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ARTICLE DE SYNTHÈSE / REVIEW ARTICLE OPEN ACCESS

Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks

Robert B. Zougmoré[1,2,*], Samuel T. Partey[1,2], Mathieu Ouédraogo[1,2], Emmanuel Torquebiau[3,4] and Bruce M. Campbell[1,5]

[1] CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, Netherlands
[2] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Bamako, Mali
[3] CIRAD, UPR AIDA, 34398 Montpellier, France
[4] AIDA, Université de Montpellier, CIRAD, Montpellier, France
[5] International Center for Tropical Agriculture (CIAT), Cali, Colombia

Abstract – In the literature, a lot of information is available about climate change perceptions and impacts in sub-Saharan Africa. However, there is limited attention in the region to emerging initiatives, technologies and policies that are tailored to building the adaptive capacity of agricultural systems to climate change and variability. In this paper, we discuss the prospects for climate-smart agriculture technologies and enabling policies in dealing with climate change and variability at different sub-regional levels of sub-Saharan Africa to sustain farm productivity and livelihoods of agrarian communities. The review provides substantial information suggesting that without appropriate interventions, climate change and variability will affect agricultural yields, food security and add to the presently unacceptable levels of poverty in sub-Saharan Africa. Although some of them were already existing, the past decades have seen the development and promotion of climate-smart agriculture innovations such as the use of high yielding drought tolerant crop varieties, climate information services, agricultural insurance, agroforestry, water harvesting techniques, integrated soil fertility management practices, etc. In the context of climate change, this appears as a stepping up approach to sustainably improving farm productivity, rural livelihoods and adaptive capacity of farmers and production systems while contributing to mitigation. The development of regional, sub-regional and national climate change policies and plans targeted at mitigating climate change and improving adaptive capacity of the African people have also been developed to enable mainstreaming of climate-smart agriculture into agricultural development plans. Financial commitments from governments and development agencies will be crucial for improving large scale adoption of climate-smart agriculture.

Keywords: agriculture development / adaptation / climate change and variability / food security / risk management

Résumé – Variabilité climatique en Afrique subsaharienne : analyse des opportunités d'agriculture climato-intelligente pour la gestion des risques. De nombreuses informations sont disponibles sur les perceptions et impacts du changement climatique en Afrique subsaharienne. Cependant, il est porté peu d'attention aux initiatives, technologies et politiques émergentes qui renforceraient la capacité d'adaptation des systèmes agricoles aux changement et variabilités climatiques. Dans cet article, nous analysons les perspectives en matière de technologies et de politiques d'agriculture climato-intelligente, qui permettraient de faire face au changement et à la variabilité climatiques dans différentes sous-régions d'Afrique subsaharienne, afin de soutenir la productivité agricole et les moyens de subsistance des communautés rurales. Les résultats de cette analyse suggèrent que les changements et variabilités climatiques affecteront les rendements agricoles, la sécurité alimentaire et aggraveront les niveaux actuels inacceptables de pauvreté en Afrique subsaharienne si des actions appropriées ne sont pas entreprises. Les dernières décennies ont vu la promotion d'innovations en agriculture climato-intelligente, dont certaines existaient déjà, telles que l'utilisation de variétés de cultures tolérantes à la sécheresse et à haut rendement,

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*Corresponding author: r.zougmore@cgiar.org.

les services d'information climatique, l'assurance agricole, l'agroforesterie, les techniques de récupération de l'eau, les pratiques intégrées de gestion de la fertilité des sols, etc. Dans ce contexte de changement climatique, l'agriculture climato-intelligente apparaît comme une approche accélérée pour améliorer durablement la productivité agricole, les moyens de subsistance ruraux et les capacités d'adaptation des agriculteurs et des systèmes de production tout en contribuant à l'atténuation du changement climatique. L'élaboration de politiques et de plans régionaux, sous-régionaux et nationaux de lutte contre le changement climatique visant à atténuer les changements climatiques et à améliorer les capacités d'adaptation des populations africaines permettra l'intégration de l'agriculture climato-intelligente dans les plans de développement agricole. Les engagements financiers des gouvernements et des agences de développement seront cruciaux pour améliorer l'adoption à grande échelle de l'agriculture climato-intelligente en Afrique subsaharienne.

