was at its most negative value (i.e., peak

Table 2 Group interviews reporting information on rainy seasons and agricultural practices

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
<i>Exposure</i>														
The rainy seasons are starting later	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
The rainy seasons are ending earlier						✓		✓		✓				
Rains are unpredictable	✓						✓	✓	✓	✓				✓
<i>Sensitivity</i>														
Too much rain in long rains can kill crops	✓	✓	✓		✓	✓	✓	✓		✓	✓		✓	
It has gotten harder to fallow the land			✓			✓					✓			✓
In the past crops were planted at set times		✓		✓			✓	✓						
Soils are losing fertility			✓		✓		✓	✓			✓			✓
Crop yields are decreasing	✓	✓	✓			✓			✓	✓	✓	✓	✓	✓
<i>Response</i>														
Farmers plant more land to maintain production		✓					✓	✓		✓		✓		
Crops are now planted following the rains	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Responses are organized into categories following components of vulnerability: exposure, sensitivity, and response. Listed responses represent statements made by three or more of the 14 groups. (✓) indicates the response was given by the group during the interview; blank space indicates the response was not given

Fig. 6 Percentage of farmers in the North (blue bar) and South (green bar) zones who use various strategies to increase seasonal yields. The number of respondents in the North and South are 229 and 60, respectively. The East zone is not included due to the small sample size of 19 farmers. 30 and 28 % of respondents in the North and South, respectively, did not have a response to this question. Examples of other strategies include planting more seeds, using different varieties, etc (color figure online)



of the cold phase) in the late 1970s (Knight et al. 2005, 2006; Zhang and Delworth 2006; Ting et al. 2011). Second, the Indian Ocean has warmed relatively rapidly over the past several decades (Williams and Funk 2011), and a modeled warming of the equatorial/tropical Indian Ocean has been shown to cause large-scale subsidence and reduced rainfall over most of CEA, including western Uganda (Hoerling et al. 2006; Mohino et al. 2011). Third, increased aerosol concentrations have been shown to increase subsidence over tropical Africa, and, in turn, suppress rainfall over CEA (Paeth and Feichter 2006; Kawase et al. 2011; Tosca et al. 2013). In addition, carbonaceous aerosols (i.e., black carbon and particulate organic matter), of which some of the highest in the world exist over CEA during savanna burning in tropical Africa (Stier et al. 2005; Paeth and Feichter 2006; Roberts et al. 2009), are thought to suppress precipitation formation in clouds (Nober et al. 2003; Rosenfeld et al. 2008) and thus reduce rainfall from those clouds.

The perceptions of farmers, especially those in the South, generally support the findings of shortened rainy seasons from satellite-based rainfall estimates. The rainfall data show the long rains now beginning approximately 1 month later compared to three decades ago (i.e., late August vs. late July), with this shift most pronounced in the South, which the majority of farmers report explicitly in group interviews and household surveys. The second dry season, which precedes the long rains, lengthened in duration by approximately 1 month. The results of water-budget analyses for the South show an increased severity of soil-water deficits during the dry seasons and at the start of the rainy seasons, especially during July, suggest that the southern farmers should be struggling at the start of the long rains. Since annual temperature in the region may have increased between 0.2 and 0.3 °C decade⁻¹ over the past three decades (Hartmann et al. 2013), available soil

moisture for the current climate is likely lower than the values provided in the results section. Nearly three-quarters of the southern farmers reported that the long rains are starting later, and this delayed onset of the long rains has also been reported by farmers in southwestern Uganda (Osahr et al. 2011). Moreover, the short-rains season also has become shorter, and over half the southern farmers perceived the short rains to be starting later and nearly half the southern farmers felt the rains were ending earlier. Overall, farmer perceptions may be tracking the drying trend observed in satellite and soil analyses.

However, it is still difficult to establish a direct link between Kibale farmers' perceptions of rainfall changes and observed long-term changes in rainfall. Decreasing agricultural productivity was a consistent theme among the group interviews; therefore, farmers' perceptions of rainfall declines in the Kibale region may reflect more the decrease in food production—which may be controlled strongly by decreasing soil fertility—than the change in rainfall (e.g., Bryan et al. 2009; Osahr et al. 2011; Rao et al. 2011). In addition, farmers may be more influenced by recent events than by long-term changes (Bryan et al. 2009), and this may have occurred in our sample given that the long rains directly preceding the 2011–2012 surveys were particularly deficient and began late (Figs. 7b, 8c). On the other hand, farmers' perceptions of an overall worsening of the short rains do not appear to be a reflection of recent extreme anomalies. Short-rains rainfall totals for the 5 years preceding the survey were not consistently wetter or drier than average (Fig. 7a), and the short rains did not start later than average or end earlier than average during those 5 years as a whole (Fig. 8a, b).

