Acknowledgement
This review was undertaken under the auspices of the AfricaInteract project funded by the International Development Research Centre (IDRC).

About AfricaInteract: AfricaInteract is a platform enabling research-to-policy dialogue for adaptation to climate change among a broad range of African stakeholders in sub-Saharan Africa. These include civil society, researchers, policy-makers, donors, and the private sector working on adaptation to climate change in the agriculture and health sectors as well as urban areas with water and gender as cross cutting issues. The overall objective of AfricaInteract is to develop a platform for the effective and efficient transfer of information to policy makers, with the ultimate aim of enhancing the resilience of vulnerable populations. AfricaInteract is funded by the International Development Research Centre (IDRC) and coordinated by the West and Central African Council for Agricultural Research and Development (CORAF/WECARD) under the auspices of the Forum for Agricultural Research in Africa (FARA). The regional focus of AfricaInteract is based on the Regional Economic Communities in the four sub regions of sub-Saharan Africa. Focal organizations coordinating regional activities are as follows: The Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) – East Africa; Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN) – Southern Africa; Commission des Forets d'Afrique Centrale (COMIFAC) – Central Africa; and Energie-Environnement et Developpment (Enda) – West Africa.

About CORAF/WECARD: The West and Central African Council for Agricultural Research and Development (CORAF/WECARD) is a constituent of the Forum for Agricultural Research in Africa, and comprising 22 National Agricultural Research Systems in West and Central Africa. CORAF/WECARD's mission is "Sustainable improvements to the competitiveness, productivity and markets of the agricultural system in West and Central Africa by meeting the key demands of the sub-regional research system as expressed by target groups" with strong alignment and commitment to the overall goal of the Comprehensive Africa Agriculture Development Programme of the New Partnership for Africa's Development. www.coraf.org

IMPRIMERIE SALAM - Tél : +221 33 860 23 33

AfricaInteract

Enabling research-to-policy dialogue for adaptation to climate change in Africa

Research and Policies for Climate Change Adaptation in West Africa Agriculture SUMMARY

Edward R. Rhodes,
Abdulai Jalloh,
Aliou Diouf

Edward R. Rhodes[1], Abdulai Jalloh[2], Aliou Diouf[3]

[1]**Agricultural Development Consultant and Chairman of the Sierra Leone Agricultural Research Institute**

[2]**Programme Manager**
Natural Resources Management Programme
Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles/West and Central African Council for Agricultural Research and Development (CORAF/WECARD),
7 Avenue Bourguiba, BP 48, cp 18523 Dakar, Senegal
[3]**Programme Officer**
Climate change, Natural resource management, Rural and urban développement
Enda Energie-Environnement-Développement, 54 rue Carnot, BP 3370 Dakar, Sénégal

Acronyms and Abbreviations

ACMAD	African Centre of Meteorological Application for Development
AGRHYMET	Agro-Hydro-Meteorology
APSIM	Agricultural Production System Simulator
CA	Conservation Agriculture
CBO	Community Based Organisation
CILSS	Comité permanent Inter-État de Lutte contre la Sécheresse au Sahel
CIMMYT	International Maize and Wheat Improvement Center
CORAF/WECARD	Council for Agricultural Research and Development in West and Central Africa
CSRP	Subregional Commission for West Africa
DFID	Department for International Development
ECOWAP	Regional Agricultural Policy for West Africa
ECOWAS	Economic Community of West African States
ENDA-TM	Environnement et Développement du Tiers-Monde
FAO	Food and Agriculture Organization of the United Nations
FARA	Forum for Agricultural Research in Africa
GDP	Gross Domestic Product
GIZ	Gesellschaft für Internationale Zusammenarbeit
GEF	Global Environment Facility
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDRC	International Development Research Centre
IITA	International Institute of Tropical Agriculture

ILRI	International Livestock Research Institute
ISFM	Integrated Soil Fertility Management
IWMI	International Water Management Institute
LGP	Length of Growing Period
NAPA	National Adaptation Programme of Action
NARES	National Agricultural Research and Extension System
NGO	Non-Governmental Organisation
ROPPA	Network of Farmers and Agricultural Producers Organizations of West Africa
SSA	Sub-Saharan Africa
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WAEMU	West African Economic and Monetary Union

Table of Contents

1. Introduction

Climate change has continued to threaten agricultural production and productivity in Africa. Vulnerability of African countries to the impact of climate change continues to increase, making Africa one of the most exposed regions in the world to climate change (Boko et al. 2007). Although evidence confirms the occurrence of climate change, there is uncertainty regarding the impacts of climate change on , nations, communities and sectors. This uncertainty renders policy formulation difficult and underscores the need for Africa to build its knowledge base to strengthen the capacity of regional and national institutions to develop the evidence base for addressing climate change adaptation issues.

With support from the International Development Research Centre (IDRC), AfricaInteract and CORAF/ WECARD commissioned a desk review of research and policies related to climate change adaptation in the West Africa agricultural sector. . This review was designed to provide the knowledge base and to support research-based policy formulation for climate change adaptation in the agricultural sector in West Africa.

In conducting this review; answers were sought to the following questions:

1. What is the role of climate change challenges in the context of the multiple challenges and opportunities facing the agriculture sector in the region?
2. What is the current state of knowledge on adaptation to climate change in the agricultural sector in the region?
3. What is the current state of knowledge on whether and how research findings are integrated in agriculture sector policies in the region?
4. What are the major gaps in research on adaptation to climate change in the agricultural sector?
5. What is needed to ensure that research findings are better integrated into agriculture sector policies?
6. What is the current state of knowledge on the stakeholders involved with research and policy on adaptation to climate change in the agricultural sector in the region, and how could stakeholder involvement be improved?

This publication is a summary of the main report published by CORAF/WECARD and Future Agricultures.

Definition of Key Concepts

***Vulnerability*:** Vulnerability is the degree to which a system is susceptible to, and unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity (IPCC 2007a).

***Adaptation to Climate Change*:** According to IPCC (2007a), adaptation comprises initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.

***Coping Strategies*:** Coping strategies are ex-post reactions to the occurrence of a risk event adopted to survive the impacts of a disaster (CGIAR 2009). They are typically immediate short term responses which may break down under extreme stresses.

Resilience: Resilience is defined as the ability of a social or ecological system to absorb disturbance, caused by climate change while retaining the same basic structure and ways of functioning, the capacity for self-organisation and the capacity to adapt to stress and change (IPCC 2007a).

Climate Smart Agriculture**:** Climate Smart Agriculture is defined as agriculture that sustainably increases productivity, resilience (adaptation), reduces /removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals (FAO 2010). The concept encompasses improved practices along agricultural value chains, appropriate institutions and policy, adequate financing and investment.

