

*Full Length Research Paper*

## Adapting to climate variability and change in smallholder farming communities: A case study from Burkina Faso, Chad and Niger

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Climate variability and change is regarded as having major impacts on key sustainable socio-economic and environmental indicators in Sub-Saharan West Africa. Because of these concerns, we investigated smallholders knowledge, skills, and aspirations about managing climate change, and document adaptation strategies used in the semi-arid regions coming from Burkina Faso, Chad and Niger. We analyzed climate data from the 1950's to the present, including daily and aggregated rainfall and temperature variability, trends and extremes. We also examined farmer perceptions of climate, particularly with what was expected and what was actually observed. Field data was collected through: (i) a semi-structured survey administered to 478 head households; (ii) from focus groups through discussion and consultation with local stakeholders by using a risk matrix. The main agro-climatic risks for farmers in these countries are: Increasing maximum and minimum temperatures; high rainfall variability; and, extreme droughts and floods. We were able to work with communities to identify and prioritize authentic climate change adaptation measures that were deemed to be both strategic and complementary to prudent natural resource management and enhanced agricultural production. Identified innovative adaptation practices that may be up-scaled include: expanding irrigation systems, adjusting crop planting times to suit localized weather and climate forecasts, plant breeding to establish more heat-stress tolerant crops and associated agroforestry. In dryland rainfall systems, it was acknowledged there is a need for greater reliance on water-stress tolerant crops, better soil and water conservation techniques associated with broad catchment management and agroforestry, and improving soil management through prudent fertilizers in sorghum crops. To address climate change, such practices need immediate wider-scale implementation.

**Key words:** Climate variability and change, farmers perceptions, agro-climatic risk, adaptation, Sahel, Africa.

### INTRODUCTION

Climate variability has historically affected West African society. This region has in our lifetime experienced

severe droughts during the years 70 and 80s. This drought event has been described as one of the most

severe in the world in duration and extent during that century (Hulme, 2001). In addition, other climate parameters such as dry spells, timing of the onset and end of the rainy season and length of growing period affect agricultural production significantly and hence food security. In most cases, crop failure in the semi-arid areas of Africa is mainly associated with a decrease in total rain, dry spells within the 'normal' crop growing season and a shorter length growing period (Araya and Stroosnijder, 2011). Climate change is likely to exacerbate these issues (IPCC, 2007).

A new pattern of rainfall variability has occurred post-90's in the Sahel West African region, characterized by a succession of much wetter and much drier years (Ali et al., 2011). However, the pattern of higher total precipitation coincides with increased mean intensity and accompanying floods. The end of the Sahelian drought post-1990s may have been premature (Ozer et al., 2003), and replaced with the realization of a new climate changed world for the peoples of this region. There has been a general warming trend throughout the region from 1960 to 2010, namely through a negative trend in the number of cool nights and more frequent warm days and warm spells (Ly et al., 2013). Observed temperatures have been increasing faster than global warming trends and expectations. The increase has fluctuated between 0.2 and 0.8°C from 1961 to 2010 (Ecowas-SWAC/OECD/CILSS, 2008). It is now inarguable that climate variability alongside climate change is now a major and permanent feature of semi-arid West Africa that needs to be confronted and appropriately dealt with (Akponikpè et al., 2010).

The agriculture sector in West Africa's includes livestock, fisheries and smallholder farming, and is a significant contributor to the economy. With less than 5% of agricultural land irrigated, rainfall variability and increasing temperature and evapotranspiration, have high socio-economic impacts on rainfed agricultural. All these challenges combine to add pressure to poverty (Mapfumo et al., 2008), natural resources depletion, diseases such as malaria and increase the vulnerability in the already vulnerable communities.

Numerous studies have already been undertaken in Africa on linking climate variability and change with farmer's perceptions and current coping strategies and applied adaptation measures (Macharia et al., 2012; Mtambanengwe et al., 2012; Henny et al., 2011; Moyo et al., 2012; Ouédraogo et al., 2010), but they have not been adequately targeted to suit west African agriculture and applied yet by extension practitioners (Mertz et al., 2011). Specific adaptation responses are important because the climate has already changed and these changes are likely to continue even if mitigation actions

are enacted immediately (Cobon et al., 2009). However, the capacity of local farming communities and their institutions to respond accordingly to the new and emerging impacts of climate change is often constrained by lack of access to resources, information, and improved technologies (Mapfumo et al., 2013). A more thorough and comprehensive nationally coordinated approach is warranted, similar to the approach taken in Tanzania (MAFC, 2014). Furthermore, using tools and practices that help end-users identify adaptations that are 'location-specific' and 'knowledge-intensive' can accelerate roll-out of adaptation options for agriculture and water (George et al., 2014).

Understanding local farmer knowledge levels about climate and climate risk is a pre-requisite to mainstreaming climate adaptation into agricultural development strategies and plans. This paper examines local knowledge and experiences of farmers in Burkina Faso, Chad and Niger, about how they are managing climate variability and change - using elements of rainfall, temperature, and climate extremes events from 1960 to 2010. This data will highlight 'best management practices' and identify lessons learned for greater uptake and successes that can therefore help accelerate adaptation to climate change if adopted on a wider scale.

The first section of this paper examines farmer understanding of climate variability and change. The second section compares farmers' perceptions of climate change and variability in relation to climatological evidence. The last section presents data on the use of a risk management approach, which uses a multi criteria matrix analyses and participatory method that can then identify adaptation options to be implemented.

