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REVIEW

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# Toward climate-smart agriculture in West Africa: a review of climate change impacts, adaptation strategies and policy developments for the livestock, fishery and crop production sectors

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**Abstract**

Many projections of the impact of climate change on the crop, livestock and fishery production sectors of African agriculture are reported in the literature. However, they may be arguably too general to understand the magnitude of impact and to inform adaptation strategies and policy development efforts that are tailored to promoting climate-smart agriculture in the West African region alone. This paper was synthesized from several scholarly literature and aimed at providing up-to-date information on climate change impacts, adaptation strategies, policies and institutional mechanisms that each agriculture subsector had put in place in dealing with climate change and its related issues in West Africa. For each subsector (crop, fishery and livestock), the current status, climate change impacts, mitigation and adaption strategies have been analyzed. In addition, we reviewed recent policy initiatives in the region that foster the development and adoption of climate-smart agricultural options to improve resilience of farming systems and livelihoods of smallholder farmers to climate change risks. From community to national and regional levels, various strategies and policies are also being taken to guide actions and investment for climate-smart agriculture in West Africa.

**Keywords:** Rural livelihood, Resilience, Food security, Climate change, Finance, Africa

## Background

West Africa remains vulnerable to episodic climate shocks (primarily drought). Food crises continue to hit the region (particularly in the dry areas), with resultant loss of lives and livelihoods, and a cycle of disaster relief that compete with long-term developments [1]. As a region that produces at least 30% of the food requirements of the African continent, increasing resilience of agricultural systems to climate change is a major developmental agenda in the quest to end hunger and reduce poverty while also mitigating greenhouse gas emissions [2]. The concept of climate-smart agriculture (CSA) dwells on this development agenda and aims at fostering the development and implementation of agriculture innovations that (1) sustainably increases agricultural productivity to support equitable increases in incomes, food security and development; (2) adapts and builds resilience to climate change from the farm to national levels; and (3) develops opportunities to reduce greenhouse gas emissions from agriculture compared with past trends [3]. Despite the potential benefits CSA could offer West Africa, it is confronted with many challenges. Notable among these is a clear understanding of

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CSA concept among farmers, policy makers and potential investors; appropriate packaging of technologies that underpin CSA practices for wider adoption by farmers; how we can manage trade-offs from the farmers' and policymakers' perspectives; marginality of agro-ecological regions in West Africa that requires research on the biophysical adaptation of CSA practices across the region; institutional arrangements to upscale CSA from the farm scale to the landscape and country levels; limited technological capabilities and human resources competence; fitting CSA into the existing policy frameworks; and the development and implementation of effective risk-sharing schemes [4].

In view of the above challenges, a major question arises: How will West Africa adapt its agriculture to the impacts of climate change and variability today and in the future? Among other factors, providing answers to this question requires starting with an understanding of various agricultural subsectors and their respective current adaptation strategies; policy developments and institutional settings may foster the adoption of sustainable agricultural systems that effectively mainstream climate change in the region. This paper therefore analyzes current and future climate change impacts, adaptation initiatives and policy developments for the livestock, fishery and crop production sectors of West Africa, with a perspective of promoting climate-smart agriculture. Together with other scholarly materials, some contents of this paper were synthesized from a working paper (WP N°118-http://hdl.handle.net/10568/67103) that served as a background document during the high-level forum of climate-smart agriculture stakeholders in West Africa, organized by the Economic Community of West African States (ECOWAS) in June 2015, Bamako, Mali.

## Livestock production sector

### Current status of livestock production in West Africa

The livestock sector remains a major contributor to rural livelihoods and the national economies of many West African nations. At least 100 million poor people including women in West Africa rely on livestock as part of their livelihood strategy [5, 6]. In the Sahelian zone, the sector accounts for about 35% of gross domestic product (GDP) and supplies about 30% of the revenue in the agriculture sector [7]. In the arid and semiarid agro-ecological zones of West Africa, livestock husbandry provides the main source of employment for the majority of the people and is by far the most important source of revenue. For both crop farmers and pastoralists, livestock serve as a productive asset to generate income, and form a key element in food security strategies in many countries of West Africa. In addition, livestock provide draft power, skins, transport and manure, and fulfill various sociocultural functions such as payment of dowry, establishment and reinforcement of relationships and source of prestige within the pastoral society [8, 9]. Livestock production in West Africa is largely associated with exploitation of natural rangelands (i.e., pastoral and agro-pastoral systems) [10]. However, livestock are also raised in mixed smallholder systems in which crop residues are increasingly becoming important as animal feed with the expansion of crop fields into marginal (grazing) lands [11].

FAO [12] revealed an increased growth rate in milk production in West Africa (from 2000 to 2010), primarily due to the fast increase in milk production in Cape Verde (8.4 percent), Mali (12.4%) and Sierra Leone (6.9%). However, the region still lags behind Northern and Southern Africa in terms of meat production (Fig. 1). Although a major contributor to the national economies of most West African countries, the sector is faced with several challenges. Technical challenges facing livestock production in the region include unfavorable policies, low and variable forage availability, poor feed quality, access to water, low productivity of indigenous breeds and degradation of rangelands. Low available forage due to low biomass production from rangelands is particularly a major problem in arid and semiarid zones in the region. Drought is another major constraint to livestock production in West Africa, particularly in the Sahelian countries [13]. Drought affects livestock production through reduced herbage production and water scarcity which often leads to high herd mortality. Besides the aforementioned, West African livestock producers are constrained by poor infrastructures for transportation, processing and marketing and weakly enforced institutional mechanisms. For example, pastoral and agro-pastoral producers in the north, who supply 60% of cattle meat, 40% of small ruminant meat and 70% of milk [7], rely on moving their cattle in search of grazing area and water every year during the Sahelian dry season to gain access to the more humid farming areas of the south. Protection of the key transhumant corridors from north to south is key for their animals to survive [7] (Fig. 2), but increasing conflicts due to more livestock competing for resources is a concern [14]. In terms of economic competitiveness, West Africa still imports animal products. Commodity chains need better infrastructure support in linking producers and traders across value chains and harmonizing the different actors of the livestock industry to foster regional trade [7]. Livestock production systems are in a transition to both a more sedentarized but possibly more intensified mode that needs proper policy support, in order to sustain the economic contributions but to adapt to changing climate conditions.

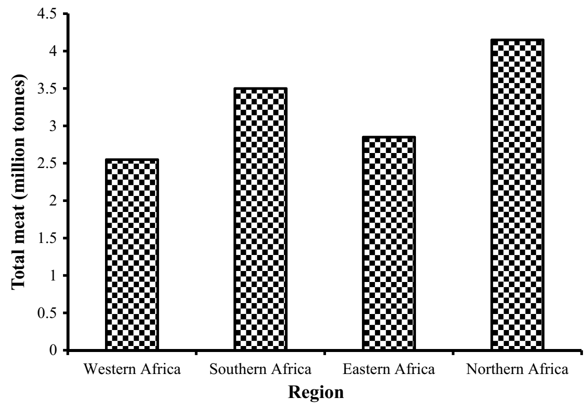


**Fig. 1** Distribution of meat in Africa in 2010. *Source*: adapted from FAO [12])

## Observed climate change impacts and projections for the livestock sector

The fifth assessment report of the IPCC reports that the vulnerability of livestock keeping communities may be amplified as climate change interacts with other stressors of the livestock sector such as rangeland degradation; increased variability in access to water; fragmentation of grazing areas; sedentarization; changes in land tenure from communal toward private ownership; in-migration of non-pastoralists into grazing areas; lack of opportunities to diversify livelihoods; conflict and political crisis; weak social safety nets; and insecure access to land and markets [15]. It is reported that the changing frequency of extreme climate conditions such as droughts and floods has had greater impacts on livestock and the associated livelihoods than average trends from climate change (that is, average change in precipitation and temperature) [16, 17]. For example, repeated occurrence of droughts in the Sahel has led to adoption of agro-pastoralism (combination of crop farming and livestock rearing within the same farm) among the pastoralists who were once solely depending on livestock for their livelihood [7]. Similarly, crop farmers have diversified in the past two decades into rearing livestock due to repeated crop failure associated with droughts [18].