Mots clés : développement agricole / adaptation / changement et variabilité climatique / gestion du risque

1 Introduction

Empirical evidence suggests that climate change will continue to have far-reaching consequences for agriculture and will disproportionately affect poor and marginalized groups who depend on agriculture for their livelihoods and have a low capacity to adapt, especially in sub-Saharan Africa (Zougmoré *et al.*, 2016). With many countries still trailing achievement of the past millennium development goals targets (Sahn and Stifel, 2003), climate change may pose challenges in the region's quest to use agriculture as the mainstream opportunity to achieving food security and poverty reduction targets of the sustainable development goals. To date, agriculture in this part of the world remains mainly rainfall-dependent, meaning that 90% of staple food production will continue to come from rain-fed farming systems (Rockström *et al.*, 2010). Factors like market and local preferences, farm productivity, crop, capacity to invest, willingness to take risks and soil quality play an important role (Ouédraogo *et al.*, 2017), but climate variability and climate extremes will induce crop failures, fishery collapses and livestock deaths, causing economic losses and undermining food security. These are likely to become more severe as global warming continues (IPCC, 2014).

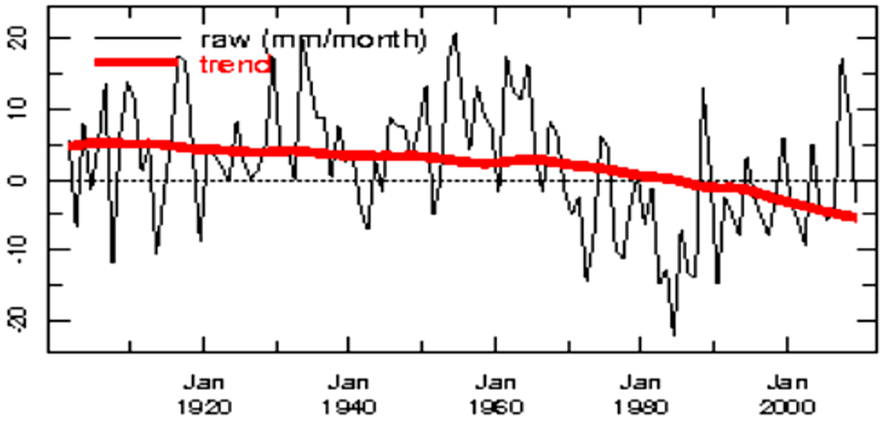
These scenarios present a major challenge to agriculture in sub-Saharan Africa, severely compromising food security and livelihoods for millions of people. Efforts to reduce food insecurity must not only target increases in production but also include building the resilience of rural communities to shocks and strengthening their adaptive capacity to cope with increased climate variability and change. The agricultural sectors (crops, livestock, forestry, fisheries) must therefore be transformed in order to feed a growing global population and provide the basis for economic growth and poverty reduction. This transformation must be accomplished without hindering the natural resource base (FAO, 2014). In the literature, a lot of information is available about climate change perceptions and impacts in sub-Saharan Africa (e.g. Serdeczny *et al.*, 2017; Ouédraogo *et al.*, 2017), but limited attention is given to emerging initiatives, technologies and policies that are tailored to building the adaptive capacity of agricultural systems to climate variability. Globally, the development and promotion of climate-smart agriculture (CSA) is viewed as an opportunity for building synergies among climate change mitigation, adaptation and food security and minimizing their potential negative trade-offs (Lipper *et al.*, 2014; Campbell, 2017; Partey *et al.*, 2018). In sub-Saharan Africa, CSA is promoted as a development agenda due to its potential positive effect on food security and poverty reduction. Several CSA technologies, tools, approaches and policies tailored to reducing climate-related risks have been developed in sub-Saharan Africa for the various sectors (crops, livestock and fisheries). In this paper, we discuss the prospects for CSA technologies and enabling policies in dealing with climate change and variability at different sub-regional levels of sub-Saharan Africa to sustain the resilience and livelihoods of farming communities.

2 Implications of climate change and variability on agriculture and livelihoods in sub-Saharan Africa

Climate change and variability are emerging as major threats to development in sub-Saharan Africa. Although local variability is important, trends in Figure 1 generally show declining precipitation and increasing temperatures for the region. In East Africa for instance, Hulme *et al.* (2001) and IPCC (2014) both projected for 2050 warmer temperatures, 5–20% more rainfall between December and February, and 5–10% less rainfall from June to August. This warmer climate will affect fishing in coastal and aquaculture systems, and will cause a decline in crop production, particularly in maize (Adhikari *et al.*, 2015). Increased drought is also eminent, particularly for the lowlands of Ethiopia. Drought-induced famines in East Africa are also expected to be further exacerbated due to the presently limited coping mechanisms and inadequate contingency planning for drought mitigation and the threat of climate change (Branca *et al.*, 2012).