## MATERIALS AND METHODS

### Site description

The study was conducted in key semi arid cropping areas in the three countries in Burkina Faso, Chad and Niger. The survey was carried out (i) in Burkina Faso, in the northern community of Bogande, Mani in the East region, Safi and Koboure in the Central North; (ii) in Chad in the Chari department; and (iii) in the Western part of Niger in Tillabery, Filingue and Kollo (Table 1). In the 3 countries, the semi arid area is characterized by annual rainfall ranging from 600 to 350 mm and from 600 to more than 825 mm in the sudanian zone. The average length of growing period ranges from 75 to 140 days (Thornton et al., 2006). The average annual temperature ranged from minimum 21.3 to 22.9°C and maximum 34.7 to 36.7°C. Cropping systems are characterized by high rainfall variability and recurrence of droughts, poor soil fertility, high human pressure on the natural resources and consequently low productivity (Traoré et al., 2000). Millet, sorghum, cowpea are the main crop growing under rainfed agriculture. The economies of the region are built mainly on rainfed agriculture. Irrigated agriculture

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**Table 1.** Average annual minimal, maximal temperatures, rainfall and length of growing period (1961-1990) for the key stations in Burkina Faso, Niger and Chad.

Country	Weather station	Latitude °N	Longitude °	Elevation (mm)	Tmin °C	Tmax °C	Annual rainfall (mm)	LGP (days)
Burkina Faso	Bogandé	13	-0.1	250			584	114
	Boulsa	12.39	0.36	313			690	117
	FadaN'gourma*	12.07	0.35	292	21.3	34.7	825	145
	Kaya	13.1	-1.1	313			670	121
Niger	Filingué	14.3	3.3	300			359	75
	Kollo	13.3	2.4	210			554	105
	Niamey*	13.28	2.1	222	22.4	36.1	539	103
	Tillabery*	14.2	1.45	209	22.9	36.7	399	80
Chad	Ndjaména*	12.1	15.1	294	20.9	35.8	520	95

\*Weather stations with minimum and maximum temperature.

and fishing along the Niger River basin are also significant activities.

### Survey data

The questionnaire was administered to a total of 478 household heads unequally distributed in the 3 countries according to the number of population and the importance of the rural activities. Random sampling was used to select the head of households for interview. This comprised 160 households in Burkina Faso, 196 in Chad, and 122 in Niger. Data was collected from January to March 2012 by Master degree students enrolled in a Climate Change and Sustainable Development Unit organized by AGRHYMET Regional Centre. A semi-structured household questionnaire was individually administered to the selected head of each household. Focus group discussions were also used to analyze and authenticate the impact of climate variability and change on farmer's livelihoods and environment (crop, water resource, soil, and other ecosystem services). The age of the respondents ranged approximately from 40 to 75 years. Data and information collected were focused on farmers' perceptions of climate variability and change, and the impact of climate variability and change on their livelihood including other data on crops, soils, water, vegetation and animals. Farmers' adaptation strategies to cope with climate variability and change were also featured. The survey also had focused questions on farmers' perceived climatic patterns to have stayed the same or changed before over the last 20 years.

### Statistical tests and ensuring reliability of data

Quantitative data was analyzed using the Student t test. Qualitative data on impacts and adaptations was collected from the risk matrix (AGO, 2006; Cobon et al., 2009). To prioritize the adaptation measures identified, a variety of criteria have been used (Miller et al., 2006; USAID, 2007) to aggregate responses about: (i) the cost to implement adaptation options; (ii) the effectiveness in terms of benefits, damages mitigated, costs avoided, (iii) the ease of implementation including issues such as barriers to implementation and the need to adjust other policies to accommodate the adaptation, (iv) technical feasibility; (v) sociocultural feasibility, and the speed of implementation. For each criteria, a score from 1 to 3 was given (1 being poor performance and 3 high performance). To select the final set of adaptation measures and assigning or level of importance of each of them, consultations with decision-makers

and stakeholders were done through the focus group survey with consensus being achieved on all options. Stakeholders included local farmers, Non-Governmental Organization local representatives of National Ministries and extension services. From these approaches, the adaptation measures with the highest score ranked most critical to implement.