2. Overview of the West Africa Agriculture Sector

West African countries are geographically grouped into Sahelian and Gulf of Guinea or Coastal agro ecological zones. Climate change may lead to changes in agro ecological zonation, and options for adaptation to climate change vary by zone (Adebayo et al. 2011). The dominant farming systems are smallholder rain fed annual and perennial crop farming, livestock rearing and fisheries. Livestock systems are agro-pastoral, pastoral and crop-livestock (Thornton et al. 2007). Nomadic pastoralists and semi-nomadic pastoralists are referred to as transhumance pastoralists (Bare 2011). The fisheries sector consists of marine fisheries, inland freshwater fisheries and inland aquaculture.

2.1 Key Development Indicators and Trends

According to the World Bank (2011a), the population of West Africa in 2009 was 306 million and is growing at an average rate of 2.65 percent (range of 1.4 percent (Cape Verde) to 4.2 percent (Liberia). Population density is variable from a low 9 persons/km^2 in Chad to a high 171 persons/km^2 in Gambia. Life expectancy is low, averaging 55 years, while infant mortality is high at 133 per 1,000 births. Male literacy ranges from 51 percent in Guinea to 90 percent in Cape Verde, averaging 63 percent.

Average GDP growth for West Africa was negative in 1980 and 1990, but since 2003 it has been positive, ranging from 3.0 percent to 5.9 percent but dropping back to 3.0 percent in 2009. Between 2000 and 2009, GDP growth averaged 4.6 percent. Total real GDP rose from US$54bn in 1980 to US$131bn in 2009; average real GDP rose from US$3.9bn in 1980 to $8.2bn in 2009.

In West Africa, the contribution of agriculture to GDP averaged 37 percent in 1980 and 25 percent in 2009.

2.2 Key Characteristics of the Climate

In the West Africa region, average annual rainfall range from 250-550mm with a length of growing period (LGP) of 60-90 days in the semi arid zone (Sahel); to 1,500–4,000mm, LGP of 270-365 days in the coastal humid zone (Jalloh et al.; 2013; 2011a; 2011b). Seasonal characteristics of monsoon rainfall, seasonal rainfall amount and the intra-seasonal distribution show high inter-annual variability. Sunshine is uniformly high, especially in the semi arid and arid zones (2,500-3,000 hours per annum). Temperatures are high with mean annual temperature above 18^{o}C; within 10 degrees north and south of the equator mean annual temperature is about 26^{o}C with a range of $1.7\text{-}2.8^{o}$C, the diurnal range being $5.5\text{-}8.5^{o}$C. Between latitude 10^{o}N and the southern parts of the Sahara, mean monthly temperature can rise up to 30^{o}C. Maximum temperatures range from $30\text{-}33^{o}$C in countries along the coast to $36\text{-}39^{o}$C in the Sahel.

3. Scientific Evidence for Implications of Climate Change for Agriculture

3.1 Crop farming

Results of modelling have been reported for millet, sorghum, maize, rice, groundnut, beans, cassava, cocoyam and cotton in West Africa (see Jalloh et al. 2013; Nelson et al. 2010; Sarr et al. 2007; Sagoe 2006; Huq and Reid 2005). Roudier et al. (2011), showed a wide spread of yield changes ranging from -50 percent to +90 percent, for West Africa. The predicted climate change impact is larger in the northern Sudano-Sahelian countries (-18 percent) than in the southern Guinea countries (-13 percent) and the negative impacts on crop productivity increase in severity as warming intensifies. Besides temperature and rainfall, increases in the concentration of carbon dioxide in the atmosphere as a result of climate change may directly impact upon yield levels of certain crops.

Apart from crop yields, impacts of climate change have been assessed in terms of crop revenues and length of growing periods. Kurukulasuriya and Mendelsohn (2008) estimated a multinomial logit to predict the probability of agro ecological zones. Reductions in crop revenue reported in West Africa were between US$9.2bn (-17 percent) and US$17.4bn (-32 percent) for the Parallel Climate model (PCM) and the Canadian Climate Centre model (CCC) respectively by 2100. Jones and Thornton (2009) studied arid and semi arid zones of sub-Saharan Africa including West Africa and found that under scenarios in which the emission of carbon is high, the number of reliable growing days (RGD) would drop below 90 days for several hectares of marginalised land. For a low emission scenario, the acreage would reduce by 50 percent. The significance of the finding is that if RGD drops below 90, rainfall may be so inadequate that maize cultivation will not be possible and cultivation of millet will be difficult.

Options for Strengthening Adaptive Capacity and Supporting Crop Farming

Research and development practitioners have advocated the use of available adaptation options which are consistent with the aspirations of National Adaptation Programmes of Action (NAPAs) to improve the response of farmers to climate change and variability to support crop farming (Farauta et al. 2012; Adesina and Odekunle 2011; World Bank 2011b; Below et al 2010; Ngigi 2009; Woodfine 2009; Harrington et al. 2008; Howden et al. 2007; Sagoe 2006). Strengthening capacity of farmers involves making adaptation options available and accessible to them as well as providing training and extension services and access to credit (Zorom et al. 2013) and markets.

Improved Varieties Tolerant to Climate Change Stresses

Plant breeders at AfricaRice, the Africa Rice Centre, have identified, in rice breeding materials, including the indigenous African rice *Oryzae glaberrima*, several traits that contribute to drought tolerance. Molecular markers are used to tag genes that contribute to drought tolerance to speed up development of drought tolerant lines. Gene pools of wild or weedy rice species *O. barthii* and *O. longistamata* are also being exploited (Manneh et al. 2007). In West Africa, the International Maize and Wheat Improvement Center (CIMMYT) and the International Institute of Tropical Agriculture (IITA) have released new maize hybrids and open pollinated maize varieties which are drought tolerant and produce 20-50 percent higher yields than other maize varieties under drought conditions (CGIAR 2010; CIMMYT 2008).

Adjustment of Planting Date and Cropping Systems

Mathematical modelling of daily maximum and minimum temperatures for selecting the best planting dates resulted in minimising the total irrigation water requirements for maize in a conditions of water shortage and competing uses (Kra and Ofosu-Anim, 2010). Researchers showed that up to 96 percent more irrigated area could be brought under irrigation without additional irrigation water through optimum planting date selection in the coastal savannah zone of Ghana. In another modelling study involving Ghana, Burkina Faso, Niger and Senegal, date of planting together with crop sequence was found to be a climate change adaptation strategy.

Crop Residue Management

Smallholder farmers in West Africa usually dispose of crop residues by burning, thereby releasing CO_2 into the atmosphere. Numerous reviews (for example Schlecht et al. 2006; Bationo and Buerkert 2001; Bationo et al. 1996) point out the benefits of crop residue restitution to soil organic matter content, water holding capacity and agricultural productivity in West Africa. The practice is therefore considered climate smart.

Integrated Soil Fertility Management

Integrated Soil Fertility Management (ISFM) stipulates the judicious combination of organic materials (animal manures, crop residues, green manures or composts) with mineral fertilisers and use of N-fixing legumes to improve fertiliser use efficiency and soil and crop productivity (Vanlauwe 2004). For swamp rice cultivation, improving fertiliser efficiency by reducing losses of N_2O gas to the atmosphere is climate smart. The International Center for Soil Fertility and Agricultural Development (IFDC) demonstrated improved N fertiliser efficiency and increased rice yields from deep placement of urea in West Africa. .