In West, Central, Eastern and Southern Africa, drought and mean annual temperature rise are the most prevalent climate variables cited to pose high risk to rain-fed crop production systems and livelihoods of subsistence farmers (Zougmoré *et al.*, 2016). In Ghana, annual mean temperatures are projected to increase by 0.6 °C, 2.0 °C and 3.9 °C by the years 2020, 2050 and 2080 respectively, whilst rainfall had been projected to decrease by 2.8%, 10.9% and 18.6% for the

A: Precipitations



B: Temperature

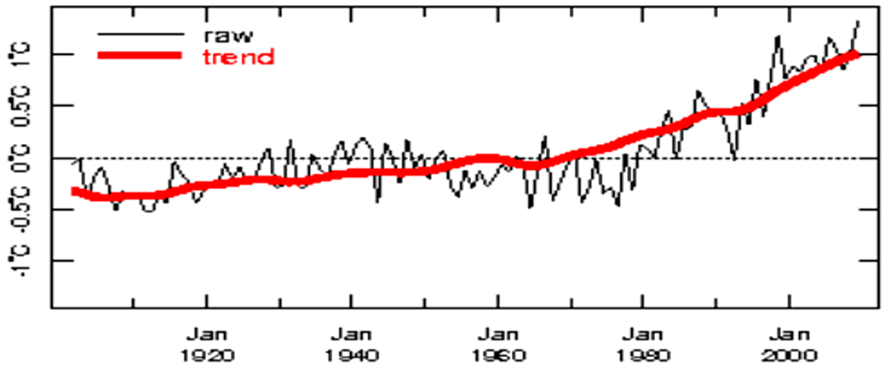


Figure 1. Changes in precipitations (A) and temperature (B) in Africa recorded from 1920 to 2000. * Based on an analysis from the Map room of the International Research Institute for Climate and Society, Columbia University, New York, USA.
Figure 1. *Modifications des précipitations et des températures en Afrique enregistrées entre 1920 et 2000.*

same periods (Antwi-Agyei *et al.*, 2012). Antwi-Agyei *et al.* (2012) showed that the projected rise in temperature and decline in rainfall could increase vulnerabilities in different parts of Ghana, particularly in the Upper West and Upper East regions which are already suffering from intense drought, inherently low soil fertility and low adaptive capacity among farming households. The repercussions of these trends are an expected reduction in the production of major food crops such as sorghum, maize and millet. These observations were also found to be consistent with reports in Central Africa where Thomas (2008) reported that drought incidences or reduction of about 10% of seasonal rainfall could translate to about a 4.4% decrease in food production in the semi-arid and sub-humid zones. Impact of climate change and variability on income diversification and food security is also reported (Brown, 2008). In Senegal, Brown (2008) reported that changes in diversity of income sources from the past to the present were related to reductions in rainfall. Overall, the Intergovernmental Panel on Climate Change (IPCC) estimates that crop and fodder growing periods in Western and Southern Africa may shorten by an average of 20% by 2050, causing a 40% decline in cereal yields and a reduction in cereal biomass for livestock (IPCC, 2014). Western, Central and Southern Africa may experience a decline in mean annual rainfall of 4%, 5% and 5% respectively. Only in East Africa is rainfall anticipated to increase (Hoerling *et al.*, 2006).

In addition to drought, flood is thought to be problematic for farmers. Figure 2 shows the frequency of floods recorded in West Africa from 1966 to 2008. The frequency of flooding has risen 6 to 12 times during the last decades (Collins *et al.*, 2009). According to IPCC (2014), climate change may account for this with future floods expected to be more frequent and more intense. In the coastal areas of Southwestern Nigeria, it was revealed that more than 70% of households were vulnerable to floods with a weighted impact index of 3.1 to 4.4 of the maximum possible score of 5.0 (Adelekan and Fregene, 2015). It was projected that with a 0.5–1 m sea level rise, Nigeria could potentially experience more frequent storm surges and an anticipated 3.2 million people would be at risk from flooding (Morand *et al.*, 2012). In Benin, increased frequency of floods in 2008 affected 25 000 ha of staple crops and 1204 ha of fields planted with cotton with an estimated 53,674 farmers badly impacted. The flooding disaster was valued at US$ 20 million (Zougmoré *et al.*, 2016).