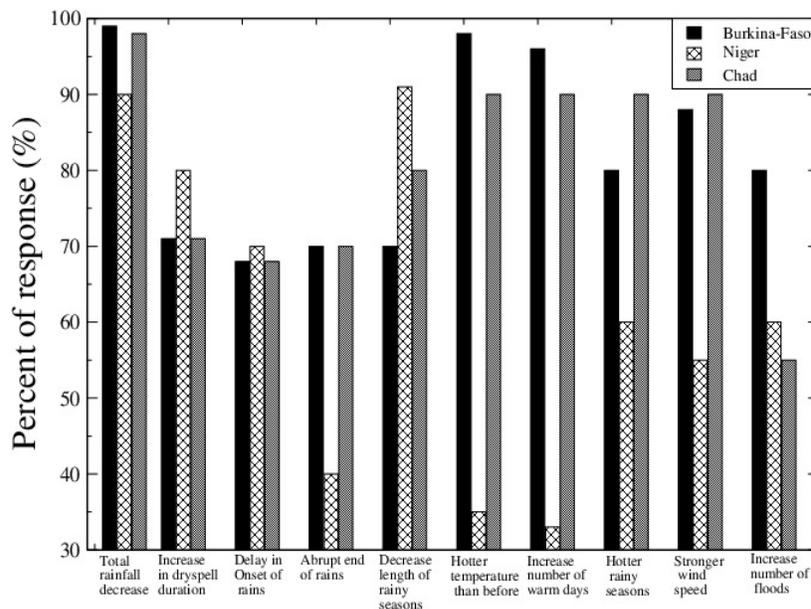
### Analyses of observed climate data

Daily rainfall, minimal and maximal temperature were collected from the AGRHYMET Regional Centre data basis completed by the National Meteorological Services of the 3 countries. Because of the high spatial rainfall variability, we selected the closest weather station to the village. Climate data rainfall, maximum and minimum temperature from 1960 to 2010, were collected and digitized (Table 1). The data were quality controlled using Rclimdex package (Zhang and Yang, 2004). Minimum and maximum temperatures and rainfall anomalies were computed with respect to the reference period 1961 to 1990. Other rain season parameters such as onset, cessation of rainy season and length of growing period were also computed (Stern et al., 2006). Several definitions are adopted for the onset and the cessation date of the rainy season (Stern et al., 1981; Sivakumar, 1988; Traoré et al., 2000). In this study, the criteria used to determine onset date is a cumulated rainfall of 20 mm or more over three consecutive days after the first day of May with no dry spell greater than 20 days in the next 30 days. The end of the season was defined as the date after the first day of September when available soil water content dropped approximately to 0.05 mm due to crop evapotranspiration. The length of growing period was calculated as a difference between the onset and the cessation dates. The Student's t-test at the 95% level of significance for the comparison of two means for the time series before 1990 and after 1990s, were applied for annual rainfall, onset date and length of growing period (Artery et al., 1973).

## RESULTS AND DISCUSSION

### Farmers' understanding of climate change

Within our sample in our study countries, > 90% of farmers from Burkina Faso and Chad consider total rainfall decrease is the greatest challenge to overcome



**Figure 1.** Farmers (n=478) considerations of greatest climate challenges to overcome in farming - from Burkina Faso (n=160), Chad (n=196) and Niger (n=122).

(Figure 1). Those from Niger considered the greatest challenge to be a shorter rainy season. In addition, >70% reported that the dry spell duration has increased over the last 20 years and drought became more severe particularly in Tillabery in semi arid Niger. An observed delay in the onset of rains was also reported by 65% of the farmers along with an abrupt end of rains by 70%. About 70% of the farmers in Burkina Faso, 90% in Niger and almost 100% in Chad reported a decrease of the length of the rainy season. In the same time, 40% of farmers indicated a rise in the number of heavy rain in the region of Tillabery. In addition, 60% of respondents in the region of Tillabery, 80% in Burkina Faso and Chad mentioned that flood increased during these last decades.

More than 90% of farmers observed increasing temperature over the last 20 years in Burkina Faso and Chad (Figure 1). Farmers mentioned that warmer days and nights have increased during the last 2 decades. However, only a third of respondents reported that temperature has increased significantly in Tillabery, Niger.

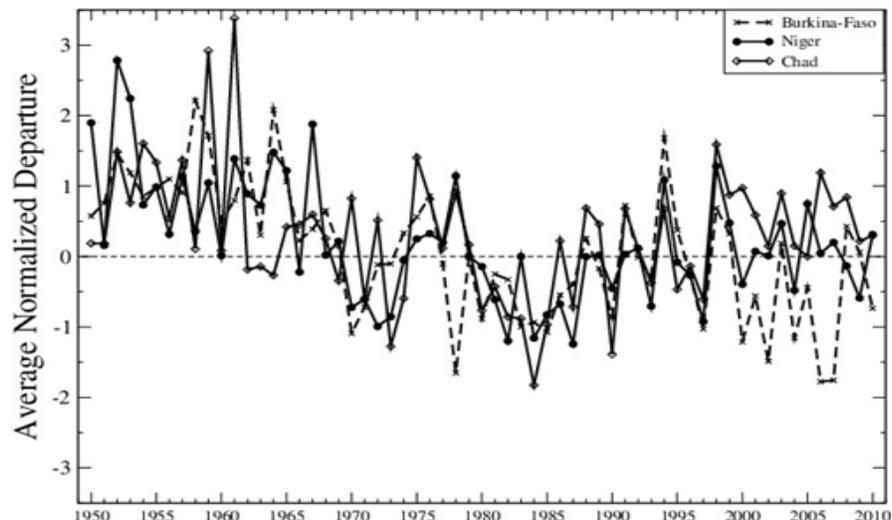
The farmers' perception of a decline in rainfall may be related to the lower moisture availability for plant growth resulted from soil fertility decline and soil erosion (Adimassu, 2014). However, Van de Giesen et al. (2010) show that farmers in the Volta region have experienced shifts in the onset of the rainy season later in the year, from April towards May. These farmers now sow 10 to 20 days later than their parents. While, Diouf et al. (2000) show spatial heterogeneity of response from LGP to climate variability and change over the Sahel region.

## Observed climate data: Trends and variability

### Rainfall

Statistically, annual rainfall has not changed in the past 20 years compared to period before, particularly from the year 60' to the present period (Figure 2). The evolution of total annual rainfall has been characterized by a succession of wet years from 1950 to 1969, followed by a period with the persistence of dry years from 1970 to 1993 (L'hote et al., 2002; Ali et al., 2008). This has resulted in a southward movement of isohyets by about 200 km (Diouf et al., 2000). While the present period experienced receiving long-term 'average' rainfall throughout the 1990s.