Soil and Water Management

Good soil and water management are prerequisites for efficient use of water, especially in situations of declining rainfall in the Sahel and semi-arid zones (Ngigi 2009), and thus these are invaluable in combating the effects of climate change. Technologies for efficient soil and water management including provision of soil cover, minimum or no tillage, rainwater harvesting and irrigation have been developed.

Agroforestry

The use of trees and shrubs in agroforestry systems helps to tackle the triple challenge of achieving food security, mitigating climate change and increasing the adaptability of agricultural systems (Torquebiau 2013; FAO 2010). Research on climate change in agro forestry systems in West Africa has focused attention on carbon sequestration potential and effect on soil fertility (Asare et al. 2008; Takimoto et al. 2008; Woomer et al. 2004). Thus carbon sequestration by traditional agricultural parklands in Senegal was estimated at only 0.4t/ha/yr with a potential of 20t/ha in 50 years (Tschakert 2004); this finding led to the conclusion that in the West African Sahel, agroforestry seems more valuable for climate change adaptation than for mitigation (Torquebiau 2013). In Mali, Takimoto et al. (2008) reported that the potential to sequester carbon in traditional agricultural parklands was greater than in live fences and fodder banks. In coastal zone countries, it was shown in Ghana that traditional shaded cocoa stored 155t/ha compared to 72t/ha for unshaded intensive cocoa (Asare et al. 2008). The productivity of the cocoa was higher in unshaded farms than shaded farms, indicating a trade-off between cocoa productivity and carbon stocks.

Biotechnology

Genetically modified organisms (GMOs) constitute a technological option for adaptation to climate change through improved effectiveness of insect pest management (Howden et al. 2007). ECOWAS,WAEMU and CILLS are harmonising regional biosafety regulations (Knight and Sylla 2011) while Burkina Faso, Mali, Ghana and Nigeria have enacted legislation allowing field trials of GM products.

Reducing Post Harvest Losses, Improving Marketing and Value Addition

In Sierra Leone in the hot humid coastal zone, research (Government of Sierra Leone 2004) has shown a range of crop losses depending upon the climate adaptation actions : 20 percent for rice and 40-50 percent for fruits and vegetables. Recovery rate is 40-50 percent of oil from palm bunches and 40 percent for green coffee beans by traditional methods. Technology is available to substantially reduce these losses, for example rapid drying after harvest to moisture content of 14 percent or less, use of mechanical rice and coffee hullers and oil palm mills**.** The predicted temperature rise from climate change will increase post harvest losses of annual crops, and thereby vulnerability of farmers to climate change, if corrective measures are not taken.

Weather Forecasting and Early Warning Systems

Modelling studies have provided better understanding of the utility of weather forecasts to smallholders. Seasonal forecasts improved farmers' situation in bad years and farmers benefited from improved incomes. . The IDRC/DFID programme showed through PAR how weather forecasting, taking into account indigenous knowledge can be successfully used to strengthen farmers' adaptive capacity to climate change (CCAA 2012).

Insurance

Index based insurance (which correlates strongly with farmers' production outcomes) can serve as a buffer against climate extremes (Ngigi 2009). Muamba and Ulimwengu (2010) studied the viability of rainfall insurance for maize producers through a mathematical programming approach in 12 districts in the northern region of Ghana. They concluded that rainfall insurance may not be applicable in all districts but may be satisfactory in districts that exhibit a positive correlation coefficient between maize yield loss and indemnity payments; and that rainfall may not be an ideal index for losses. Some smallholder farmers in Ghana have been able to insure their crops against climatic risk through the Ghana Agricultural Insurance Programme (GAIP).

3.2 Livestock Raising in a Multi-Stressor Context

Climate change is likely to have major impacts on poor livestock keepers in SSA and on the natural resources on which they depend. Impacts on the arid-semi arid livestock system (LGA) for all but two West African countries are predicted to be strong. In general, impacts of climate change for livestock raising include changes in the productivity of forage, reduced water availability, land use, species composition, quality of plant feed material, changing severity and distribution of livestock diseases and changes in the marketing and prices of livestock products (IUCN 2010; Thornton et al. 2007).

Water and Feeds, Changes in Primary Productivity and Species Composition

Livestock demand for water increases as temperature increases. For *Bos indicus* water intake increases from about 3kg per kg dry matter intake at 10^{o}C ambient temperature to 5kg at 30^{o}C and to about 10kg at 35^{o}C (NRC 1981, Thornton et al. 2007). The effect of climate change on livestock production is generally expressed through changes in feed resources, which could influence feeding options, grazing management, prices of stover and grain, cost of feeds and overall livestock productivity.

Livestock Health

Climate change impacts on vector borne diseases, for example predictions of climate and population change on tsetse fly density indicates that tsetse populations and animal trypanosomiasis will decrease in the semi arid and sub humid zones of West Africa. In addition to vector borne diseases, helminth infections of small ruminants will be influenced by changes in temperatures and humidity.

Genetic Improvement and Tolerance to Stress

Genetic improvement of livestock is an important technological option for adaptation to climate change and other stresses. The West African Dwarf sheep is robust and has strong sexual vigour that enables it to withstand the stress of climate, disease and irregular feeding and has different coat colours. In Nigeria, Fadare et al. (2012) studied the effect of coat colour on heat stress, using physiologic indicators and blood parameters and showed that selection of white coloured sheep to control heat stress is desirable.

3.3 Vulnerability and Adaptation of Pastoral Systems

Restriction of transhumance, loss of access to key resources and sedentarisation policies leading to land degradation are the stresses pastoralists have to contend with apart from climate change. Impacts of climate change and variability on agro-pastoral and pastoral systems in Niger, assessed through farm surveys, reveal that increased labour emigration, increased dependence of households on remittance from labour migrants, increased ownership of livestock by non-livestock specialists. It also increased need to supplement livestock feed and reduced livestock mobility were the major effects over the past two decades (CGIAR 2009).

3.4 Vulnerability and Adaptation of Fisheries and Aquaculture Systems

Projected climate change, population and market changes acting together cause major declines in fish stocks in West Africa, if adaptation measures are not undertaken (Warren et al. 2006, cited in IPCC 2007; Allison et al. 2005; ECF/PIK 2004). Lam et al. (2012) used models to estimate that total landings of 14 West African countries will drop by about 8 eight percent and 26 percent from 2000-2050 for a low and high greenhouse gas emission scenario respectively. In addition, the study indicated that the Exclusive Economic Zones (EEZs) of Ghana, Côte d'Ivoire, Liberia, Togo, Nigeria and Sierra Leone will experience over 50 percent reductions in landings under a high emission scenario. The total landed value was estimated to drop from US$732m to US$577m between 2000 and 2050 for the high emission scenario.