Climate change is expected to affect livestock at both the species and breed levels, although this is a major research gap. Specific impacts of climate change on livestock may include changes in availability and quality of forage resources, access to water, species and breeds of livestock that can be kept, livestock mobility and animal

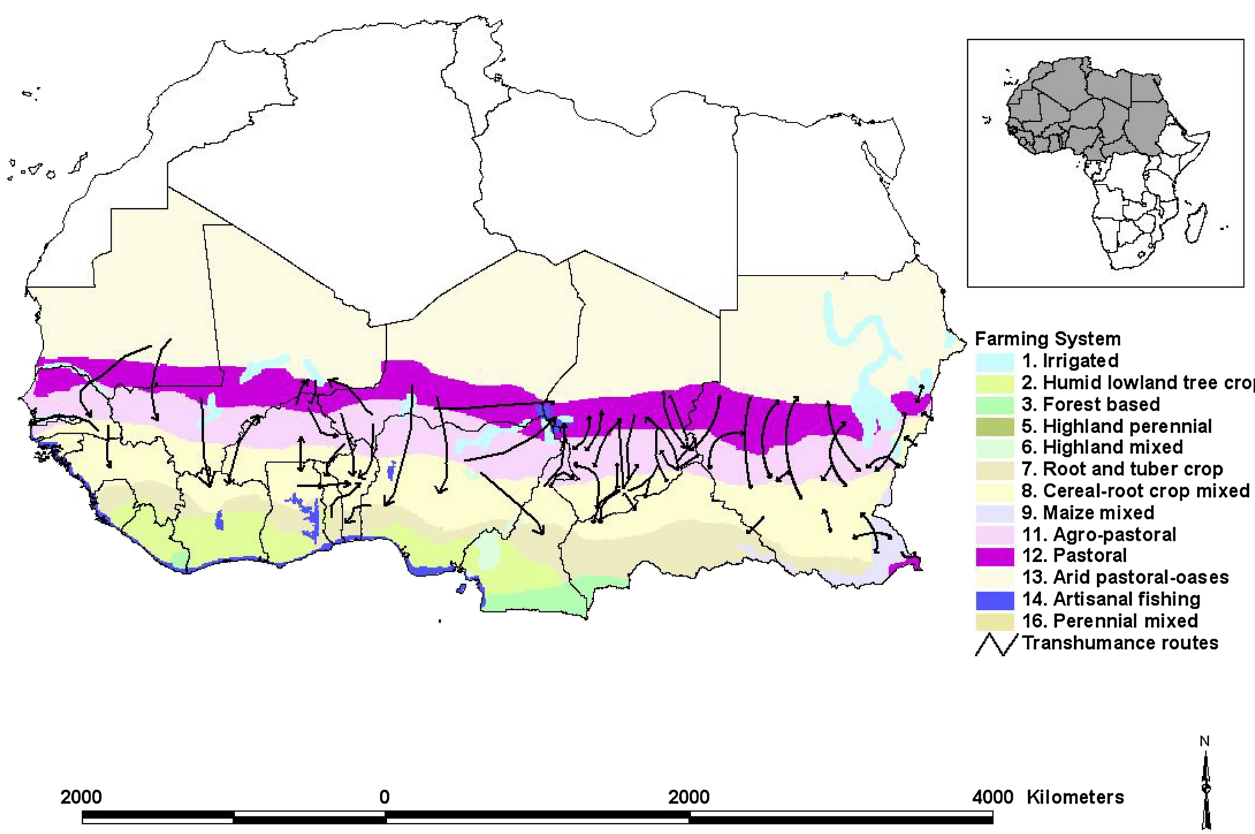


**Fig. 2** Distribution of livestock movement across different farming systems in West Africa (*Source*: Zougmore et al. [27])

diseases (emerging and re-emerging diseases) [19]. A hotter and drier climate in the arid and semiarid zones of the region may favor livestock species and breeds that thrive well under heat stress and those with less water requirements such as small ruminants (sheep and goats) and camels [20]. This is already the case in West African Sahel with the shift in livestock species from cattle before the droughts of early 1970s and 1980s to sheep and goats [21] as the latter (small ruminants) are less costly, hardier, require lower feed and reproduce faster than cattle. A hotter and drier climate in subhumid and humid zones will modify the habitat of the endemic livestock breeds which are resistant to trypanosomiasis, the major animal disease in the zones, and will consequently alter the breeds that can be kept. However, climate change impacts on forage availability and quality may include: changes in herbage growth, changes in floristic composition of vegetation, changes in herbage quality and changes in the importance of crop residues as animal feed [22]. Generally, the impacts of climate change on herbage growth will depend on the plant species as increase in future $CO_2$ levels may favor different grass species than currently, while the opposite is expected under associated temperature increases [23]. The consequences of these impacts for livestock producing households depend on the development pathway taken, such as population growth, changes in income levels, growth in regional trade and degree of technological development [22]. Meanwhile, the current low adaptive capacity is expected to make the region particularly vulnerable to climatic shocks such as drought and flood. In general, the impacts of climate change on the poor livestock keepers will be context-specific, reflecting factors such as geographic location, socioeconomic profiles, prioritization and concerns of individual households, as well as institutional and political constraints [24].

A critical challenge that will face livestock keepers particularly pastoralists is the inevitable switch from their livelihoods that are intertwined with their customs and traditions over generations. Some climate models predict growing wetness in large areas of key cattle-producing countries like Niger, Nigeria and Mali. High rainfall could make these areas inappropriate for cattle production due to increase in disease pressure. The consequences will be very grave in acquiring much needed skills in exclusively growing crops particularly those that are adapted to wet conditions which the herders have not been accustomed to. In addition to threats to their cattle, the infrastructure with regard to houses and roads is adapted to dry conditions. Persistent rainfall will pull down the characteristic mud houses and fragile roads. In the meantime, however, livestock will remain an important asset to help households manage climate risks.