For most stations, the amounts of annual rainfall during the period before and after 90 are not significantly different according to Student's t-test at 5% probability level. Only a few number of selected stations such as Kaya (Burkina Faso) show a significant decrease of the amount of rainfall during the past 20 years (Table 2). From the beginning of the 90s, another mode of variability, characterized by a succession between wet and dry years seems to have started in the region (Ali, 2011). This high rainfall variability could be probably due to climate change during the past 20 years. In the same period, the maximum day precipitation amount have increase in general in the semi arid West Africa region (Gachon et al., 2007). In addition, the average number of flood events have increased from less than 2 per year before 1990 to more than 8 to 12 per year during the 2000s (Sarr, 2012). The years 2000, particularly 2007,



**Figure 2.** Average annual rainfall normalized departure from 1950 to 2010 in the studied weather stations in Burkina Faso, Niger and Chad.

**Table 2.** Mean comparison of annual rainfall before and after 1990 (before and after the past 20 years), (significant if observed Student t test > critical Student test = 2.001).

Weather station	Annual rainfall (mm)				Observed t
	Before 1990	After 1990	Difference before and after 1990	Confidence interval at 95 % level around the mean difference	
Tillabéry	442	420	-22.4	[-90.2 ; 45.4]	0.66
Niamey	564	545	-19.23	[-94.6 ; 56.2]	0.5
Kollo	568	521	-46.58	[-127.7 ; 34.6]	1.14
Filingué	418	387	-31.1	[-109.8 ; 47.6]	0.79
FadaNgourma	883	853	-29.51	[-113.7 ; 54.7]	0.7
Kaya	692	587	-105.01	[-198.8 ; 11.2]	<b>2.24</b>
Bogandé	634	629	5.2	[-68.5 ; 79.01]	0.142
Ndjaména	561	587	25.31	[-57.1 ; 107.7]	0.61

2008 and 2009, have experienced several cases of floods in West Africa with severe destruction of infrastructure and significant crop losses (Sarr and Lona, 2009). The impacts of these events were probably amplified by the land change affecting runoff.

### **Onset and length of growing period**

In this region, agricultural farmers system is highly vulnerable to the rainfall component such as onset, and length of growing period variability (Dodd and Joliffe, 2001). Onset date occurs according to the station, from the second decade of May to third decade of June (Table 3). The observed length of growing period (Table 4) ranges between 80 days in the northern part of the region (Tillabery) and 150 days in the south of Burkina Faso (Fada Ngourma). The onset date, the length of growing

period during the past two decades and the period before did not show significant difference according to the Student's t test (Tables 3 and 4). Only the station of Kollo in Niger shows a significant late onset date during the present period. Alhassane et al. (2013) showed that the agro-climatic risks of the recent period (1991 to 2010) are still the same as those in the historical drought period of 1970 to 1990. Onset dates of the cropping season show a quasi-stationary trend from 1970 to 2010. In addition, the succession of wet and dry periods recorded from 1990s does not seem to favor the extension of length of growing period.

### **Temperature**

From 1990 to 2010, a clear trend of increase is observed for the minimal and maximal temperatures (Figure 3a and

**Table 3.** Mean comparison of onset date before and after 1990, (significant if observed Student t test > critical Student test = 2.001).

Onset date					
Weather station	Onset date before 1990 (mm)	Onset date after 1990 (mm)	Difference before and after (mm)	Confidence interval at 95% level around the mean difference	Observed t
Tillabery	24 June	20 June	-5	[-16.1; 6.7]	0.82
Niamey	04 June	03 June	-1	[-13.1; 11.1]	0.17
Kollo	31 May	14 June	13	[-2.8; 23.4]	<b>2.50</b>
Filingue	23 June	18 June	-5	[-17.5; 6.9]	0.80
FadaNgourma	11 May	11 May	0	[-11; 10]	0.05
Kaya	28 May	26 May	-2	[-12.9; 8.5]	0.40
Bogandé	24 May	29 May	-5	[-17; 7.7]	0.77
Ndjaména	16 June	17 June	2	[-11.5; 14.8]	0.26

**Table 4.** Mean comparison of annual length of growing season before and after (significant if observed Student t test > critical Student test = 2.001).

Length of growing season (LGP)					
Weather station	LGP 1990 (day)	LGP after 1990 (day)	Difference before and after (day)	Confidence interval at 95 % level around the mean difference	Observed t
Tillabéry	80	80	0	[-12.3 ; 12.06]	0.02
Niamey	105	109	4	[-9.9 ; 17.9]	0.57
Kollo	108	96	-12	[-26.0 ; 0.57]	1.91
Filingue	80	84	4	[-9.3 ; 17.24]	0.60
FadaNgourma	149	144	-5	[-17.15; 6.7]	0.87
Kaya	121	123	2	[-10.5 ; 14.2]	0.29
Bogandé	120	116	-6	[-20.4 ; 9.2]	0.7
Ndjaména	99	99	0	[-12.8 ; 14.5]	0.1