Aquaculture

Omitoyin and Tosan (2012) found that the proportion of artisanal fisherfolk involved in aquaculture in Lagos State is increasing as a form of climate change adaptation (diversification), because of the dwindling size and diversity of fish catch from open waters resulting from climate change. ,

Studies on the breeding of Tilapia (Eknath et. 2007) and the stocking density of Tilapia and the African catfish in Côte d'Ivoire (Coulibaly et al. 2007; Ouattara et al. 2003) suggested that aquaculture fish improvement and management can serve as adaptation strategies to climate change and variability. WorldFish has developed an improved variety (Akosombo) of the Nile Tilapia that grows 30 percent faster than non-improved varieties and is now boosting productivity in West Africa (Spore 2013a). WorldFish is also working with partners in SSA to refine integrated aquaculture-agriculture technologies and cycling of nutrients on farms; this work has relevance to West Africa and is climate smart.

Insurance

Insurance in the aquaculture sector in West Africa is poorly developed and insurance is being advocated as a risk management strategy to combat climate change. A case study conducted in the Ondo and Ekitii states of southern Nigeria found that only 8.3 percent of fish farmers were insured by private companies. Only 33.5 percent of those insured were compensated by insurance companies after the incidence of floods, and the compensations were delayed. Only 12.8 percent received financial aid from the government after a flood (Adebo and Ayelari 2011).

4. Sector Policies for Climate Change Adaptation in West Africa Agriculture

4.1 Climate Change Considerations in Continental and Regional Agriculture Sector Policies

NEPAD's Comprehensive Africa Agriculture Development Programme (CAADP), lists the '*vagaries of climate and consequent risks'* as one of six challenges to achieving a productive agriculture. 'Land and water management', which is very important for adapting to climate change, is a Pillar of CAADP. In addition, the environmental initiative of NEPAD prioritises climate change as one of 10 programmatic areas. Africa Union's concern for climate change is also elaborated in its policy framework for pastoralism in Africa (AU 2010).

The ECOWAS Regional Agricultural Policy for West Africa (ECOWAP) and the Offensive for Food Production and Against Hunger (ECOWAS 2005) are the framework of reference that provide the principles and objectives assigned to the agricultural sector and to guide interventions in agricultural development in West Africa. ECOWAP recognises that deterioration of climate characterised by reduced rainfall and high temperatures and flooding, are important challenges for West Africa's agriculture to increase productivity while protecting the natural resources base and boosting production systems resilient to climate change.

4.2 Agriculture Considerations in Regional and National Climate Change Policies

In 2010, ECOWAS adopted a Regional Action Program to Reduce Vulnerability to Climate Change in West Africa (ECOWAS 2009a; 2009b). It was agreed at the International Conference for Reduction of Vulnerability to Climate Change of Natural, Economic and Social Systems in West Africa of 2007 held in Burkina Faso and the 2008 Ministerial Meeting on Climate Change in Benin to develop and implement a programme of action to reduce vulnerability of West Africa and Chad to climate change. CILSS, the Economic Commission for Africa (ECA) and ACMAD were mandated to develop the programme. The goal of the ECOWAS programme is to develop regional mechanism, actors and capacity to provide support to governments and communities to adapt to climate change. The low income developing countries in West Africa developed NAPAs under the guidance of UNFCCC while Nigeria, Ghana and Côte d'Ivoire developed national adaptation documents separately. Gender was strongly emphasized in the development of some NAPA of Burkina Faso.

5. Research Gaps in Climate Change Adaptation and Sector Policies in West Africa Agriculture

Studies in West Africa on adaptation research and policy reveal incomplete technical knowledge of how to adapt sustainably to climate change in agriculture and weakness in policy formulation and implementation (CGIAR 2011; Sultan et al. 2010; FAO 2010; 2008; Ngigi 2009; Thornton et al. 2007; Huq and Reid 2005). This section summarizes gaps in knowledge and deficiencies in research and policy for adaptation to climate change.

5.1 Key Research Gaps and Challenges

Crops

In West Africa, knowledge is lacking in several thematic areas such as (i) how, in response to climate change, farmers shift to different crops, affecting feeding habits, nutrition and cultural norms; (ii) conservation agriculture; (iii) adaptation at the watershed level; and (iv) on the productivity of biofuel crops in water stressed environments. Improved varieties of Jatropha are not available to be promoted as a biofuel crop in Mali and Ghana. Limited research has been conducted on climate change and tree crops/agroforestry.

Livestock/Pastoral Systems

Research gaps in adaptation research in the livestock/pastoral sectors include limited knowledge of the following: vegetative composition and biodiversity of rangeland ecosystem under changes in grazing pressure; rangeland restoration, seeding and water retention techniques; appropriate livestock species mix under changing climate based on different physiological and nutritional characteristics; changing phenotypic variation in herds and their resilience to climate change; genetic characterisation of indigenous animals; animal breeding systems for meeting the challenges of improving productive traits while maintaining adaptive traits; preservation of animal genetic diversity as a global insurance against unanticipated change; and limited tools (models) and methods to determine adaptation options which may be appropriate for various situations.

Fisheries

The key gaps in marine fisheries research include limited knowledge on fishing stocks in the EEZs, value of the stocks, decline and change in habitats. Others include quantification of scenarios combining climate to fish models and lack of knowledge on species that could adapt to new environments (Badjeck and Diop 2010). Knowledge in aquaculture is inadequate in relation to new strains of aquaculture species tolerant to lower quality water and higher levels of salinity induced by climate change and management for high productivity.

Cross Cutting Gaps

Weaknesses in understanding the wide-ranging processes underlying the performance of markets, ecosystems and human behaviour contributes to the uncertainties associated with modelling the impacts of climate change in the agricultural sector (Nelson et al. 2013). Available methods are unreliable for the predictability of the onset of the rainy season and intra-seasonal variability and how to design weather forecast applicable for smallholder situations. There is also limited knowledge on the applicability of index based insurance for smallholders. Other areas of limited knowledge are: (i) climate change adaptation through control of plant and livestock diseases; (ii) thresholds in natural systems beyond which adaptation may be very difficult

(iii) assessment of the effectiveness of adaptation options and understanding likely adoption rates, (iv) trade-offs, costs and returns of adaptation strategies; (v) effective ways of communicating climate change information and its consequences on livelihoods and the environment; (vi) women's strategic interests (access to land and credit, decision making power, etc.) in responding to climate change and variability; and (vii) relative benefits of promoting regional and global trade for crops, livestock and fisheries products.

5.2 Key Policy Gaps and Challenges

National policies in West Africa (for example - Nigeria, Ghana and Senegal) are more robust for technological practices than policies for non-technical risk management, for example trade. International trade is expected to play a critical role in climate change adaptation but there is poor understanding of how all of these will play out and the nature of appropriate policies.

One major weakness in West African countries is that climate change and adaptation do not feature in National Agricultural Development Policies and Strategies.