### Adaptation strategies and mitigation options for the livestock production sector

In addressing climate change adaptation for livestock-based livelihoods, key questions to consider include: (1) Which types of livestock management are suited to climate change and where? (2) which animal species and breeds should be kept in which areas and what are the trade-offs? (3) which animal diseases should we focus on? (4) are there current livestock-based livelihood systems in the region that are best suited to climate change adaptation? (5) how can we add value to the existing livestock-based adaptation strategies? (6) are there policy and institutional mechanisms to enhance adaptation of livestock production systems to climate change and variability? (7) how could the capacity of rural institutions be strengthened to use appropriate tools and strategies to cope better with consequences of climate change? (8) how could we balance the need for short-term adaptation, which is often reactive, with long-term climate change adaptation planning? At community level, climate change adaptation should be considered in the context of other significant drivers of change (demographic change, economic development, market opportunities). Livestock production systems should be "climate-smart" by contributing to increasing food security, adaptation and mitigation in a sustainable way. Any livestock management practice that improves productivity or the efficient use of scarce resources can be considered climate-smart because of the potential benefits with regard to food security, even if no direct measures are taken to counter detrimental climate effects [25]. For livestock-based livelihood, adaptation options depend on the climatic risks, agro-ecological zones, the livestock production systems and the socioeconomic profiles of the household (Table 1). A community's capacity to adapt to climate change and the associated risks depends on its economic resources, geographic location, available technologies and information, infrastructures, institutions and networks [24]. Generally, poor infrastructures and weak institutions inhibit adaptive capacity and planning of a community. For most livestock keepers in West Africa, adaptation options are often not limited to livestock but a mixture of livelihood options including crop agriculture, non-agricultural activities and migration [14, 26].

Mitigation measures in the livestock sector could include technical and management options that promote reduction of greenhouse gas (GHG) emissions from livestock: efficient livestock feeding systems, balanced feed rations and efficient manure management. While improving feed resource use efficiencies would improve livestock productivity and reduce emissions per unit of product, one major challenge is finding the right behavioral incentives to encourage greater feed resource use

**Table 1 Adaptation options for livestock-based livelihoods to major climatic risks in West Africa. *Source*: Zougmore et al. [27]**

| Agro-ecological zone | Dominant livestock system | Climatic risk | Adaptation option |
|---|---|---|---|
| Arid | Pastoral<br>Agro-pastoral | Drought | Shift to small ruminants and camels<br>Livestock mobility to semiarid/subhumid zones<br>Commercial activities<br>Growing of adapted crop varieties in the "oasis"<br>Migration (local and regional) |
| Semiarid | Pastoral<br>Agro-pastoral<br>Peri-urban livestock | Drought<br>Flood<br>Bush fire | Shift to small ruminants<br>Livestock mobility to subhumid zone<br>Better integration of crop and livestock<br>Commercial activities<br>Growing of adapted crop varieties, e.g., drought-tolerant millet/sorghum<br>Fodder conservation<br>Migration (local and regional) |
| Subhumid/humid | Mixed crop livestock<br>Peri-urban livestock | Flood<br>Bush fire<br>Vector-borne diseases, e.g., ticks, trypanosomiasis | Intensification of crop-livestock production<br>Growing of cash crops, e.g., cotton<br>Fodder production and conservation<br>Use and conservation of endemic livestock breeds<br>Commercial activities<br>Moving out of agriculture to service industry |
| Coastal | Peri-urban livestock | Flood<br>Water erosion<br>Vector-borne diseases | Use and conservation of endemic livestock breeds<br>Commercial activities<br>Moving out of agriculture to service industry |

efficiency, taking advantage of a win–win opportunity. It is now well understood that while many communities are highly adaptive and community-based approaches are critical, many governments and donors worry that a more concerted effort at higher levels of action and governance are needed to move beyond the so-called incremental adaptation and bring about the transformations that will allow for systemic adaptation [27]. This is even more necessary if synergies between adaptation and mitigation are to be found and taken advantage of to promote gains on both fronts. One challenge to this is the need for better integration between agriculture and livestock ministry staff and climate change units, so that climate change issues can be integrated into ongoing development planning. Another challenge is the lack of support for pastoral production systems and the failure to recognize that these are highly adaptive systems which resist conformation to the standard "intensification" model [14, 27]. In West Africa, livestock make tremendously important contributions to economies and food security. In terms of financing flows available, agriculture in general, and livestock in particular, suffers from inherent biases in the current mitigation financing mechanism. The Clean Development Mechanism excludes agriculture by and large, and there are a few voluntary carbon markets with interest in agriculture, particularly agroforestry and livestock production. Within these schemes, however, there is a bias toward "high potential" systems such as intensive dairy, where gains could be made from improving feeding practices. More extensive grazing-based systems are considered to be too difficult institutionally to manage. In terms of adaptation financing, many countries now have National Adaptation Programs of Action (NAPAs), but often agriculture is given short attention, and often the funds get "stuck" at the national level, failing to reach the local communities [3].

## Fishery sector

### Current status of fisheries in West Africa

West African fisheries encompass a wide range of ecological and socioeconomic components. Africa has huge potential for fish farming in terms of land availability with 31% of its surface area suitable for small-scale fish farming and 13% suitable for commercial fish production. African fisheries contribute significantly to food and nutritional security of an estimated 200 million people and provide a source of income for over 10 million who are engaged in production, processing and trade [28]. The artisanal fishery sector dominates employment in the fishing industry. The fishermen that operate the artisanal fishing industry use traditional wooden boats, sometimes motorized, with a variety of gear types, including nets, lines and seines. The industrial fishing is however operated by non-African trawlers and fleets with less direct economic and employment benefits. Total number of jobs created in the sector is over 5.6 million, while total number of direct jobs is over 1.8 million [29]. Women are responsible for artisanal processing and distribution of fish to urban centers and inland. Traditional processing methods include smoking, drying, salting and curing. Industrial processing exists in some countries. In many countries, inaccessibility of cold storage facilities inhibits the growth of a value-added industry [29].

West African population is estimated to increase to 430 million by 2025, and more than half of the region's population consumes fish products on a daily basis which accounts for up to 3–5% of total GDP [30]. As at 2012, total fish production in West Africa stood at about 2.9 million metric tonnes with the largest percentage contributions from Nigeria (32), Senegal (16), Mauritania (15) and Ghana (14) (Fig. 3) [12]. Although marine fish and invertebrates exported from West Africa amounted to only US$600 million annually [24] and contributed only about 2% to the total export value from West Africa countries, the fisheries sector in the region continues to play an important role in the local economy of countries like Mauritania and Senegal which are net exporters of fish [31]. However, Smith et al. [32] revealed that the low level of exports from West Africa relative to other regions reflects access agreements between West African countries and countries in Europe and Asia. Meanwhile, aquaculture, which is the world's fastest growing food production system, growing at 7% annually is still at developing stage in West Africa. It has, however, recently received higher levels of governmental and private support [32].