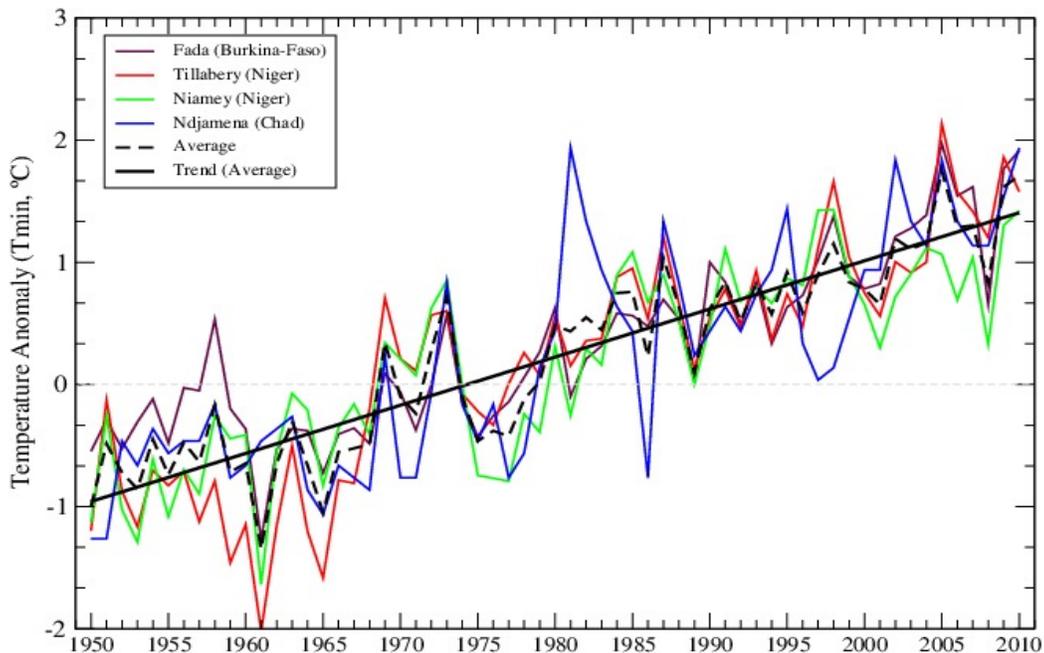
b). All the stations showed an increase of annual mean minimum and maximum temperatures from the years 90 compared to the period before. The value appears to be increasing at a faster rate for the minimum than for the maximum. Before the 90' and the past two decades, minimum temperature increased significantly from 1.3 to 1.1°C for all the weather stations (Table 5 and Figure 4a and b). In the same time, the maximum temperature showed a significant increase from 0.75 to 1°C. Over the two periods, the average increase of temperature in this region was 1.04°C. Indeed, Caesar et al. (2006) show that minimum temperature has increased faster than maximum temperature, thus contributing to narrow the diurnal temperature range. According to IPCC (2013), the globally averaged combined land and ocean surface temperatures showed a warming of 0.85 [0.65 to 1.06]°C over the period 1880 to 2012. In addition, Ly et al. (2013) showed a general warming trend in the entire region from 1960 to 2010 with a negative trend in the number of cool nights and more frequent warm days and warm spells. Over the same period, the occurrence of extreme hot days and nights has increased by 8.2 and 8.6 days / decade, respectively (New et al., 2006). This warming is

projected to continue and will likely be accompanied by more extreme climate events (Vincent et al., 2005).

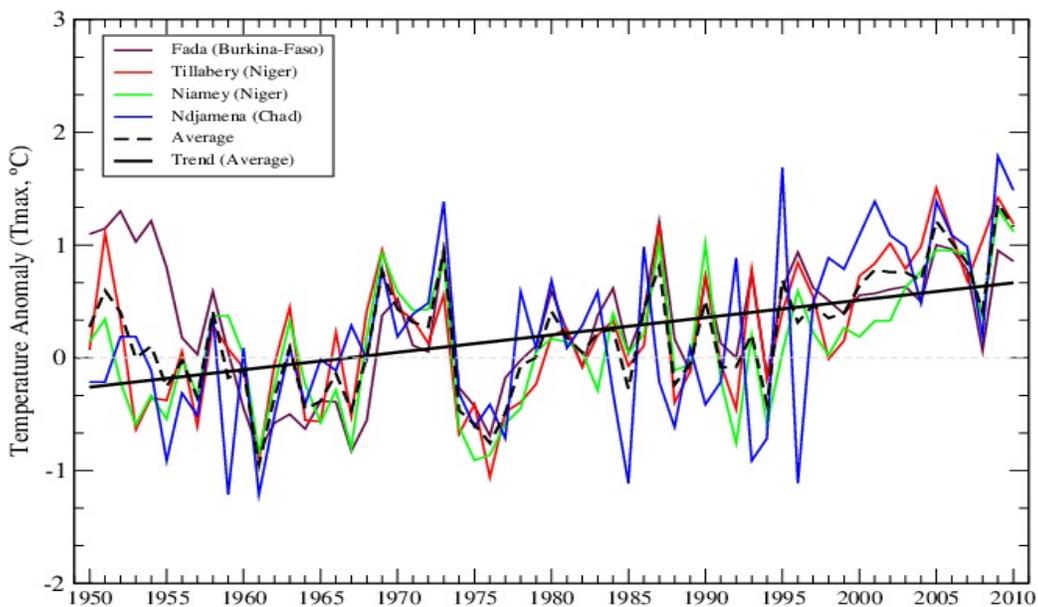
#### Farmers' perceptions compared to observed meteorological data

The survey showed that farmers perceived climate to have changed in the past 20 years. In general, farmers (more than 90% in Burkina Faso and Chad) felt that temperature had increased over the past 20 years. Farmers reported that present temperatures have been increasing faster than the period before the 1990s. Observed temperature data showed a clear signal of general warming trend throughout the region during the period from 1960 to 2010.