There are major policy gaps in several areas including (i) strengthening climate communication and information networks to improve timely delivery of weather information, (ii) protection of dry season reserves and livestock corridors from encroachment by crop farmers, ;(iii) integration of Sahelian and coastal zone livestock markets;(iv) transboundary control of water resources; and (v) management of marine fisheries resources in the Atlantic Ocean. Other areas include;; strengthening capacity for flexible policies that continuously respond to changes; collaborative learning processes and understanding of the context in which decisions are made and the capacity of decision-makers to change; gender imbalance in access to factors of production; mainstreaming gender into all climate adaptation policies and strategies; and weak institutional capacity to generate and utilise adaptation technologies.

6. Stakeholders and Opportunities for Research Collaboration on Climate Change in West Africa Agriculture

6.1 Stakeholders

A diverse range of stakeholder organisations in West Africa collaborate in research on climate change adaptation. Stakeholders include political and economic institutions, scientific/technical/development organisations, and farmers' associations.

Political and Economic Organisations:

ECOWAS is responsible for regional integration of agricultural development initiatives and agricultural policies which are aligned to the Africa Union's NEPAD and CAADP. CILSS, with a membership of 13 West African states, is mandated to promote research on food security and desertification. CILLS has set up a website on technologies for food security and climate change adaptation and provides a portal on climate change.

River Basin Authorities

River Basin Authorities in West Africa include the Niger Basin Authority, the Lake Chad Basin Authority, the Gambia Basin Authority, the Organization of Senegal River and the Mano River Union. Their mandates include promotion of inter-state cooperation for development of the national resources of the river basins; harmonisation of national development policies relating to water resources; development of projects and programmes; reducing the vulnerability of member states to climate risk; and promotion of sub-regional security.

Scientific, Technical and Development Organisations, Civil Society and Farmers' Organisations

The National Agricultural Research and Extension Systems (NARES) in West Africa are major stakeholders for developing options to respond to climate change and other stresses. They work in partnership with CGIAR centres such as AfricaRice, IITA, and ICRISAT which have headquarters in Cote d'Ivoire, Nigeria and Niger respectively. ILRI, the World Agroforestry Centre, IWMI and the International Food Policy Research Institute (IFPRI) have a strong presence in West Africa through projects. Major research efforts of national and international research include developing improved plant materials or livestock and associated crop/livestock and soil management practices for increasing agricultural productivity and protecting natural resources. These technologies are particularly relevant in strategies for climate change adaptation.

Regional climate monitoring initiatives and early warning systems are operational in West Africa; initiatives include those of ACMAD and AGRHYMET Regional Centre. According to Niang (2007) ACMAD and AGRHYMET Regional Centre are regarded as centres of excellence in climate change related research in the West Africa.

Development partners include FAO, UNEP, UNDP, USAID, DFID, IDRC, the International Fund for Agricultural Development (IFAD), Gesellschaft für Internationale Zusammenarbeit (GIZ) and NGOs. Some development partners have produced useful guides on mainstreaming gender into policies and tools for guiding policy development on climate change adaptation (FAO 2012) and adaptation tool kits (Enda 2013). IDRC, in partnership with DFID, has funded an important programme on Climate Change Adaptation in Africa (CCAA). GEF has provided funds for the development of NAPAs and implementation of some adaptation projects. GIZ has established a West African Science Service Center on Climate Change and Adapted Land Use (WASCAL), in Burkina Faso focusing on the Guinea savannah zone.

Several NGOs in West Africa work with smallholders on improving agricultural water management which is relevant to climate change adaptation. The Network of Farmers' and Agricultural Producers' Organizations in West Africa (ROPPA), is an important stakeholder in climate change adaptation issues

6.2 Opportunities

According to Niang's (2007) opportunities for influencing policies on climate change in West Africa depend on the type of organisations. Thus, although many sub-regional organisations have links with political decision-makers, the nature of the link depends on whether they are (1) political organisations such as CILSS and WAEMU where Heads of State are the ultimate decision-makers; (2) organisations in which political decision-makers are represented at the highest levels, for example the river basin authorities; (3) organisations under government supervision such as AGRHYMET Regional Centre; and (4) independent organisations such as the NGOs.

Cost sharing opportunities in climate change adaptation matters involve national, river basin and regional organisations (Niasse 2007). These opportunities are: (1) collaboration in the establishment and use of decision support knowledge bases; (2) collaboration in the development and sustainable exploitation of trans- boundary natural resources and ecosystems; (3) identifying, promoting and disseminating appropriate climate change adaptation technologies; and (4) establishing a regional framework for consultation on climate change and impacts. The formal private sector (creditors, input suppliers, marketers) is grossly under-represented on climate change issues.

The space between researchers and technocrats (civil servants), through membership on boards of national research institutes, has not been fully exploited. CORAF/WECARD's current policy of promoting competitive grants demonstrates evidence of partnership between a range of stakeholders within countries is an opportunity for strong collaboration between climate change adaptation stakeholder organisations.

7. Conclusion and Recommendations

7.1 Conclusions

Smallholders in West Africa are highly vulnerable to climate change because of several social, economic and environmental factors. Climate change adaptation challenges for the agricultural sector are considerable, since smallholders operate in multi-stressor environments where productivity is determined by many interacting factors. Climate change has implications for population growth, water resources and demand, land resources and gender issues.

In West Africa, environmental temperatures will increase due to climate change with negative consequences for crops, livestock, pastoral and fisheries. Technological options originally designed to address issues of food security and conserve natural resources are relevant for climate change adaptation.

Critical gaps in research on climate change adaptation in the agricultural sector include: modelling scenarios, risk management on weather forecasting and communication, index based insurance, marketing and trade. Adaptation strategies are mainly short to medium term to respond to the immediate needs of resource poor farmers.

West African countries have made deliberate attempts for agricultural development policies to incorporate predicted climate change scenarios. Activities of the wide range of key stakeholders continue to promote strengthening capacity for climate change adaptation in West Africa.

7.2 Recommendations

1. Tackling climate change in the context of multi-sector challenges

A comprehensive approach involving coordination of interdisciplinary research in the crops, livestock, fisheries and forestry sectors is recommended, recognising the cross-cutting issues of water, energy and gender.

2. Improving adaptation to climate change by smallholders

Improved access by smallholders to best agricultural practices, improved credit systems, through rural banks and microcredit schemes and improved access to markets are required to promote climate change adaptation. Farmer training activities should be conducted on the options for adaptation to climate change, for example reduction of post harvest losses and value addition to agricultural produce, as well as strengthening agricultural extension services to promote climate change adaptation.

