ATMOSPHERIC SCIENCE LETTERS
Atmos. Sci. Let. (2012)
Published online in Wiley Online Library
(wileyonlinelibrary.com) **DOI:** 10.1002/asl.368

Royal Meteorological Society

Present and future climate change in the semi-arid region of West Africa: a crucial input for practical adaptation in agriculture

Benoît Sarr*
Training and Research Department, Agrhymet Regional Centre, Niamey, Niger

**Correspondence to:
B. Sarr, Training and Research Department, Agrhymet Regional Centre, Niamey, Niger.
E-mail:
b.sarr@agrhymet.ne*

Received: 8 April 2011
Revised: 10 September 2011
Accepted: 22 November 2011

Abstract

Climate change trends and projections based on observation and climate model were reviewed in West Africa (WA). Historically, the region has experienced decades of severe drought along with cycles of above average rainfall which have greatly affected agricultural production. Future projections indicate decreased rainfall over the Sahel coastline. Observations already indicate an average increase in temperature of between 0.2 and 0.8 °C; when projected, this increases further to between 3.0 and 4.0 °C. Of greater concern, however, is the late onset, early cessation dates of rainfall and reduction of length growing period (LGP) which are now locally negatively impacting agriculture in the region. Furthermore, projections indicate a 20% reduction of LGP in 2050. These results represent essential input for accelerating agricultural adaptation to climate change. Copyright © 2012 Royal Meteorological Society

Keywords: **West Africa; semi-arid region; trend; projection; climate change; adaptation**

1. Introduction

The economies of the semi-arid region of countries in West Africa (WA) are built predominantly on agriculture, which is highly influenced by climate variability and change.

Climate variability is deeply rooted within the West African society. Adapting to climate variability has been a characteristic of West African rural society (ECOWAS-SWAC/OECD/CILSS, 2008). Of particular note has been the 1930–1960 wet period, the 1970–1980 droughts and the experience of receiving long-term 'average' rainfall throughout the 1990s. Recent studies suggest a return to a 'closer-to-normal regime' in the region since the mid-1990s with precipitation now being slightly above the average long-term 1901–1998 (Nicholson and Selato, 2000). However, this precipitation coincides with a positive trend for increased mean intensity, and flood situations. Historically, the occurrence of a repeated cyle of drought and floods has continued to affect the subregion, especially the Sahel (15°N–17°N band across Africa) resulting in catastrophic famine (Mohamed *et al*., 2002). Rainfall and rainy season characteristics (onset, dry spells, LGP, etc.) have significant effect on food productions. In most cases, the causes of crop failure in the semi-arid areas of Africa are attribued mainly to dry spells, shorter LGP due to late onset and/or early cessation of rain and decrease in total rain (Araya and Stroosnijder, 2011). All these challenges exacerbate the WA populations' vulnerability both to the high natural variability of the climate and the climate change trend expected in future (Mertz *et al*., 2011). Drought causes negative socio-economic implications for food production, human welfare and political stability (Benson and Clay, 1998). This deterioration in living conditions has resulted in growing scientific interest for mainstreaming climate change into an agricultural development plan. The purpose of this review is therefore to undertake an assessment of the prevailing climate in WA. The objective of the study is to have an updated knowledge on the present state and future agroclimatic trend as crucial inputs into the design of research programs aiming to adress the issue of food security in the region.

2. Possible causes of climate variability

The rainfall over WA is controlled by global climate teleconnections, including those associated with El Niño-Southern Oscillation, North Atlantic Oscillation and regional climate systems which include intertropical discontinuity, monsoons, subtropical anticyclones, sea surface temperature (SST) anomalies, atmospheric winds and the location of the Jet stream, etc. Drought comes along with a fundamental change of the global SST pattern (Diedhiou and Mahfouf, 1996; Giannini *et al*., 2003). The climate of WA is also influenced by anthropogenic impact from land use changes, which affect vegetation cover, surface albedo and soil moisture (Douville, 2002). Nicholson (2001) suggested that rainfall anomalies over sub-Saharan WA are primarily triggered by SST changes and secondarily enhanced in amplitude and period by local feedbacks with vegetation, surface albedo and soil moisture. Some authors suggest that the impacts of changes in land use and especially deforestation may be among the factors explaining the recurrence of severe droughts in the Sahel (Charney *et al.*, 1975; Xue and Shukla, 1993; Zheng and Eltahir, 1998). The process of desertification, caused basically by wind erosion, drought as a result of low rainfall and dust transport, also contributes to the degradation of soils in the region (McLeod, 1976). However, recent observations indicate a consistent trend of increasing vegetation greenness in much of the region, and is explained by recent increased rainfall and land use changes (Brooks, 2004; Olsonn, 2005). Increasing rainfall over the last few years and other factors such as land use change certainly explain this change.