While climate variability is a substantial concern for most farmers in the Kibale region, they have employed few strategies to cope with the perceived shortened growing seasons and associated decrease in soil moisture. Cultural

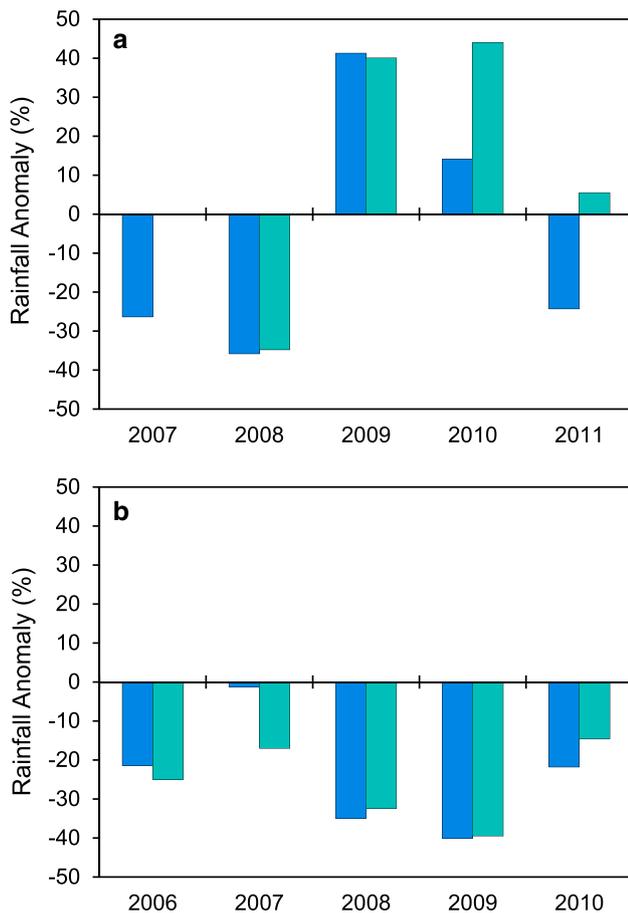


Fig. 7 Deviations from the 1983–2014 means for the North (blue bar) and South (green bar) zones for **a** short-rains rainfall and **b** long-rains rainfall. The years shown are the 5 years preceding the distribution of the surveys to farmers (color figure online)

norms, access to information, local institutions, and resource governance can offer both opportunities and constraints for coping strategies, but assessing those relationships was beyond the scope of this work. Farmers throughout the region are worried about dry conditions and uncertainty regarding the proper time to plant (i.e., the start of the rainy seasons can be highly variable, and several days of rain can be followed by long dry periods). Some group-interview participants claimed that the long rains is the only true growing season now and that some farmers have even stopped growing during the short rains. The farmers' main strategy to increase yields is to acquire more land for cultivation. A common practice is for farmers to drain wetlands and plant crops, trees, and pasture grass (Hartter 2010). Group-interview participants claimed that farmers who have been able to start growing in wetlands, areas along rivers, or forested areas are getting better yields than others; wetlands or areas close to rivers have become more sought after cropland.