3. Filling gaps in research on adaptation to climate change

Conventional scientific research and participatory action research should be adopted in climate change adaptation research. The right balance should be maintained between research for developing short term and long term strategies. New strategic research should be conducted in the context of existing initiatives at the national, regional and in collaboration with international research organizations of the CGIR Centers.

i. Technical research on crops, livestock and fisheries

Research themes and topics on climate change adaptation should include: a).crop and animal improvement for yield and tolerance to biotic and abiotic stresses; b). effects of climate change on incidence of crop and animal pests and diseases; c). fine tuning conservation agriculture to biophysical and socioeconomic conditions for high smallholder uptake; livestock conservation of genetic diversity through gene banks; d) pasture improvement based on controlled grazing, mobility, e). fluctuating herd size and different livestock species; f). animal manure management; g). increasing quality and adding value to crops, livestock and fisheries products; h). nutritional value of processed products; i). improving efficiency of agricultural water use in the crops and livestock sectors;` j). reclamation of land degraded by salty water; k) prolonging the growing season; l). climate change and tree crops; screening and matching agroforestry species and plant populations with ecological zones and agricultural practices; and m). agroforestry and use of biochar as technologies for soil improvement and climate smart agriculture. Work on climate resilient sustainable intensification of aquaculture, including identification of suitable stocks and increasing feed efficiency should be initiated.

ii. Socioeconomics and policy research

Research is recommended on the policy process and political factors influencing (i) priorities and climate change adaptation; land use patterns ; (ii) land use regulations and mobility of pastoralists; (iii) costs and returns of adaptation options, quantity and value of fish stocks;(iv) ex ante evaluation and effectiveness of adaptation options, , (v) adoption rates and determinants of adoption; (vi) analysis of existing marketing structures to improve efficiency and to determine how regional integration of markets and global markets will be important in responding to climate change;(vii) gender considerations in adaptation to climate change and variability; and(viii) effect of knowledge of climate change and variability on achievement of national development goals in poverty reduction, food security at national and regional levels.

4. Risk management dealing with stocks, weather forecasting and insurance

Risk management should involve feasibility studies of buffer stocks, improvement in the quality of meteorological data collection and weather forecasting tools and techniques as well as early warning systems to reflect the needs of farmers; innovative insurance schemes for smallholder crop farmers, livestock keepers and fisher folk.

5. Improving policy formulation and how research findings can be better integrated into

Agricultural policies Opportunities for regional policy planning and cooperation through ECOWAS, CILSS, the River Basin Authorities and ROPPA should be exploited. ECOWAS should intensify efforts in harmonising trade policies and fostering regional and sub-regional cooperation in the fisheries sector. Coherent marine fishing policies in the region and flexible arrangements should be set up to prevent overfishing, cope with the changing and dwindling marine stocks and arrest poaching by foreign trawlers. Multi-sectoral policy formulation must be flexible, gender sensitive and address gender imbalance in access to land and credit. For successful adaptation it is necessary to progress from policy formulation to enacting legislation and enforcing laws.

6. Improving stakeholder involvement in research and policy on adaptation

Collaboration between stakeholders within countries should be strengthened through Innovation Platforms and Participatory Action Research. Scientists should work together in regional projects on climate change adaptation. The private business sector should be encouraged to participate in dialogues on climate change adaptation. Civil society, farmers' associations and journalists should be supported to link researchers with policymakers and be encouraged to participate with stakeholders in training and scenario building workshops. Donors should give higher priority to support negotiations in agriculture and climate change financing.

8. References

Adebayo, K., Dauda, T.O., Rikko, L.S., George, F.O.A., Fashola, O.S., Atungwu, J.T., ... Osuntade, O.B. (2011) *Emerging and Indigenous Technology for Climate Change Adaptation in Southwest Nigeria*, Nairobi, Kenya: African Technology Policy Studies

Adebo, G.M. and Ayelari, T.A. (2011) 'Climate Change and Vulnerability of Fish Farmers in South Western Nigeria', *African Journal of Agricultural Research,* 6(18):4230-4238

Adesina, F.A. and Odekunle, T.O. (2011) 'Climate Change and Adaptation in Nigeria: Some Background to Nigeria's Response', *III International Conference on Environmental and Agricultural Engineering*, IPCBEE Vol. 15, Singapore: IACIT Press

Adjibade, L.T. and Shokemi, O. (2003) 'Indigenous Approaches to Weather Forecasting in Asa L.G.A. Kwara State, Nigeria', *Indilinga: African Journal of Indigenous Knowledge Systems,* 2:37-44

Aduna, A.B. (2011) *Finding New Points of Influence: Building Partnership between Research and Policy Worlds in Ghana*, presented at the 3rd International Forum on Water and Food,14-17 November, Tshwane, South Africa: CGIAR Challenge Program on Water and Food, International Water Management Institute and Food and Agriculture and National Resources Policy Analysis Network

Asare, A., Wade, S.A., Ofori-Frimpong, K., Hadley, P. and Norris, K. (2008) *Carbon Storage and the Health of Cocoa Agroforestry Ecosystems in South Eastern Ghana*, presented at the Open Science Conference on Africa and Carbon cycle, 25-27 November, Accra, Ghana: The Carbo Africa Project

Associated Press (2006) *Shrinking of Lake Chad*, 14 December / http://www.globalpolicy.org/component/content/article/198/40377.html

AU (2010) Policy *Framework for Pastoralism in Africa: Securing Protecting and Improving the Lives, Livelihoods and Rights of Pastoral Communities*, Addis Ababa, Ethiopia: African Union

Badjeck, M. and Diop, N. (2010) ‘The Future is Now: How Scenarios can Help Senegalese and Mauritanian Fisheries Adapt to Climate Change’, *Nature & Faune,* 25(1):68-74

Badjeck, M., Katikiro, R.C., Flitner, M., Diop, N. and Schwerdtner, M.K. (2011) *Envisioning 2050: Climate Change, Aquaculture and Fisheries in West Africa*, Workshop Report 2011-09, 14-16 April 2010, Dakar, Senegal: WorldFish

Bare, M.I. (2011) ‘The Future of Pastoralism in the Sahel Zone of West Africa: Exploring the Causes and Consequences’, *Information, Society and Justice*, 1&2:163-184

Bationo, A. and Buerkert, A. (2001) ‘Soil Organic Carbon Management for Sustainable Land Use in Sudano-Sahelian West Africa’, *Nutrient Cycling in Agroecosystems,* 61:131-142

Bationo, A, Rhodes, E., Smaling, E.M.A. and Viscer, C. (1996) ‘Technologies for Restoring Soil Fertility’, in Mokwunye, A.U., de Jager, A. and Smaling, E.M.A. (eds), *Restoring and Maintaining the Productivity of West African Soils: Key to Sustainable Development*. Miscellaneous Fertilizer Studies No. 14, Muscle Shoals, AL: International Fertilizer Development Center, pp.61-82

Boko, M., Niang, I., Nyong, A., Vogel, C., Githero, A., Medany, M., ... Yanda, P. (2007) ‘Africa’, in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contrbution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, UK: Cambridge University Press

Brittaine, R. and Lutaladio, N. (2010) *Jatropha, a Smallholder Bioenergy Crop: The Potential for Pro-Poor Development*. Integrated Crop Management Bulletin 8-2010, Rome, Italy: Food and Agriculture Organization

CCAA (2009) ‘Stories from the Field: Putting Tested Options into Practice in Benin’, in *CCAA 2008-2009 Year in Review*, Climate Change Adaptation in Africa Programme, Ottawa, Canada and London, UK: International Development Research Centre and Department for International Development