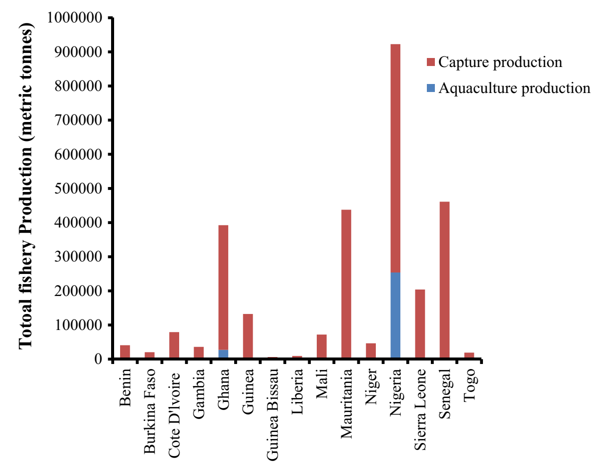


**Fig. 3** The distribution of total fishery production among some West African countries in 2012 (*Source*: adapted from FAO [12])

### Observed climate change impacts and projections for the fishery sector

Climate change is projected to impact the fisheries and aquaculture sector [33]. FAO [33] reported that the projected changes due to climate impact in West Africa coastal fisheries include changes in the composition, production and seasonality of plankton and fish populations. These projected impacts of climate change on fisheries will affect both the social and economics for fishing fleets and fishing communities. Many climate models have projected that the West Africa Inland fishery zones will be impacted by potential reduction in floodplain zones for seasonal inland fishing areas as a result of lowered precipitation. Increased demand for dam infrastructure for access to water or energy will also exacerbate the reduction in fish landings for seasonal inland fishing. Allison et al. [34] projected that in addition to precipitation and temperature changes, changes in sea level rise, land-based runoff and increasing frequency of storms and storm surges threaten coastal infrastructure, aquaculture located in riparian and coastal zones, and loss of harbors or homes. Omitoyin and Tosan [35] reported that climate change is already modifying the distribution of fish species, thus affecting habitat size, species diversity and productivity of Lagos Lagoon in Nigeria. The total landings of 14 West African countries were estimated to fall by about 8 and 26% percent from 2000 to 2050 due to low and high greenhouse gas emission scenario, respectively [31, 36]. In addition, the study indicated that the Exclusive Economic Zones (EEZs) of Ghana, Cote d'Ivoire, Liberia, Togo, Nigeria and Sierra Leone will experience up to and above 50% reductions in landings under a high emission scenario. The total landed value was estimated to drop from US$732 million to US$577 million between 2000 and 2050 for the high emission scenario [31, 36]. Associated Press [37] reported low fish catch in Lake Chad, while field observation on Lake Chad in 2012 shows that there is not only reduction of fish catch but also of total area covered by water. Rhodes et al. [36] reported that in Cote d'Ivoire, major fish species are being affected by changes in fresh water flows and greater intrusion of salt water into lagoons and lakes. Moreover, impact on aquaculture will include increasing seasonal and annual variability in rainfall leading to flooding and drought extremes. In Nigeria, Adebo and Ayelari [38] reported potential flood incidences which could wash away fish from small fish farms in Nigeria. Furthermore, Lam et al. [31] projected that climate change may lead to substantial reduction in marine fish production and decline in fish protein supply in West Africa by the 2050s under the Special Report on Emission Scenarios (SRES) A1B. Combining with economic parameters, they projected a 50% decline in fisheries-related jobs and a total annual loss of US$311 million in the whole economy of West Africa. These changes are expected to increase the vulnerability of the region (through economics and food security) to climate change [31].

### Adaptation strategies and mitigation options for the fishery production sector

Small-scale fisheries and aquaculture have contributed little to the causes of climate change but will be among the first sectors to feel its impacts. For instance, surface water resources in West Africa are concentrated in a few watershed areas in the Niger, Lake Chad, Senegal, the Gambia and the Volta [39]. Following the decrease in rainfall since the 1970s, the main rivers have witnessed a drop in their stream flows. The Niger River's (Onitsha) stream flow fell by 30% between 1971 and 1989; those of the Senegal and Gambia Rivers fell by almost 60% [39]. According to studies by McCartney et al. [40], water resources development is vital for the well-being and livelihoods of the people living in the Volta River Basin and central to the economic development of the riparian countries. There remains great uncertainty about how climate change will affect water resources of the basin. However, it is shown that anticipated reductions in rainfall, and increases in temperature and potential evapotranspiration, would affect both river flow and groundwater recharge, which in turn will impact the performance of existing and planned reservoirs and hence irrigation and hydropower schemes [40]. On average, only 75% of annual irrigation water demand is expected to be supplied by 2050 and just 52% of potential hydroelectricity will be generated. The rise in sea levels has had a direct impact on submergence and coastal erosion, an increase in flood-prone areas and an increased salinity in estuaries and coastal water tables. Mangrove swamps, which occupy large surface areas in Nigeria, Guinea, Guinea Bissau, Cameroon and Senegal, are particularly sensitive [41]. The submergence of these mangrove swamps or coastal lagoons could lead to a loss in biodiversity. The cost of adaptation could amount to at least 5–10% of GDP. Changes in coastal ecosystems will have a direct bearing on settlements and productivity. Fish stocks and coastal dwellers will have no alternative but migrate. The resultant shortage of labor in source areas and pressure on limited natural resources in destination areas could result in many undesired outcomes. In the fisheries sector, $CO_2$ emissions from harvesting and shipping of fish and fish products are estimated at 0.05 Gt year$^{-1}$ with Africa producing 3.6% of the world's $CO_2$ emissions. About three-fourth of the total emissions from agriculture and land use originate in developing countries [23]. At the scientific and technical levels, adaptation and mitigation options may include relevant research to enable fisheries and aquaculture to adapt to climate change with countries and regions streamlining on:

- reduction of GHG emissions from fishing activities by: (1) improving fuel efficiency through switching to more efficient gear types or vessels, (2) switching to sails or changing fishing practices; (3) use of bulk sea freight rather than air freight or non-bulk sea freight or (4) increasing consumption closer to the source (reducing travel distance);
- removal and storage of atmospheric carbon through coastal ecosystems management of mangroves, sea grass beds, salt marshes [42];
- use of more stable fishing vessels of all sizes to allow for fishing further away from the coastal area to follow targeted species and resist inclement weather;
- use of fish aggregating devices to lure fish back within the traditional fishing grounds;
- new diseases and preventive treatments;
- search for new and better adapted aquaculture species to confront sea level rise;
- better feeds and feeding practices that are more ecosystem friendly;
- strengthening of technology transfer mechanisms to share weather as well as market information with farmers;
- promoting insurance among fish producers and aquaculturist

## Crop production sector

### Overview of crop production in West Africa

Crop production in West Africa is mainly rainfed and remains vulnerable to climate change manifested in unpredictable rainfall patterns and high temperatures. The five leading crops by harvested area in West Africa are (in millions of hectares) millet (16.0), sorghum (14.3), cowpea (10.3), maize (7.8) and rice (5.7) [43]. Sustaining the yields of these major crops has been challenged (among other factors) by declining soil fertility [44] and expected climate change impacts. Farm sizes are usually small and involve the use of simple farm tools like hoes and cutlasses. Most farmers practice low-input agriculture with limited fertilizer and pesticide use. Diversity is the norm in West African farming systems. Even at the level of the individual farm unit, farmers typically cultivate 10 or more crops in diverse mixtures that vary across soil type, topographical position and distance from the household compound.