During the past 20 years, succession of wet and dry years has been noted. Since the mid-1990s, rainfall measurements did not show a downward trend in rainfall amount. Closer normal to above average rainfall amounts have predominantly been noted. Then, the perceived change in rainfall reported by farmers differed with the observations. Therefore, farmers still remember the



**Figure 3a.** Minimum temperature anomalies relative to 1961-1990 average in the four reference weather stations.



**Figure 3b.** Maximum air temperature anomalies relative to 1961-1990 average in the four reference weather stations.

severe droughts of the 70s and 80s but have not captured well the return to better rainfall conditions since the beginning of the 90s which is also accompanied with high rainfall variability. This is probably related to the high inter annual variability of rainfall which is perceived by farmers as a period of rainfall decrease.

Over the past 20 years, a delay in the onset of the rainy season or early cessation greater than the period before was not observed. Alhassane et al. (2013) has shown that present agro-climatic risks remained similar to the historic drought from 1970 to 1990. However, it still probably differed from the wet period of the 50s and

**Table 5.** Mean comparison of minimal and maximal temperature before and after 1990, (significant at 95 % level if observed Student's t test > critical Student test = 2.001)

Weather station	Minimal temperature			Maximal temperature		
	Difference before and after 1990°C	Confidence interval at 95% level around the mean difference	Observed t- test	Difference before and after 1990°C	Confidence interval at 95% level around the mean difference	Observed t-test
Tillabery	1.3	[0.9; 1.71]	<b>6.8</b>	0.7	[0.38 ; 0.95]	<b>4.66</b>
Niamey	1.1	[0.8; 1.41]	<b>7.2</b>	0.4	[0. 12; 0.68]	<b>2.81</b>
FadaNgourma	1.2	[0.9; 1.41]	<b>9.08</b>	0.4	[0. 09; 0.69]	<b>2.67</b>
Ndjaména	1.2	[0.8; 1.53]	<b>6.23</b>	0.74	[0. 37; 1.12]	<b>4.03</b>

60s. The number of floods were perceived to have increased by a higher proportion of farmers in Burkina Faso and Chad (80%), and Niger (60%). Afterwards during the 90s, more extreme event occurrences and the number of flood events have increased in West Africa compared to the period from 1966 to the early 1980s. In the same time, (Gachon et al., 2007) showed a positive trend of the 90<sup>th</sup> percentile of daily total rainfall and the number of days with precipitation exceeding the 90<sup>th</sup> percentile with respect to 1961–1990.

#### ***Climate change impact and innovative farmer's adaptation strategies***

From farmers' perceptions and agroclimatic trends analysis with 50 years of daily rainfall and temperature data observations, the main climate risks in the region can be summarized in decreasing order of importance as: (i) increasing maximum and minimum temperatures; (ii) high rainfall variability; and, (iii) extreme droughts and floods.

In Burkina Faso, Chad and Niger, farmers have attributed a decrease in yield to climate variability and change. According to focus group discussions, another impact of climate change is also manifested, by a decline in soil fertility, because farmers have had to repeatedly replant crops, and abandon longer-cycle varieties (Table 6). Indirect effects also include the increase in plant health problems (diseases and attacks on crops). One of the main impacts of climate change is the loss of surrounding biodiversity. In terms of water resources, the results varied according to country. In Burkina Faso, farmers recorded a depletion of ponds and water points while in Niger, cases of disappearance of ponds and formation of new ponds that did not exist before were reported. Higher rainfall variability and increase in heavy rains in some parts of the Sahel would explain some of these observations. Concerning the irrigated cropping system in Niger, negative impacts of climate change, particularly include temperature increases in accelerating maturation of seedlings in nurseries of lettuce, cabbage and onion. At transplanting, increased abortion rates of

all vegetable crops was also noted by farmers, particularly cabbage and tomato. Finally, the increased evaporation, combined with the decline of water resources translate into lower crop yields are considered as the major climate change impacts on production.

To manage rainfall variability, communities in the region have already implemented a wide range of adaptive measures such as micro water harvesting (Zaï) techniques, stone lines (60%), conservation of sorghum residues and organic matter (Barbier et al., 2008). With regard to present climate risk and possible amplification due to climate change, farmers expressed and prioritized new needs in term of adapting agriculture to climate variability and change.