CCDARE (2008) *Ghana National Climate Change Adaptation Strategy: Draft Report*, Climate Change and Development: Adapting by Reducing Vulnerability Programme, Nairobi, Kenya and New York, NY: United Nations Environment Programme and United Nations Development Programme

CGIAR (2008) *Alliance of CGIAR Center Best Bets to Boost Crop Yields in Sub-Saharan Africa: Current Products of the Alliance of CGIAR Centers*, Rome, Italy: CGIAR

CGIAR (2009) *IdentifyingLivestock-Based Risk Management and Options to Reduce Vulnerability to Drought in Agro-Pastoral and Pastoral Systems in East and West Africa*. Final Report, CGIAR System-Wide Livestock Programme, Nairobi, Kenya: International Livestock Research Institute

CGIAR (2010) 'Drought Hardy Maize', *CGIAR News*, November 2010, Rome, Italy: CGIAR / http://www.cgiar.org/web-archives/www-cgiar-org-enews-november2010-story_07-html/

CORAF/WECARD (2011) *Agricultural Best Bets in West and Central Africa,* Dakar, Senegal: West African Council for Agricultural Research and Development

Dieye, A.M. and Roy, D.P. (2012) 'A Study of Rural Senegalese Attitudes and Perceptions on Climate Change', Environmental Management, 50:929-941

ECOWAS (2005) *The Regional Agricultural Policy*, Abuja, Nigeria: Economic Community of West African States

ECOWAS (2008) *Environmental Policy*, Abuja, Nigeria: Economic Community of West African States

Enda (2013) *Adaptation Tool Kit: Guidebook for Researchers and Adaptation Practitioners Working with Local Communities*, Dakar, Senegal: Enda Energie-Environnement-Développement

Fadare, A.O., Peters, S.O., Adeleke, M.A., Ozoje, M.O, Yakubu, A. and Sonibare, A.O. (2012) 'Physiological and Haematological Indices Suggest Superior Heat Tolerance of White Coloured West African Dwarf Sheep in the Hot Humid Tropics', *Tropical Animal Health and Production,*

FAO (2008) Expert Meeting on Climate Change Adaptation and Mitigation, 5-7 March, Rome, Italy: Food and Agriculture Organization

FAO (2010) *Climate Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation,* Rome, Italy: Food and Agriculture Organization

FAO (2013) *Climate Smart Agriculture Sourcebook*, Rome, Italy: Food and Agriculture Organization

GEF (2012) *Burkina Faso: Integrating Climate Resilience into Agricultural and Pastoral Production for Food Security in Vulnerable Rural Areas through the Farmers Field School Approach,* Washington DC: The Global Environment Facility

Gologo, H. (2012) *Adaptation is Informing and Involving Farmers in Benin*, Ottawa, Canada: International Development Research Centre

Government of Liberia (2013) *Climate Change Adaptation in Agriculture: Capacity Needs Assessment*, Monrovia, Liberia: Ministry of Agriculture

Government of Sierra Leone (2004) Agricultural Sector Review and Agricultural Development Strategy, Freetown, Sierra Leone: Ministry of Agriculture and Food Security and Ministry of Fisheries and Marine Resources

Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M. and Meinke, H. (2007) 'Adapting Agriculture to Climate Change', *Proceedings of the National Academy of Sciences*, 104(50):19691-19696

Huq, S. and Reid, H. (2005) *Climate Change and Development: Consultation on Key Researchable Issues,* London, UK: International Institute for Environment and Development

IDS (2011) *Research to Policy for Adaptation: Linking African Researchers with Adaptation Policy Spaces*. *Final Project Report*, Brighton, UK: Institute of Development Studies

IFPRI (2006) *Regional Strategic Alternatives for Agriculture Led Growth and Poverty Reduction in West Africa. Final Draft Report*, Washington DC: International Food Policy Research Institute

IPCC (2007a) *Climate Change 2007. Synthesis Report. Contribution of Working Group I, II, III to the 4th Assessment Report to the Intergovernmental Panel on Climate Change*, Geneva, Switzerland: Intergovernmental Panel on Climate Change

IPCC (2007b) *Climate Change 2007. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the 4th Assessment Report to the Intergovernmental Panel on Climate Change*, Geneva, Switzerland: Intergovernmental Panel on Climate Change

IUCN (2010) *Building Climate Change Resilience for African Livestock in Sub-Saharan Africa,* Nairobi, Kenya: International Union for Conservation of Nature, World Initiative for Sustainable Pastoralism

Jalloh, A., Rhodes, E.R., Kollo, I., Roy-Macauley, H. and Sereme, P. (2011a) *Nature and Management of Soils of West and Central Africa: A Review to Inform Farming Systems Research and Development in the Region*, Dakar, Senegal: West and Central African Council for Agricultural Research and Development

Jalloh, A., Sarr, H., Kuiseu, J., Roy-Macauley, H. and Sereme, P. (2011b) *Review of Climate Change in West and Central Africa to Inform Farming System Research and Development in Subhumid and Semiarid Agroecologies of the Region*, Dakar, Senegal: West and Central African Council for Agricultural Research and Development

Jalloh, A., Nelson, G.C., Thomas, T.S, Zougmoure, R. and Roy-Macauley, H. (eds) (2013) *West African Agriculture and Climate Change*, Washington DC: International Food Policy Research Institute

Jallow, B.P., Barrow, M.K.A. and Leatherman, S.P. (1996) 'Vulnerability of the Coastal Zone of the Gambia to Sea Level Rise and Development of Response Strategies and Adaptation Options', *Climate Research,* 6:165-177

Jones, P. and Thornton, P.K. (2009) 'Croppers to Livestock Keepers: Livelihood Transitions to 2050 in Africa Due to Climate Change', *Environment Science and Policy,* 12:427-437

Knight, R. and Sylla, F. (2011) *2011 Francophone West Africa Biotechnology Report,* Washington DC: Global Agricultural Information Network

Kolavalli, S., Flaherty, K., Al-Hassan, R. and Baah, K.O. (2010) *Do Comprehensive Africa Agriculture Development Program (CAADP) Processes Make a Difference to Country Commitments to Develop Agriculture? The Case of Ghana*. IFPRI Discussion Paper 01006, Washington DC: International Food Policy Research Institute

Kra, E.T. and Ofosu-Anim, J. (2010) 'Modeling Maize Planting Date to Minimize Irrigation Water Requirements', *Australian Journal of Agricultural Engineering,* 1(2):66-73

Kurukulasuriya, P. and Mendelsohn, R. (2008) *How Will Climate Change Shift Agroecological Zones and Impact African Agriculture?* Policy Research Working Paper 4717, Washington DC: The World Bank

Lam, V.W.Y., Cheung, W.W.L, Swartz, W. and Sumalia, U.R. (2012) 'Climate Change Impacts on Fisheries in West Africa: Implications for Economic, Food and Nutritional Security', *African Journal of Marine Science*, 34(1):103-117