### Observed climate change impact and projections for the crop production sector

Many projections on West Africa's future climate prognosticate adverse impacts that are likely to lead to productivity crises unless sustainable solutions are in place. While many CMIP5 models indicate a wetter core rainfall season with a small delay to rainy season by the end of the twenty-first century [45], many authors have argued that Regional Climate Models (RCMs) can alter the sign of rainfall change of the driving four General Circulation Models (GCM), especially in regions of high or complex topography [46–48]. The IPCC estimates that crop growing periods in West Africa may shorten by an average of 20% by 2050, causing a 40% decline in cereal yields and

**Table 2 Projected changes (%) in crop yields from 2000 to 2050 owing to climate change in West Africa *Source* based on analysis in Jalloh et al. [26]**

| Water | Crop | Median | CNRM | CSIRO | ECHAM | MIROC |
|---|---|---|---|---|---|---|
| Rainfed | Groundnuts | −6.8 | −5.8 | −7.7 | −9.2 | 0.3 |
| Rainfed | Maize | −5.5 | −2.3 | −8.1 | −6.0 | −4.9 |
| Irrigated | Rice | −19.0 | −19.9 | −12.4 | −20.0 | −18.2 |
| Rainfed | Rice | 0.9 | 4.4 | 0.5 | 0.9 | 1.0 |
| Rainfed | Sorghum | −13.9 | −15.9 | −9.5 | −14.8 | −13.0 |
| Rainfed | Soybeans | −5.0 | −1.5 | −8.4 | −1.6 | −14.2 |
| Irrigated | Wheat | −21.4 | −37.8 | −10.9 | −28.5 | −14.3 |

All GCMs are from the AR4 and represent the A1B scenario

a reduction in cereal biomass for livestock [23]. This has been attributed to the expected 5% decline in rainfall and frequently long-lasting and intense droughts which is likely to increase the area of arid and semiarid land by 5–8% by 2050 [23].

However, the four climate models used by Jalloh et al. [26] all projected a rise in temperature, which is expected to hit hard in West Africa. The average rise in temperature for the four GCMs ranged from 1.5 to 2.3 °C for between 2000 and 2050, while changes in mean annual rainfall ranged from a drop of 23 mm per year to a rise of 22 mm per year. Table 2 shows the predicted change in yield of major food crops owing to climate change impacts in West Africa by 2050. The predicted yield changes in Table 2 have been based on the DSSAT crop model and the four GCM models [26, 49]. As reported in Table 2, only rainfed rice seems to show a positive response. Meanwhile, losses to wheat and irrigated rice are projected to be around 20%; sorghum, 14%; and maize, soybeans and groundnuts, between 5 and 7%. These projections have been similarly reported by Knox et al. [50] and Roudier et al. [10]. Figure 4 shows the detailed projected changes in yield of rainfed sorghum across West Africa for CSIRO, A1B and GCM models. For all the crops and GCMs analyzed, there is a band in the northern boundary of currently cultivable areas which might not be cultivated in future due to increase in temperature (Fig. 4). Some of the reductions in productivity along the southern portions of the coastal countries may be due to declining rainfall as predicted by some of the climate models. Table 3 reports the results of a different analysis which used a global partial equilibrium model of food and agriculture, called IMPACT. This model takes into account productivity changes from the crop model analyses, but includes projected technological growth [26]. As a result, there are large yield increases projected, even under climate change. Additionally, the model takes into consideration global demand for food, based on higher GDP projected for the future, and a large population. When equilibrium prices rise sufficiently, farmers intensify production, sometimes enough to increase yields under climate change above the yields of the no climate change scenario. However, Table 3 should not be read as suggesting that climate change will be generally positive for agriculture. Table 2 already shows that the direct effects of climate change on agriculture will be mostly negative. The large productivity increases in Table 3 emphasize the importance of continuing technological improvement and should suggest the value of continued and increased investment in agricultural research and extension, along with productivity-enhancing investments in irrigation, mechanization, fertilizer supply and climate-smart agriculture.

With climate change affecting crop yields and productivity, changes in the commodity price of major food crops are also inevitable. Table 4 shows the IMPACT model projections in world food prices for some major food crops in West Africa from 2010 to 2050. Median wheat price under climate change will more than triple, while without climate change, it would only increase by two-thirds of the price in 2010. This increase in the price of major food crops in the region is expected to reduce access to food among resource-poor households, a situation that will increase the incidences of malnutrition and undernourishment among children. Table 5 shows the IMPACT projections of climate change on malnutrition among children in West Africa based on two scenarios. While the reductions of numbers appear to be modest by 2050 (Table 5), with a growing population, the percentage of malnourished children might be reduced by almost half, even with climate change, due to projections in GDP and per capita growth outpacing the food price growth, especially under the optimistic economic–demographic scenario. In light of the recent comparisons between the Coupled Model Intercomparison Project (CMIP) and the Agricultural Model Intercomparison Project (AgMIP) [51], we have noted that there is much variation among climate models, crop models [51] and economic models. Scientists, unfortunately, have not been able to come to general agreement on future projections. With so many

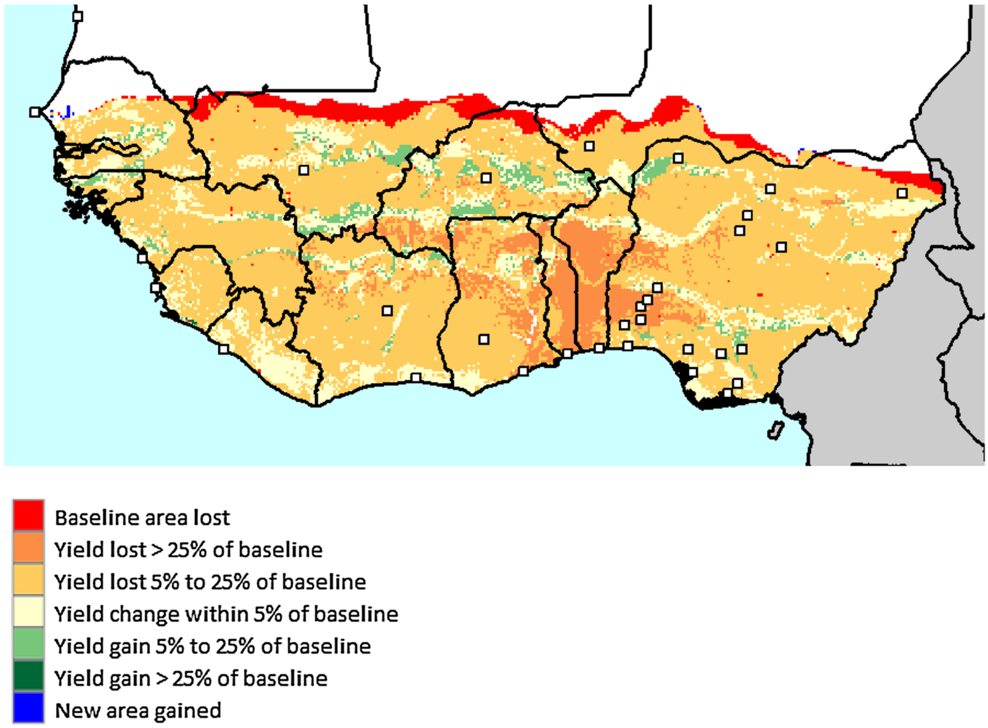


**Fig. 4** Yield changes for rainfed sorghum based on CSIRO A1B GCM for the period 2000–2050. *Source*: Jalloh et al. [26]

**Table 3 Projected changes (%) in crop productivity from 2000 to 2050 owing to climate change in West Africa based on the IMPACT model *Source* adapted from Nelson et al. [49]**

| Crop | No climate change | Median of 4 GCMs | MIROC | MIROCCSIRO | | CSIRO A1B |
|---|---|---|---|---|---|---|
| | | | | B1 | A1B | B1 |
| Cassava | 49.5 | 46.3 | 37.2 | 62.5 | 35.5 | 55.5 |
| Cotton | 90.9 | 80.8 | 76.5 | 85.2 | 71.4 | 89.1 |
| Groundnuts | 42.0 | 42.5 | 43.9 | 47.3 | 35.4 | 41.1 |
| Maize | 57.4 | 57.3 | 59.8 | 58.7 | 53.0 | 55.9 |
| Millet | 147.2 | 154.0 | 176.2 | 156.2 | 151.9 | 147.5 |
| Rice | 89.3 | 89.1 | 89.1 | 89.7 | 87.5 | 89.1 |
| Sorghum | 94.1 | 97.4 | 106.3 | 99.4 | 95.5 | 95.2 |
| Soybeans | 81.5 | 79.2 | 77.7 | 78.5 | 80.0 | 84.6 |
| Sweet potatoes and yams | 73.5 | 60.7 | 49.1 | 84.0 | 48.1 | 72.3 |

Values are for the baseline economic–demographic scenario

diverse potential outcomes, it is unwise to put all investment into overcoming a single outcome. Rather, the approach should be multipronged and should be focused on giving farmers many options.