3. Present trend indications for projected rainfall and drought

In the WA drylands agricultural zones, rainfall ranges between 200 and 600 mm a year are low and unevenly distributed in time and space. The latest rainfall trend shows the most significant climatic change that has occurred in the semi-arid regions (Redelsperger *et al.*, 2006). There was a general decline in seasonal July, August, September rainfall throughout the 1961–1990 period in the order of 150–200 mm. According to Le Barbé and Lebel (1997), the precipitation deficit during the dry periods in WA was essentially due to a deficit in the number of rainfall events during the rainy season. Thus, over the Sahel region, rainfall decrease has been about 0.8–1 mm per day in July–August. Means have dropped by 20–30% between the relatively wet period 1931–1960 and the dry decades 1970–1979 and 1980–1989 (Gachon *et al.*, 2007). This equates to a 150 km shift in the rainfall isohyets over the Sahel (Diouf *et al.*, 2000). However, since the mid-1990s, above average rainfall totals have been noted predominantly in the Eastern Sahel (Ali *et al.*, 2008).

The dramatic change from wet conditions in the 1950s to much drier conditions in the 1970s and 1980s represents one of the strongest interdecadal signals on the planet in the 20th century (Redelsperger *et al.*, 2006). The drought in this zone since the late 1970s is described as one of the most severe in duration and extent at a continental scale in the world during that century (IPCC, 2007).

The decrease in the total cumulative precipitation is chiefly attributable to a significant drop in the number percentage of rainy days and a minor increase in dry spells for the period 1960–1990. Another contributing factor is attributable to a decrease in rainfall intensity. The negative trend for total precipitation is less generalized for the period 1961–2000 than for the previous 30-year period. However, the 90th percentile of daily total rain and the number of days with precipitation exceeding the 90th percentile with respect to the reference period 1961–1990 show a positive trend (Gachon *et al.*, 2007) along with more extreme event occurrences. At the same time, from 1995, to the present river and dam stream flows increased markedly by between 6 and 18 per year. While, from 1966 to the early 1980s, the number of floods was less than 2 per year. In 2007, 2008 and 2009, several cases floods in WA caused severe destruction to infrastructure, significant crop losses, and extensive land erosion and degradation. In Burkina Faso, a total of 9300 ha of cultivated fields was destroyed in 2009 (Sarr and Lona, 2009).

With respect to the expected future climate, Global Circulation Models (GCMs) have so far performed poorly in simulating rainfall in the past, which is a precursor to projecting future rainfall. Rainfall projections for the WA region therefore remain largely uncertain. However, projected rainfall shows that the drying-out process will affect the West African coast up to its 15°N latitude (Christensen *et al.*, 2007). The Sahelian coastline in general, is likely to experience a decrease in precipitation by around 15 to 20% by 2100 (IPCC, 2007). In WA, most of the initial National Communications reports (UNFCCC, 2008), indicate that monthly rainfall projection values by 2100 under the ECHAM4 and HADCM2 models are similar to current climate rainfall values (1961–1990). However, the CSIRO-TR and UKTR models show an insignificant decrease in rainfall below current monthly rainfall values. Projected palmer drought severity index indicates more drought conditions in the western part of WA (Senegal, Mauritania).

Future projections are quite uncertain, with some models predicting a significant increase in rainfall, others a decrease, yet others no significant change. Part of the uncertainty derives from the vastly different model responses to greenhouse gases forcing (Cook, 2008). In summary, rainfall for WA is projected to be 20% above or below average depending on which model is used.

4. Present and future trends and variability of the temperature

In WA, observed temperatures have been increasing faster than global warming. The increase varied between 0.2 and 0.8° C since the end of the 1970s. This trend is stronger for minimum rather than maximum temperatures (ECOWAS-SWAC/OECD/CILSS, 2008). Moreover, maximum warming is expected to occur during the summer months, which coincide with the rainy season (Christensen *et al.*, 2007). Climate models for forecasting temperature changes in Africa are perceived to be more reliable. This is supported by the IPCC (2007), where it is documented global warming would be more intense in Africa than in the rest of the world. The average rise in temperature between 1980/1999 and 2080/2099 under B2 and A2 scenario would be between 3 and 4 °C for the continent as a whole 1.5 times greater than at the global level. The potential evapotranspiration (PET) changes associated with high temperature, solar radiation and wind speed. (Allen *et al.*, 1998) will be increased significantly with this expected temperature rise. Already, Coulibaly (2007) reported that, over the Senegal River Valley, just a +1.5° C mean air temperature change corresponds to an increase of 10% of PET.