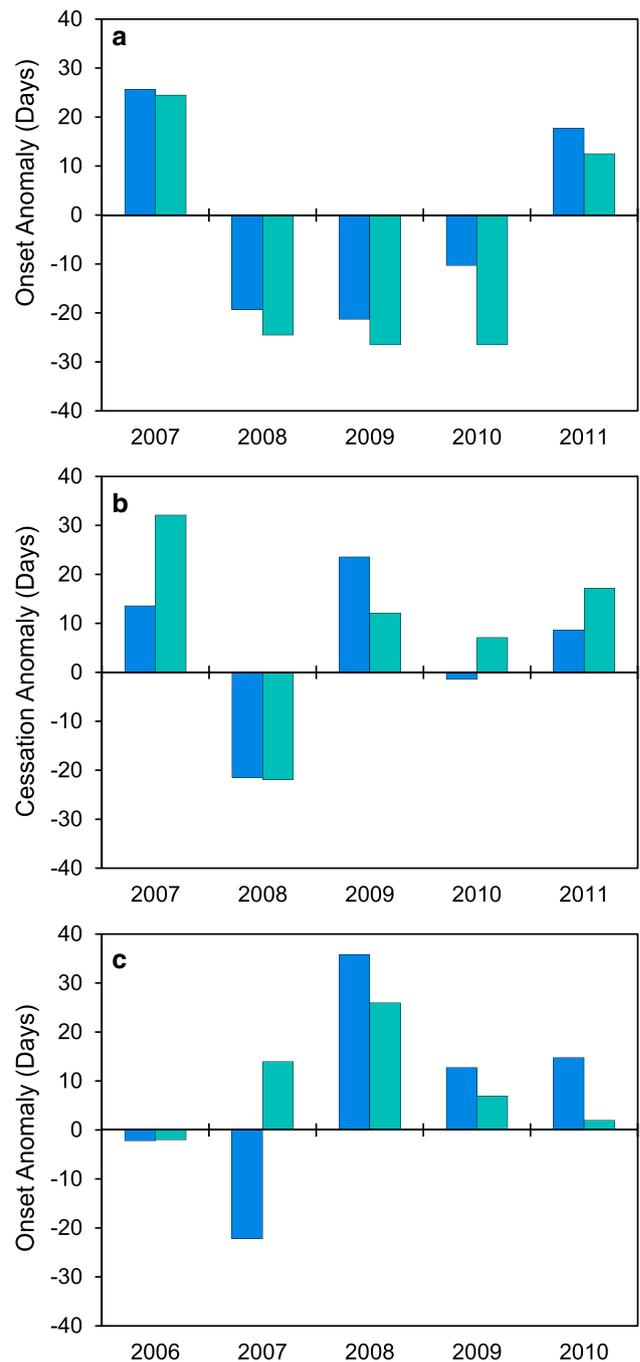


Fig. 8 Deviations from the 1983–2014 means for the North (blue bar) and South (green bar) zones for **a** short rains onset, **b** short-rains cessation, and **c** long-rains onset. The years shown are the 5 years preceding the distribution of the surveys to farmers (color figure online)

Over the next several decades, smallholder farmers in the Kibale region, and western Uganda in general, should continue to experience decreasing crop yields, despite projected increases in rainfall. Climate models show much uncertainty in precipitation changes in the near-term (2016–2035), with a projected slight increase; however, the

models also show that the projected significant warming of western Uganda will prohibit an increase in soil moisture, even with the increased rainfall; soil moisture may actually decrease (Kirtman et al. 2013). Soil moisture will decrease even more if precipitation continues to decline, rather than increase slightly. Simulated maize yields—based only on projected climate conditions and assuming no changes in smallholder farming practices—for western Uganda in 2050 are 5–20 % lower than current yields (Thornton et al. 2009). An assumed decrease in soil fertility caused by increased pressure on the land (e.g., lack of fallowing) by exponentially increasing human populations and a continuing lack of external inputs (e.g., fertilizer) to the soil will exacerbate the decreasing yields.

In the face of actual, perceived, and projected deteriorating agricultural conditions, there is now even more pressure on existing forests and wetlands in the Kibale region. Forests and wetlands immediately within Kibale National Park have remained mostly intact of the past several decades; however, forest and wetland patches surrounding the park have become increasingly fragmented (Hartter and Southworth 2009; Jacob et al. 2014). The remaining forests and wetlands, most of which are protected within the national park, not only support the region's rich biodiversity, but also provide households with fuelwood, thatch, medicinal plants, vines, water, fish, and honey (Hartter and Southworth 2009; Naughton-Treves et al. 2011). The lack of a clear boundary demarcation, management responsibilities, and tenure of these wetlands and forests has contributed to the decline and degradation of these important resource areas across Uganda (Hartter and Ryan 2010).

Conclusions

Through a joint analysis of satellite-based rainfall estimates and perceptions of smallholder farmers in the vicinity of Kibale National Park in western Uganda, we find that rainy seasons in the Kibale region, especially the southern portion, have shortened from 1983 to 2014, and local farmers have perceived those changes. Changes in rainfall likely caused an increase in soil-water stress throughout the region, especially in the South during the dry seasons and at the start of the rainy seasons. Southern farmers perceived larger decreases in rainfall than did the northern farmers. However, the farmers may not have actually been perceiving multi-decadal term trends in rainfall, since other biophysical factors as well as socioeconomic and agro-economic factors affect their perceptions of climate variability. Farmers report that crop yields have decreased substantially, and the decrease can be tied not only to shortened growing seasons but also to a decline in soil fertility.

Available land is scarce in the region; therefore, few farmers fallow their land. In addition, the use of external inputs to soil is nearly nonexistent. Consequently, it is possible that farmers' perceptions of rainfall declines in the Kibale region may reflect more the decrease in soil fertility than the change in rainfall and associated soil moisture. Irrespective of past rainfall variability and the farmers' perceptions of it, future food insecurity poses a challenge to farmers in Kibale region, and presumably all of western Uganda if population keeps increasing, agricultural practices do not change, and projections of a continued decline in soil water are correct.

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