### Adaptation strategies and mitigation options for the crop production sector

For the crop production sector, a number of CSA technologies including conservation agriculture, alternate wetting and drying approach (AWD) for rice production, agroforestry and "zaï" water conservation technology have been promoted to contribute to the development of sustainable cropping systems in the region. Important references including FAO's Climate-Smart Agriculture Sourcebook [52], and their earlier "Save and Grow" [53] publications outline a number of practices and technologies for building the resilience of crop production systems against climate change:

**Table 4 Projected changes (%) in world prices of West African food crops owing to climate change impacts from 2010 to 2050 *Source* based on analysis conducted for Nelson et al. [49]**

| Crop | No climate change | Median of 4 GCMs | MIROC A1B | MIROC B1 | CSIRO A1B | CSIRO B1 |
|---|---|---|---|---|---|---|
| Rice | 54 | 84 | 83 | 87 | 85 | 82 |
| Wheat | 66 | 202 | 121 | 106 | 99 | 93 |
| Maize | 103 | 160 | 209 | 165 | 156 | 145 |
| Sweet potatoes and yams | 60 | 130 | 141 | 96 | 156 | 120 |
| Cassava | 18 | 57 | 78 | 50 | 64 | 42 |
| Sugarcane | 77 | 110 | 125 | 113 | 108 | 103 |
| Sorghum | 82 | 107 | 115 | 104 | 110 | 104 |
| Millet | 8 | 10 | 8 | 8 | 14 | 13 |
| Groundnuts | 13 | 34 | 35 | 33 | 37 | 33 |

The price changes are from the baseline economic–demographic scenario

**Table 5 Projected number and percentage of children (under 5 years) in West Africa expected to be malnourished due to climate change effects from 2010 and 2050 based on the IMPACT model *Source* based on analysis conducted by Nelson et al. [49]**

| Scenario | 2010 | | 2050 | | | |
|---|---|---|---|---|---|---|
| | | | No climate change | | Average of max. and min. of 4 GCM–SRES scenarios | |
| | Number | Percent | Number | Percent | Number | Percent |
| Baseline | 15,157 | 31.0 | 12,415 | 20.9 | 13,913 | 23.4 |
| Optimistic | 14,733 | 30.2 | 7,615 | 15.1 | 8,949 | 17.1 |

(a) Cultivar development—in the realm of cultivar development, this would include developing varieties that withstand higher temperatures. But it would also include varieties that are resilient to drought, pest, weeds, salinity, flooding, etc. The best new varieties would be ones resilient to more than one threat considering it takes many years to develop and test new cultivars. A recent study on the economic impact of climate change on cereal crop production in Northern Ghana [54] indicated that early season precipitation was beneficial for sorghum, but harmful for maize. However, mid-season precipitation tended to promote maize production. Temperature levels for all seasons impacted negatively on net revenue for both crops, except during the mid-season, when temperature exerted a positive effect on net revenue for sorghum. Our findings suggest that appropriate adaptation strategies should be promoted to reduce the negative impacts of prevailing climate change on cereal crop production.

(b) Water management—along with cultivar development, supporting farming techniques should be developed. These might include irrigation and water harvesting. There may be benefits from shifting the focus from large-scale public irrigation to small-scale private irrigation, which may include more efficient management and distribution of water, related to the user actually bearing the costs of the water use, bypassing issues related to equitability and funding in large-scale schemes. Furthermore, one of the critical issues surrounding climate change is the variability in weather, with floods and droughts both becoming more frequent. Water conservation and supplementation are both important to develop when feasible, especially in marginal areas. For instance, research for development work to build climate-smart farming systems through integrated water storage and crop-livestock interventions has been conducted in Burkina Faso, Mali and Ghana [55]. Through this project, synergies that exist between water retention interventions (such as zaï, contour ridges, dugouts, small reservoirs) and crop-livestock interventions (such as trees and legumes, fodder production, crop residue management) have been identified to improve water availability for crops, livestock and humans throughout every year [55].

Although research studies on the economics of soil and water management on farmers' fields are still scarce, various scientific papers tend to report a cost-effectiveness of these practices. Reij and Smaling [56] estimated the costs of establishment and maintenance of zaï pits for soil water and fertility management at US$250 $ha^{-1}$ $year^{-1}$ and US$65 $ha^{-1}$ $year^{-1}$, respectively. Furthermore, Barro et al. [57] reported that manual zaï could be labor-intensive, requiring about 300 h·man $ha^{-1}$. Mechanized zaï using cattle traction has been studied on structurally degraded Lixisols in Burkina Faso [58]. Labor time was reduced to 22–36 h $ha^{-1}$ with mechanized zaï, which also increased sorghum grain yield by 34 % compared to that obtained with manual zaï. The mechanization of the zaï generated a significant benefit of up to US$300 $ha^{-1}$) with sorghum cropping. It may therefore constitute an interesting alternative for increasing the income of the smallholders besides contributing to the preservation of the environment. Fox et al. [58] found that the combination of rainwater harvesting and surface irrigation yielded a net profit of US$151 $ha^{-1}$ to US$622 $ha^{-1}$ for smallholder irrigation in Burkina Faso [59]. Zougmoré et al. [60] also reported that in the semiarid West Africa, the combination of soil and water conservation measures (stone bunds, grass strips) with application of compost resulted in financial gains of 241–300 $ha^{-1}$ $year^{-1}$ (in USD$ equivalent) under adequate rainfall condition. Without nutrient inputs, soil and water conservation (SWC) measures hardly affected sorghum yields, and without SWC, fertilizer inputs also had little effect. However, combining SWC and nutrient management caused an increase in sorghum yield.