In response to perceived and observed changes in weather patterns, local stakeholders' priorities for adaptations focused in shifting the times of planting dates and relying more on heat stress tolerant crops. They also now have associated agroforestry and forage production crops plus wind breaks to lessen effects of higher temperatures (Niger, irrigated system). In rainfall systems, the main adaptation strategies are targeting more rapidly maturing crops, supplemental irrigation, improving soil fertility management combined with agroforestry (Table 6). According to Traoré et al. (2014), crop management practices based on adjusting the planting date and choices of improved variety are the adaptation strategies most readily available to farmers to deal with the effects of climate variability. However, investment in equipment to manage land is also required to ensure adequate and supportive governance for food security (Mati, 2011). In addition, policies to encourage farmers to use irrigation systems and raise cropping intensity for irrigated area are needed (Valipour, 2014). The effects of different agroforestry techniques in enhancing the resilience of agricultural systems against adverse impacts of rainfall variability, increased temperature; reduced water availability, soil erosion as well as pests, diseases and weeds are accepted by farmers. Agroforestry systems play an important role in terms of increasing carbon stocks in the terrestrial biosphere and then offer opportunities for linking adaptation and mitigation (Albrecht and Kandji, 2003;

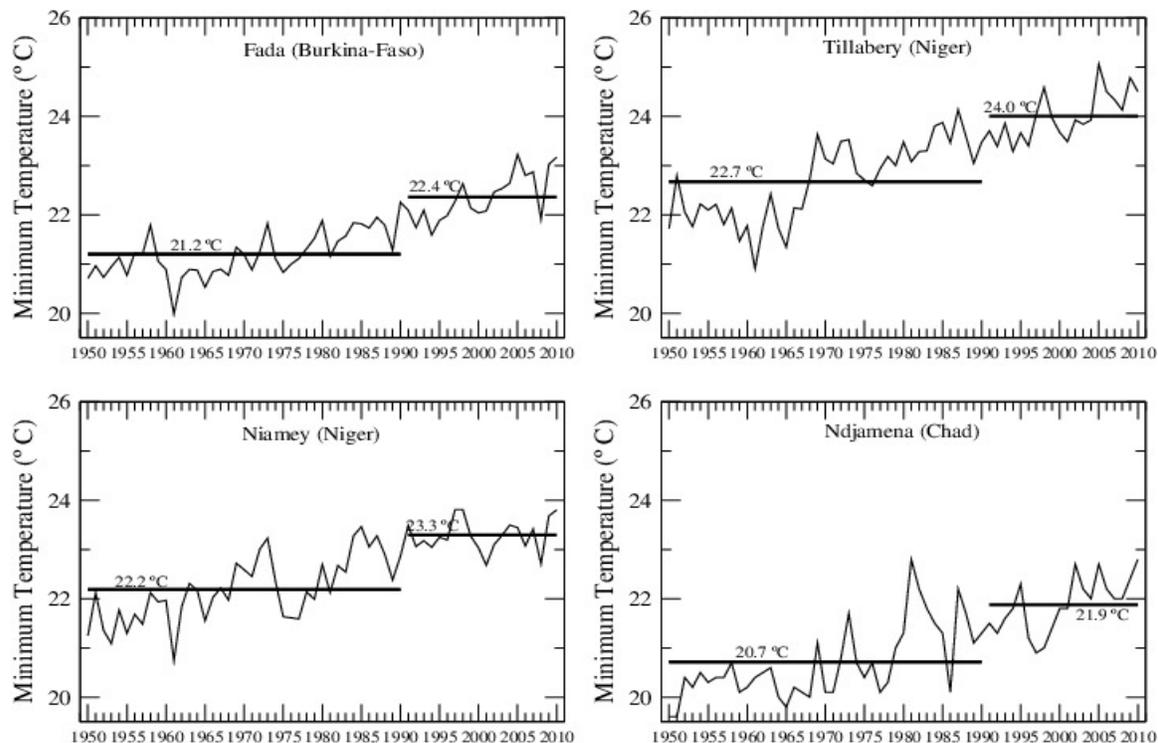


Figure 4a. Average pre- and post-1990 minimum air temperature at four reference stations in West Africa.