5. Present and future trends of the onset, cessation dates and length of growing period

Agricultural production in WA is highly vulnerable to the onset, cessation dates and LGP variability (Dodd *et al.*, 2001), particularly the interannual variability of onset which is greater than that of cessation dates (Sivakumar, 1988). Onset occurs, according to the different agroclimatic zones, from April to July.

Farmers have experienced shifts in the onset of the rainy season later in the year, from April towards May. These farmers now sow 10–20 days later than their parents (Van de Giesen *et al.*, 2010). According to Camberlin and Diop (2003), the cessation date in Senegal shows a significant trend towards earlier dates. An abrupt shift was observed occurring around 1970. This, combined with a trend for the delayed onset led to a shortened LGP. Laux *et al.* (2008) describe an earlier onset of the wet season in the Volta basin, of 0.4–0.8 days/year, while the end of the rainy season has remained relatively fixed. The analyses of the onset and cessation date variability over Nigeria show late onset dates in a few places during the times series 1941–1970 (Anuforom, 2009). However, from the dry period 1971–2000, late onset is now consistent across many parts of the country, particularly to the North. Prior to 1970, the earlier cessation date of rains was observed in a few parts of Nigeria. During the last decade 1971–2000, the earlier cessation of the rains have affected many parts of Nigeria, particularly the west, east and northeast of the country. Recently, detailed atmospheric modeling over the semi-arid region of WA (Kunstmann and Jung, 2003; Biasutti and Sobel, 2009) have projected that the shift in the onset of the rainy season may continue to move forward. In summary, the onset will shift to later periods in the year about 1 month. However, the end of the rainy season as well as the total amount of rainfall for the period 2030–2039 will remain more or less the same.

To identify geographic areas where climate change and subsequent impacts on crops and livestock may be relatively large, LGP is a more useful indicator. It is an effective integrator of changes in rainfall amounts and patterns and temperatures (Thornton *et al.*, 2006). Over the semi-arid region, Diouf *et al.* (2000) show spatial heterogeneity of response from LGP to climate variability and change. The eastern part of the Sahel experienced expansion in the growing season, while many other areas particularly in the western Sahel (Senegal, Guinea Bissau, Mali) recorded a shortening of LGP. The trend of prolongation of LGP in the eastern part of the Sahel is linked to better rainfall conditions during the mid-1990s (Ali, 2008). Depending on the emissions scenario and climate model used, up to 25% of Africa's landmass, particularly the semi-arid zone, may suffer reduction in LGP of 20% in 2050 or more and threatening the livelihoods of nearly 280 million people (Thornton *et al.*, 2006).

6. Conclusion on adapting agriculture to climate change

There is large consensus that in WA one of the major climate change impacts will be on rainfall, making it more variable and less reliable. This will affect the onset and length of growing seasons, particularly in semi-arid areas where yields from rain-fed agriculture could be reduced by up to 20–50% by 2050 (Sarr *et al.*, 2007). Greater climate variability which incorporates the later onset, higher temperatures and increased potential evapotranspiration will make farming systems more highly vulnerable to climate change. Climate change will significantly affect food production and requires immediate and ongoing adaptation (Gornall *et al.*, 2010). A wide range of adaptive actions can be implemented to reduce or overcome some negative effects of climate change on agriculture. Famers have already adapted a wide range of techniques intended to increase crop yield (Barbier *et al.*, 2008). To manage the late onset, a shortening of LGP, dry spells after sowing and during sensitive periods of the crop to water and temperature stress, planting crops adapted to the new climate patterns, developing new drought and heat-resistant varieties should be experienced. In addition, rapidly maturing crops will enable farmers to better utilize the rains in a growing period. In the Sudano–Sahelian area, rain frequently stops at the end of August or early in September and crops have to suffer from water deficit for the rest of the growing period. To prolong the growing period, supplementary irrigation should be recommended to farmers. Where there is limited access to water for irrigation, surface runoff can be harvested, stored in farm ponds and used in case of dry spell events or early cessation of rain (Araya and Stroosnijder, 2011). Furthermore, agricultural water and land including crop, forest and biodiversity management (AWLM) can also be used as an adaptation measure. AWLM includes a holistic approach and targeting the type of technology to local conditions (Mati, 2011). Cropping and agronomic adaptation options that promote already existing 'best management practices' can be implemented by developing and promoting diversification, adjusting timing of field operations, soil fertility management and use of agroforestry. Conservation tillage techniques have the multiple benefits which include reduction of water loss by evaporation, and improved pest, diseases and weed control. Improved field water management can also be achieved through the adoption of soil and water conservation techniques such as mulch, grass strips, earthen bunds, half moon, stone lines, zaï and also reduce excessive surface runoff and soil erosion. As a result, water infiltration and moisture storage in the crop root zone as well as optimization of water for plant growth can be improved. Investment in equipment and energy to manage water and land and the institutionalization of water users association are also required to ensure adequate and supportive governance for food and water security. These adaptation options options are essential for better managing the impacts of climate change and improving livelihoods in the WA region.