(c) Agroforestry—integrating trees with crops can have several advantages when done properly. Trees can sometimes serve as "nutrient pumps," bringing nutrients that are too deep for crops. They can be used to enhance soil nitrogen, when nitrogen-fixing trees are planted. Their leaves can serve as mulch which might suppress some weed growth but would also help cool the soil, overcoming some of the impacts of temperature rise on crop growth. Furthermore, the litter would eventually be converted to soil organic matter (SOM), which has important properties in relation to soil nutrient retention. In Niger and the Sahel zones, an African alliance to combat desertification is improving food security, through tree planting and farmer-managed natural regeneration (FMNR). A synthesis report by Nyasimi et al. [61] and Reij et al. [56] showed that farmers have grown 200 million new trees on cultivated fields in West Africa. The natural regeneration and the improvements that it brings in soil fertility, fodder, food and fuelwood, have been valued at US$56 $ha^{-1}$ $year^{-1}$ or a total annual value of US$280 million. These fields contribute an additional 500,000t of cereals, providing food for about 2.5 million people. The trees contribute to climate change adaption by reducing wind speed and decreasing damage to crops from windblown sand. In addition, a cost and benefit analysis showed FRMR has a low investment cost (about USD$20 $ha^{-1}$) with an internal rate of returns of 31% if managed for fuelwood production over 20 years [62] with cereal production within an initial five-year period before canopy closure. Taking into account all factors, including enhanced soil fertility and increased food, wood and fodder supply, FNMR can bring an estimated benefit of USD 56 $ha^{-1}$ $year^{-1}$ [63, 64].

(d) Soil carbon sequestration—Soil organic matter has been known for years to be beneficial to cultivation, due to its abilities to improve soil structure and enhance water and nutrient retention. The challenge is to leave enough (or place enough) vegetation for the SOM to increase. Agroforestry is one option, but other possibilities include no-till agriculture, off-season cover crops, use of animal manure and biochar (a by-product of the pyrolysis of biomass under limited oxygen conditions) [65]. Although soil carbon sequestration has direct benefits to the farmer and mitigates climate change, increasing SOM may increase the emission of some greenhouse gases. Not all the science on this latter point is settled. However, it is reported that nitrous oxide, a greenhouse gas approximately 300 times more powerful than carbon dioxide, can be emitted during nitrification and denitrification from organic matter [66, 67].

(e) Seasonal weather and climate forecasting—With climate information services, farmers will be able to plan their planting and make projections about rainfall distribution patterns and temperature variations. Local ICT companies and meteorological institutions must be supported in providing the most accurate and reliable information to farmers. Recently, a sound approach was successfully implemented (1) to designing tailored climate information services and (2) to communicate them appropriately to farmers for their farm management decision making vis-à-vis climate variability in Senegal [68]. A collaboration between scientists and the national meteorological agencies of Senegal, Ghana and IT-based service providers allowed developing more accurate and specific seasonal rainfall forecasts and to raise capacity of partners to do longer-term analysis and provide more targeted information for farmers. The forecast information provided includes the total rainfall, the onset and end of the rainy season, plus a 10-day forecast across the rainy season. The information is conveyed to farmers as agro-meteorological advisories that are tailored to meet their local needs. In

Senegal for instance, through a partnership with 82 rural community-based radio stations promoting economic development through communication and local information exchange, the seasonal forecast is now reaching about 740,000 rural households across the 14 administrative regions [68]. In Ghana, through a private ICT-based platform, market price alerts, climate-smart agricultural advice, weather forecast and voice messages on climate-smart agricultural practices are sent out to farmers from Northern Ghana in the language of their (farmers) choice. This platform has so far trained and improved about 835 farmers' (of which 33% are females) access to and use of downscaled seasonal forecast and climate-smart agriculture technologies and practices (agro-advisories) through mobile phones [69]. Furthermore, the agricultural value chain programs in Burkina Faso and Senegal also disseminated seasonal forecast information and climate-smart agricultural options to farmers from various agricultural sectors [70]. A cost–benefit analysis in Burkina Faso by Ouedraogo et al. [70] showed that farmers exposed to climate information have used less local seed and more improved seed for cowpea and sesame production. They also used less organic manure and more fertilizers for sesame production. Cowpea producers exposed to climate information obtained higher yields while covering lower inputs costs and their gross margins were therefore higher compared to non-exposed farmers.

(f) Fertilizer efficiency—In addition to the use of inappropriate types of fertilizer depending on the soil type and native soil fertility, too much fertilizer, or fertilizer applied at less than optimal levels and times can be wasted, going beyond the reach of the crop. Not only is this economically inefficient, but the fertilizer can be converted to nitrous oxide and emitted to the atmosphere. However, the right type of fertilizer applied at proper times and amounts can be used efficiently by the crops while minimizing emissions. This may involve promoting integrated soil fertility management that seeks, among other things, to enhance the soil organic matter content of the soils, which improves nutrient retention [71].

(g) Rice water management—With optimal management of water in a rice system, such as alternate wet and dry (AWD), methane emissions can be reduced without adversely impacting yield and potentially increasing yields. It may also prove to be a more efficient use of water in many locales. The danger of such a system is that if done incorrectly, the nitrous oxide emissions will increase so much that they will negate any gains in methane emission reduction [72].

## Socioeconomic consequences of climate change and the economic implications for climate-smart agriculture adoption in West Africa

With almost 70% of West African populace dependent on agriculture, climate change will have far socioeconomic consequences for national economies and individuals. Climate change impacts on production are expected to translate into economic impacts at various scales: (1) At the farm level, climate change will cause reduced income for households which will limit the capacity to acquire physical assets and meet the cost of child education and health [73]. In Northern Ghana for instance, estimates from the Ricardian regression models showed that precipitation and temperature impacted significantly on net revenue per hectare of maize and sorghum. Indeed, increasing precipitation (by 1 mm), while decreasing temperature (by 1 °C), would affect net revenue, but differently across seasons and among various crops [54]. This will worsen existing poverty, exacerbate inequalities and trigger both new vulnerabilities and some opportunities for affluent individuals and communities who can take advantage of shocks and crises, given their flexible assets and power status [74]. This confirms the important link between climate and crop revenue and the need to take action to reinforce existing adaptation options and to even develop new ones. (2) At the national level, climate change may have macroeconomic consequences for countries whose national economies are dependent on agriculture. Interacting with other non-climatic stressors such as environmental degradation, market volatility and declining soil fertility, climate change can hinder agricultural development by discouraging investments [73]; (3) at the regional level, climate change impact on production will have (i) quantity and price effects, with increased tension on markets; and (ii) impacts on bilateral contracts and/or import/export behavior, with disruption of trade patterns [73].

The quest to promote climate-smart agriculture in West Africa will not come at a low cost. This necessitates regional-level large-scale investments that require innovation, cooperative action and political will to urgently and adequately address current and projected shortfalls for adaptation and mitigation [3]. Generally, information relating to the investment needs for agriculture and climate finance is limited and may not include all related investment needs [75]. Earlier projections have shown the entire Africa will require about USD 48.5 billion per year to meet the investment needs of the agriculture sector and about USD 3 billion per year investments toward climate change adaptation over the period 2005/7–2050 [75, 76]. At least a quarter of these investment needs will be required for West Africa which has a high dependence on agriculture and its related activities. Further, there will be extra costs toward research, capacity building and planning for climate change adaptation. These investments would have to come from national budgets (aligned with national goals and priorities relevant for CSA), private sector funds and bonds, concessionary mechanisms, bilateral and multilateral funding, development banks, global adaptation funds (e.g., Green Climate Funds), etc.