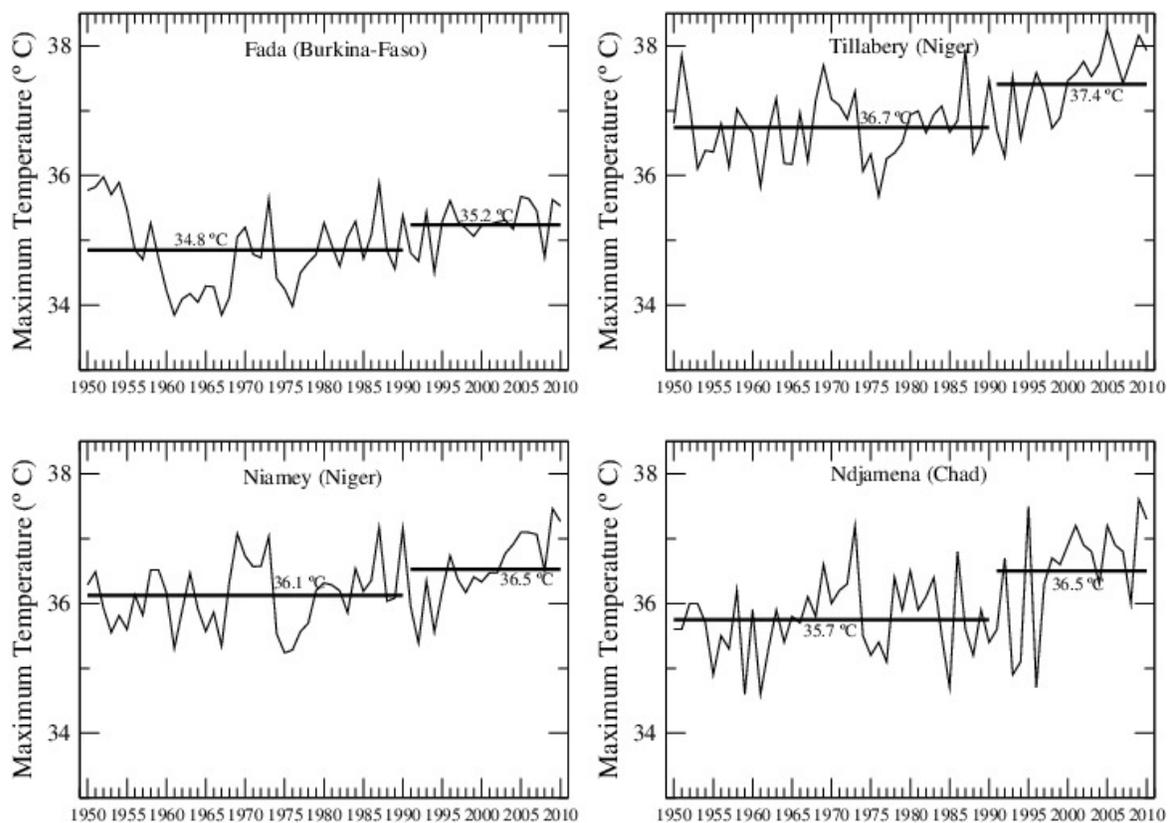


Figure 4b. Average pre- and post-1990 maximum air temperature at four reference weather stations in West Africa.

**Table 6.** Matrix of specific climate change impacts and innovative adaptation measures.

Country	Department /area ecological zone and cropping system	Agro and observed climate risk	Main perceived and observed climate risk	Climate impact issues	Farmers' priorities adaptations measures	Rank
Niger	Region of Tillabery 350 -500 mm Irrigated system across the Niger river (irrigated vegetable crop)	Temperature increase Rainfall variability	Increase of abortion rates of all vegetable crop (nurseries and planting stage) Reduced water availability Decrease in crop yield(water stress)	Shift of planting dates and to heat stress tolerant crops associated to agroforestry to cope with high temperature : development of Sahelian farmland with a wide variety of tree species (Moringa oleifera, Bauhinia rufescens, Accacias trees, Lawsonia inermis, Eucalyptus sp, Ziziphus mauritania) for windbreaks and production of air animal feed	1	
					Research on crop calendar, particularly on early planting vegetables crop	2
	Region of Tillabery 350 -500 mm Rainfed system	High rainfall and rainfall component variability, drought, Heavy precipitation and flood events	Abandonment of long-cycle varieties, Increase of frequency or replanting Decrease in crop yield	Supplemental irrigation associated with early rapidly maturing crop, tillage before planting and use of fertilizer	1	
Chad	Region of Chari-Baguirmi (Department of Chari) Soudano Sahelian zone 400 to 700 mm	Dought, rainfall variability, Shortened LGP , Heavy precipitation and floods events.	Reduced flood recession sorghum areas Decrease in crop yield and production	Use of improved soil and water conservation management practices, crop diversification, and better soil and fertilizer management in sorghum flood recession cropping	1	
				Use of seasonal rainfall forecast in rainfall cropping system	2	
Burkina Faso	Region East and Central North Soudanian zone 600 -800 mm Rainfed system	Rainfall decrease reduction of LGP Flood events	Yield decrease Crop losses by waterlogging	Use of crop water stress tolerant Better soil and water conservation techniques	1	
				Management of lowland and improved drainage	2	

Atela, 2012).

In Chad, the use of improved soil and fertilizer management practices, crop diversification is favored. These fertile land flood recession, which retain moisture, have higher potential compared to rainfed land. Intensification of this flood -prone land is attractive because it has so far been more profitable in the recent past. Considering the large geographical extent of these land systems in Chad (Salamat, Guera, Batha), the positive contribution this could make to satisfy food

security and address climate change in Chad is worth further investigation. In fact, diversifying crops and cultivars, staggering planting date and managing soil fertility were identified as the major adaptation options to stabilize production against increased rainfall variability (Rurinda et al., 2014).

In Burkina Faso, stakeholders favored the use of drought tolerant varieties, and better agricultural water and land management to address drought. Improving the management of lowland grown crops, are also required. The use

of the seasonal climate forecasts are already helping farmers and could help farmers even more to manage climate risk mainly rainfall, onset and cessation date variability if such forecasts were more timely and targeted (Roncoli et al., 2002).

## Conclusion

This work revealed that farmers from Burkina

Faso, Chad and Niger are keen observers of climate variability and change and use this information in risk-averse approaches. Farmers are aware of increased temperature, greater rainfall variability and changes to the crop growing period. Furthermore, they have a clear perception of the increasing frequency of extreme events such as hotter temperatures and flooding. These changes are corroborated by observed temperature and rainfall trends. Farmers perceive the major climate risks to manage in agriculture remain as: increased temperature; higher rainfall variability; droughts; and floods. A matrix of innovative adaptations measures were identified to help manage agriculture and water in rainfed and irrigated cropping systems. These adaptations measures focused on heat stress or water stress tolerant crops associated with complementary agroforestry; early maturing crops; supplemental irrigation; the use of improved soil and fertilizer management practices; and the use of the seasonal climate forecasts. These adaptation options, if adopted on a larger scale, will enhance management of the impacts of climate change in the region and assist in climate change mitigation. Resourcing these 'location-specific' and 'knowledge-intensive' practices and accelerating the uptake of such techniques given the scenario and timeline of the changing climate will be the next challenge (OCDE, 2009).

### Conflict of Interest

The authors have not declared any conflict of interest.

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