Acknowledgements

This work was supported by funding from the European Union/Global Climate Change Alliance initiative (GCCA).

References

Allen RG, Pereira LS, Raes D, Smith M. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements – FAO, irrigation and drainage 56, 300.

Ali A, Lebel T. Amani A. 2008. Signification et usage de l'indice pluviométrique au Sahel. *Sécheresse* **19**: 227–235.

Anuforom AC. 2009. Climate change impacts in different agro-ecological zones of West Africa. International Workshop on Adaptation to Climate Change in West African Agriculture at Ouagadougou, Burkina Faso, 20.

Araya A, Stroosnijder L. 2011. Assessing drought risk and irrigation need in northern Ethiopia. *Agricultural and Forest Meteorology* **151**: 425–436.

Barbier B, Yacouba H, Karambiri H, Zorome M, Somé B. 2008. Human vulnerability to climate variability in the Sahel: Farmers' adaptation strategies in northern Burkina Faso. *Environmental Management* **43**: 790–803

Benson C, Clay E. 1998. The impact of droughts on sub- Saharan African economies. World Bank technical paper, 401, 80.

Biasutti M, Sobel AH. 2009. Delayed Sahel rainfall and global seasonal cycle in a warmer climate. *Geophysical Research Letters* **36**: 1–5.

Brooks N. 2004. Drought in the African Sahel: long-term perspective and future prospects, Working Paper 61. Norwich, Tyndall Centre for Climate Change Research, 37.

Camberlin P, Diop M. 2003. Application of daily rainfall principal component analysis to the assessment of the rainy season characteristics in Senegal. *Climate Research* **23**: 159–169.

Charney JG, Stone PH, Quirk WJ. 1975. Drought in the Sahara: a biogeophysical feedback mechanism. *Science* **187**: 434–435.

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon WT, Laprise R, Magana Rueda V, Mearns L, Menendez CG, Raïsaïnen J, Rinke A, Sarr A, Whetton P. 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Climate Change 2007: The Physical Science Basis*. Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA.

Coulibaly H. 2007. Impact du changement climatique sur les besoins en eau du riz irrigué dans la vallée du fleuve Sénégal, Mémoire de fin d'études pour l'obtention du Diplómes d'ingénieur en agrométéorologie. Centre Régional Agrhymet, Niamey, Niger, 66.

Cook K. 2008. Climate science: the mysteries of Sahel droughts. *Nature Geoscience* **1**: 647–648.

Diedhiou A, Mahfouf JF. 1996. Comparative influence of land and sea surfaces on the Sahelian drought: a numerical study. *Annales Geophysicae* **14**: 115–130.

Diouf M, Nonguierma A, Abou A, Royer A, Somé B. 2000. Lutte contre la sécheresse au Sahel: acquis et perspective au Centre Régional Agrhymet. *Sécheresse* **11**: 257–266.

Dodd D, Jolliffe IT. 2001. Early detection of the start of the wet season in semiarid tropical climates of western Africa. *International Journal of Climatology* **21**: 1251–126.

Douville H. 2002. Influence of soil moisture on the Asian and African monsoons. Part II: interannual variability. *Journal of Climate* **15**: 701–719.

ECOWAS-SWAC/OECD/CILSS. 2008. Climate and Climate Change. The Atlas on Regional Integration in West Africa. Environment Series. January 2008. http://www.atlas-westafrica.org

Gachon P, Gauthier N, Bokoye AI, Parishkura D, Cotnoir A, Tramblay Y, Vigeant G. 2007. Working Group II: variability, extremes and climate change in the Sahel: from observation to modelling, Report on Canadian Contributions to the CIDA–CILSS Project (A030978-002) Climate Change Adaptation Capacity Support, 220.

Giannini A, Saravanan R, Chang P. 2003. Oceanic forcing of Sahel rainfall on interannual and interdecadal time scales'. *Science* **302**: 1027–1030.