## Regional initiatives and policy development efforts for promoting climate-smart agriculture

Developing or reinforcing adaptive mechanisms to deal with the negative effects of climate change is considered a priority by West Africa policy makers, but this requires considerable changes in national and local governance, legislation, policies and financial mechanisms. Policy initiatives and developments that promote CSA in West Africa do exist, but studies monitoring and evaluating their effectiveness are limited. Before the African Union Summit in 2014 (which led to the development of the African Climate Smart Agriculture Coordination Platform, NEPAD Planning and Coordinating Agency, (NPCA)), most countries in the Committee for Drought Control in the Sahel (CILSS) in the ECOWAS region had between 2007 and 2009 formulated and adopted their National Adaptation Programs of Action (NAPA) which included various interventions under CSA for climate change mitigation and adaptation [77, 78]. In addition, some projects under the NAPA covered more specific areas such as (i) mainstreaming climate change-related issues in agricultural policies, programs, plans and projects; (ii) implementing good adaptation practices in the sectors most vulnerable to climate change; (iii) preventing and mitigating food crises; (iv) providing information, education and communication to stakeholders; (vi) strengthening early warning systems on climate change, etc. [79]. To improve and sustain the aforementioned, ECOWAS adopted in 2005 a common agricultural policy, the ECOWAP/CAADP as the regional version of the NEPAD's Comprehensive Africa Agriculture Development Program (CAADP) [79]. The implementation of ECOWAP/CAADP was based on coordinated interventions at national and regional levels through the development of National Agricultural Investment Programs (NAIPs) and a Regional Agricultural Investment Programme (RAIP) at community level [79, 80]. A synthesis report from the ECOWAS communications indicates ECOWAS intensions to improve the shortcomings of the NAIPS and RAIPs in the quest to sustainable food security in the face of climate change challenges by (i) integrating CSA in the NAIPs of the 17 ECOWAS/CILSS countries and in the RAIP at regional level; (ii) assisting the countries in increasing climate funding mobilization for CSA within the framework of their NAIPs and developing a CSA monitoring-evaluation framework in the context of ECOWAP/CAADP monitoring-evaluation system; and (iii) strengthening interinstitutional dialogue and cross-sector cohesion around CSA between agricultural policies and programs for climate adaptation and water management both at national level and at regional level [79]. Furthermore, ECOWAS and regional stakeholders developed in 2015 an intervention framework for CSA in West Africa coupled with the creation of a West Africa Climate-Smart Agriculture Alliance for proper implementation. This was presented during COP 21 in Paris as a regional initiative (dubbed: "Promotion of Smart Agriculture towards Climate Change and agroecology transition in West Africa") that aims to support the transition toward agro-ecology in West Africa, dwelling on CSA principles to reinforce the resilience of vulnerable populations [81]. Protocols in the implementation of the initiative involve the (1) creation of a platform to share knowledge: capitalization of technics and ecology-intensive practices, data on investments and data on carbon sequestration; (2) promotion of these practices through agro-meteorological support: climate modeling and of its impacts on agriculture, strengthening of the production and dissemination of information systems; (3) production and dissemination of best practices; (4) supporting the scale-up of best practices: the use of agroforestry species with carbon sequestration capacities, storm water management, soil regeneration and fertilization; (5) reinforcement of national and regional capacity building in policies and strategies: promotion of best practices in programs and projects, trainings; and (6) mobilizing financial and technical resources: access to the International Climate Fund (primary channel of climate change finance), creation of expert pools.

Within the ECOWAS region, some countries have now mainstreamed climate change and CSA into national action plans and policies. In 2011, the Government of Nigeria and civil society organizations developed a National Adaptation Strategy and Plan of Action on Climate Change for Nigeria (NASPA-CCN). The document was developed through multistakeholder consultations [79]. Ghana also launched the National Climate-Smart Agriculture Action Plan (2016–2020) in 2015 under the technical and scientific auspices of the Ministry of Food and Agriculture and the Ghana science-policy dialogue platform on climate change, agriculture and food security [82]. Mali has also formulated a National Policy on Climate Change (PNCC) accompanied by a National Implementation Strategy consisting of 147 actions for the 2012–2017 periods. The sectorial orientations on which CSA is based within the framework of the PNCC are yet to be identified [79]. However, a CSA prioritization exercise has been undertaken with key national actors to define cost-effective climate-smart technological options that could be considered for implementation in each agro-ecological zone [83].

## Conclusions

There is substantial evidence that climate change is already impacting West African livestock, fishery and crop production sectors and would continue to have disastrous effects in the future if appropriate mitigation and adaptive measures are not in place. For instance, current cereal production is expected to reduce by 40% in 2050, while an expected 5% decline in rainfall and frequently long-lasting and intense droughts will predictably increase the area of arid and semiarid land by 5–8%. Intense droughts will have consequential effects on floristic composition of vegetation, changes in herbage quality and changes in the importance of crop residues as animal feed. In addition, climate change is expected to modify the distribution of fish species, thus affecting habitat size, species diversity and productivity of lagoons in the region. The mounting consensus of the vulnerabilities of the crop, livestock and fishery production sectors to climate change means that every day of inaction could make the consequences more catastrophic and irreversible. Although the Kyoto Protocol places great emphasis on mitigation efforts (reducing greenhouse gas emissions and creation of sinks), its impact on climate change will not be seen immediately even if the most effective reductive measures are implemented. Therefore, developing or reinforcing adaptive mechanisms to deal with the negative effects of climate change must be a high priority. The promotion of climate-smart agricultural (CSA) practices is one mainstream opportunity to mitigate climate change while sustaining the productivity of agricultural systems. In addition, CSA can help build adaptive capacity, so that farmers, service providers to farmers and key institutions have the ability to respond effectively to longer-term climate change as well as being able to manage the risks associated with increased climate variability. Recent developments at the political level give hopes for large-scale CSA adoption for improved resilience to climate change and food security in the region. CSA is already endorsed for inclusion in the NEPAD program on agriculture and climate change by the African Union, while in the framework of the formulation of the ECOWAP + 10, the new common agricultural policy for the region, ECOWAS seeks for a focus on the mainstreaming of climate change and CSA into local plans and policies of member countries. While policy developments are advancing, governments would have to raise the levels of national agricultural investments and create adequate and effective financial mechanisms to achieve large-scale landscape adoption of CSA. Further, research for development and dissemination of CSA technologies has to be intensified in the region.

### Abbreviations

AgMIP: Agricultural Model Intercomparison Project; AU: African Union; AWD: alternate wet and dry; CAADP: Comprehensive Africa Agriculture Development Program; CMIP: Coupled Model Intercomparison Project; CILSS: Committee for Drought Control in the Sahel; CSA: climate-smart agriculture; CSIRO: Commonwealth Scientific and Industrial Research Organization; DSSAT: Decision Support System for Agrotechnology Transfer; ECOWAS: Economic Community of West African States; NAIP: National Agricultural Investment Programs; NASPA-CCN: National Adaptation Strategy and Plan of Action on Climate Change for Nigeria; NAPA: National Adaptation Programs of Action; NEST: Nigerian Environmental Study/Action Team; NPCA: NEPAD Planning and Coordinating Agency; PNCC: National Policy on Climate Change (translated from French); RAIP: Regional Agricultural Investment Programme.

### Authors' contributions

RZ and AJ wrote the review on the crop production sector; RZ again coordinated the entire literature review process. STP worked on combining the various reviews, improving the coherence of content, writing a background to the review, conclusions and abstract. BO wrote the review on the fishery sector. MO and TT edited and reviewed the policy context of the paper. AA, PE and MS wrote the review on the livestock sector. All authors contributed to the final editing and reviewing of the entire manuscript. All authors read and approved the final manuscript.

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### Competing interests

The authors declare that they have no competing interests.

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