Manneh, B., Kiepe, P., Sie, M., Ndjiondjop, M., Drame, N.K., Traore, K., ... Futakuchi, K. (2007) 'Exploiting Partnerships in Research and Development to Help African Rice Farmers Cope with Climate Variability', *Journal of Semi-Arid Tropical Agricultural Research*, 4:1-24

Mapfumo, P., Nsiah-Adjei, S., Mtambanengwe, F., Chikowo, R. and Giller, K.E. (2013) 'Participatory Action Research (PAR) as an Entry Point for Supporting Climate Change Adaptation by Small Holder Farmers', *Environment and Development,* 5:6-22

Molden, D., Frenkenk, K., Barker, R., de Fraiture, C., Mati, B., Svendsen, M., ... Findlayson, M. (2007) 'Trends in Water and Agricultural Development', in *Comprehensive Assessment of Water Management in Agriculture*, Colombo, Sri Lanka: International Water Management Institute

Namara, R.E, Barry, B., Owosu, E.S. and Ogilve, A. (2011) *An Overview of the Development Challenges and Constraints of the Niger Basin and Possible Intervention Strategies*. Working Paper No. 144, Colombo, Sri Lanka: International Water Management Institute

NBA (2007) *Project Implementation Document.* Report 43582, Niamey, Niger: Niger Basin Authority

Nelson, G.C., Rosegrant, N.W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., ... You, L. (2010) *Food Security, Farming and Climate Change to 2050: Scenarios Results*, Policy Options, Washington DC: International Food Policy Research Institute

NEST (2011) *Gender and Climate Change Adaptation: Tools for Community-Level Action in Nigeria – A Tool Kit,* Nigeria Environmental Study/Action Team, Ibadan, Nigeria: Building Nigeria's Response to Climate Change

Ngigi, S.N. (2009) *Climate Change Adaptation Strategies: Water Resources Management Options for Smallholder Farming Systems in Sub-Saharan Africa,* The MDG Center for East and Southern Africa, New York, NY: The Earth Institute of Columbia University

Niang, I. (2007) *Institutional Framework in Relation to Climate Change in West and Central Africa.* Consultancy Report, Climate Change Adaptation in Africa Programme, Dakar, Senegal: Université Cheikh Anta Diop

Niasse, M. (2007) *Elements of a Regional Climate Change Adaptation Strategy based on the Risk Sharing Approach in West Africa*, Consultancy Report, Ottawa, Canada: International Development Research Centre

NRC (1981) Effect of environment on nutrient requirements of domestic animals. Subcommittee on Environmental Stress, Washington: National Research Council, National Academy Press

Omitoyin, S.A. and Tosan, F.B. (2012) 'Potential Impacts of Climate Change on Livelihood and Food Security of Artisanal Fisherfolks in Lagos State, Nigeria', *Journal of Agricultural Science,* 4(9):20-30

Roncoli, C., Ingram, K. and Kirshen, P. (2001) 'The Costs and Risks of Coping with Drought: Livelihood Impacts and Farmers Responses in Burkina Faso', *Climate Research,* 19(2):119-132

Roudier, P., Sultan, B., Quirion, P. and Berg, A. (2011) 'The Impact of Climate Change on West African Crop Yields: What Does the Recent Literature Say?', *Global Environmental Change*, 21:1073-1083

Rhodes, E.R., Bationo, A., Smaling, E.M.A. and Viscer, C. (1996) ‘Nutrient Stocks and Flows in West African Soils’, in Mokwunye, A.U., de Jager, A. and Smaling, E.M.A. (eds), *Restoring and Maintaining the Productivity of West African Soils: Key to Sustainable Development*. Miscellaneous Fertilizer Studies No. 14, Muscle Shoals, AL: International Fertilizer Development Center, pp.22-32

Sagoe, R. (2006) *Climate Change and Root Crop Production in Ghana,* Accra, Ghana: Environmental Protection Agency

Sarr, B., Traore, S. and Seyni, S. (2007) *Evaluation de l’incidence des changements climatique sur les rendments des cultures cerealieres en Afrique Soudano-Sahelienne*, Niamey, Niger: AGRHYMET Regional Centre

Schalatek, L., Nakhooda, S., Barnard, S. and Caravani, A. (2012) *Climate Finance Regional Briefing: Sub-Saharan Africa,* Berlin, Germany: Heinrich Böll Foundation

Schlecht, E., Buerkert, A., Tielkes, E. and Bationo, A. (2006) ‘A Critical Analysis of Challenges and Opportunities for Soil Fertility Restoration in Sudano-Sahelian West Africa’, *Nutrient Cycling in Agroecosystems,* 76:109-136

Shah, T., Burke, J. and Vilholth, K. (2007) Groundwater : a global assessment of water management in agriculture, Colombo: International Water Management Institute

Sultan, B., Barbier, B., Fortilus, J., Mboye, S.M. and Leclerk, G. (2010) ‘Estimating the Potential Economic Value of Seasonal Forecasts in West Africa: A Long Term Ex Ante Assessment in Senegal’, *Weather, Climate and Society,* 2:69-87

Takimoto, A., Nair, P.K.R. and Nair, V.D. (2008) ‘Carbon Stock and Sequestration Potential of Traditional and Improved Agroforestry Systems in the West African Sahel’, *Agriculture, Ecosystems and Environment,* 125:159-166

Thornton, P., Herrero, M., Freeman, A., Mwai, O., Rege, E., Jones, P. and McDermott, J. (2007) ‘Vulnerability, Climate Change and Livestock: Research Opportunities and Challenges for Poverty Alleviation’, *Journal of Semi-Arid Tropical Agricultural Research,* 4(1):1-23

Torquebiau, E. (2013) *Agroforestry and Climate Change,* FAO Webinar, 5 February 2013, CIRAD - Agricultural Research for Development

UNOWA (2007) *Urbanization and Insecurity in West Africa*. UNOWA Issue Paper, New York, NY: United Nations Office for West Africa

Urama, K.C. and Ozor, N. (2010) *Impacts of Climate Change on Water Resources in Africa: The Role of Adaptation*, Nairobi, Kenya: African Technology Policy Studies Network

Wiggins, S. and Leturque, H. (2010) *Helping Africa to Feed Itself: Promoting Agriculture to Address Poverty and Hunger*. FAC Occasional Paper 002, Brighton, UK: Future Agricultures Consortium

Woodfine, A. (2009) *Using Sustainable Land Management Practices to Adapt to and Mitigate Climate Change in Sub-Saharan Africa*. Resource Guide 1.0, Midrand, South Africa: TerrAfrica

Woomer, P.L., Tieszen, L.L., Tappan, G., Toure, A. and Sall, M. (2004) 'Land Use Change and Terrestrial Carbon Stocks in Senegal', *Journal of Arid Environments*, 59:625-642

World Bank (2010) *Economics of Adaptation to Climate Change in Ghana,* Washington DC: The World Bank