Gornall J, Betts R, Burke E, Clark R, Camp J, Willett K, Wiltshire A. 2010. Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transactions of the Royal Society* **365**: 2973–2989.

IPCC. 2007. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press: Cambridge, UK; 976.

Kunstmann H, Jung G. 2003. In *Water Resources Systems – Water Availability and Global Change*. Franks S, *et al*. (eds). IAHS Publication 280: 149–159.

Laux P, Kunstmann H, Bárdossy A. 2008. Predicting the regional onset of the rainy season in West Africa. *International Journal of Climatology* **28**: 329–342.

Le Barbé L, Lebel T. 1997. Rainfall climatology of the HAPEX-Sahel region during the years 1950–1990. *Journal of Hydrology* **43**: 188–189.

Mati BM. 2011. Agricultural water management: a strategy for climate change adaptation in Africa, AICAD-WBI Regional Training of Trainers: Climate Change and Sustainable Land-Water Management, February 22–25, 2011, Nairobi, 5.

McLeod NH. 1976. Dust in the Sahel: cause of drought? The Politics of Natural Disaster, sous la dir, de Michael Glantz. Praeger Publishers: New York; 3–13.

Mertz O, Mbow C, Reenberg A, Genesio L, Lambin EF, D'haen S, Zorom M, Rasmussen K, Diallo D, Barbier B, ahim Bouzou Moussa IB, Diouf A, Nielsen JO, Sandholt I. 2011. Adaptation strategies and climate vulnerability in the Sudano-Sahelian region of West Africa. *Atmospheric Science Letters* **12**: 104–108.

Mohamed BN, Duivenbooden V, Aboussalam S. 2002. Impact of climate change on agricultural production in the Sahel-Part 1. Methodological approach and case study for millet in Niger'. *Climate Change* **54**: 327–348.

Nicholson S, Selato J. 2000. The influence of la Niña on African rainfall. *International Journal of Climatology* **20**: 1761–1776.

Nicholson SE. 2001. Climatic and environmental change in Africa during the last two centuries. *Climate Research* **17**: 123–144.

Olsson L, Eklundhb L, Ardo J. 2005. A recent greening of the Sahel trends, patterns and potential causes. *Journal of Arid Environments* **63**: 556–566.

Redelsperger JL, Thorncroft C, Diedhiou A, Lebel T, Parker DJ, Polcher J. 2006. African monsoon multidisciplinary analysis (AMMA): an international research project and field campaign. *Bulletin of the American Meteorological Society* **87**: 1739–1746.

Sarr B, Lona I. 2009. Les fortes pluies et les inondations enregistrées au Sahel au cours de l'hivernage 2007: variabilité et/ou changement climatique, 14 ème Colloque International SIFEE Changement climatique et évaluation Environnementale, Niamey, 29.

Sarr B, Traoré S, Salack S. 2007. Évaluation de l'incidence des changements climatiques sur les rendements des cultures céréalières en Afrique soudano-sahélienne, Conférence internationale pour la réduction de la vulnérabilité des systèmes naturels économiques et sociaux en Afrique de l'Ouest face aux changements climatiques, Ouagadougou, 27.

Sivakumar MVK. 1988. Predicting rainy season potential from the onset of rains in southern sahelian and sudanian climatic zones of West Africa. *Agricultural and Forest Meteorology* **42**: 295–305.

Thornton PK, Jones PG, Owiyo TM, Kruska RL, Herero M, Kristjanson P, Notenbaert A, Bekele N. 2006. Mapping Climate Vulnerability and Poverty in Africa, Report to the Department for International Development, ILRI, Nairobi, 200.

Traoré SB, Reyniers FN, Vaksmann M, Kouressy M, Yattara K, Yoroté A, Sidibé A, Koné B. 2000. Adaptation à la sécheresse des écotypes locaux de sorgho du Mali. *Sécheresse* **11**: 227–237.

UNFCCC. 2008. National Communications from non-Annex I Parties. http://unfccc.int/national reports/non-annex i natcom/submitted natcom/items/653.php

Van de Giesen N, Liebe J, Jung G. 2010. Adapting to climate change in the Volta Basin, West Africa. *Current science* **8**: 1033–1037.

Xue Y, Shukla J. 1993. The influence of land surface properties on Sahel climate. Part I: desertification. *Journal of Climate* **6**: 2232–2245.

Zheng X, Eltahir AB. 1998. The role of vegetation in the dynamics of West African monsoons. *Journal of Climate* **11**: 2078–2096.