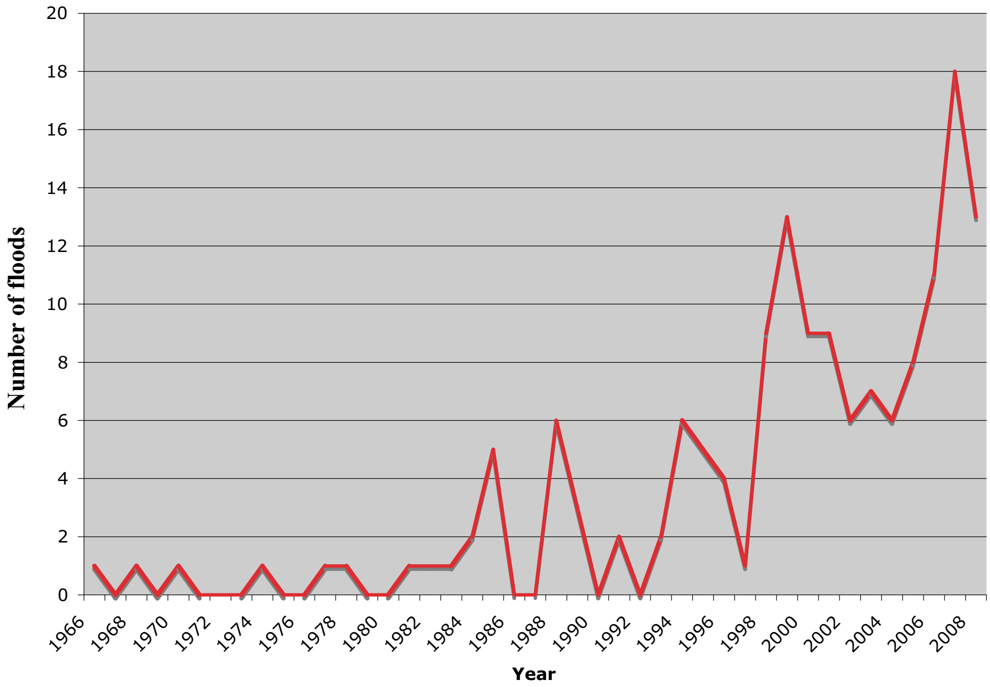


Figure 2. Number of floods recorded in West Africa from 1966 to 2008 (adapted from Collins *et al.*, 2009).
Figure 2. *Nombre d'inondations enregistrées en Afrique de l'Ouest de 1966 à 2008 (adapté de Collins* et al.*, 2009).*

3 What opportunities exist for developing CSA for climate risk management in sub-Saharan Africa?

In this section, we discuss the prospects for CSA in dealing with climate change and variability at different sub-regional levels of sub-Saharan Africa. FAO (2014) defined CSA as agricultural innovations that achieve:

- increased productivity for improved food security;
- improved adaptation and resilience to climate change and variability;
- and reduced greenhouse gas emissions (mitigation) where possible.

3.1 West and Central Africa

West Africa already has a high and fast growing population. There is therefore limited scope for increasing agricultural production through extensification. Instead, the available literature (e.g. Buah *et al.*, 2017; Jalloh *et al.*, 2011; Sanou *et al.*, 2016) reports that improving food security will require animal breeds with resilient genetic potential, crop varieties with greater tolerance to stresses such as drought, insects and diseases, and a focus on soil carbon as well as sustainable land and soil fertility management techniques. Sustainable natural resource management is thought to be the most critical factor in agricultural production in the region (Rhodes *et al.*, 2014). In recent years, the region has witnessed an expansion of the maize mixed farming system in the semi-arid and sub-humid zones (Mason *et al.*, 2015). There is also growing emphasis on agroforestry and rangeland management, where dominant pastoral systems and livestock feed resources would otherwise decline. On the other hand, the increasing prospects for both smallholder and large scale irrigated systems are likely to modify crop-livestock interactions and open new opportunities for CSA (Rhodes *et al.*, 2014). Provided sustainable irrigation opportunities are found, CSA approaches to simultaneously increase crop productivity and reduce greenhouse gas emissions could emerge in irrigated rice and fisheries (including aquaculture) systems (Zougmoré *et al.*, 2016). Meanwhile, opportunities for CSA in Central Africa arise from a growing but food-insecure population, and for which increasing agricultural productivity does not only enhance food security but also save forest resources. Depletion of forests in the forest-based farming systems will most likely lead to large greenhouse gas emissions and loss of ecosystems services. CSA options that limit expansion of cultivated areas into forests or alternatively seek to establish new agricultural production systems that can at least restore ecosystem services and values are required.

3.2 East Africa

The development of CSA best practices will need to focus on pathways to sustainable intensification of cropping systems, increasing efficiencies in livestock production systems, conservation of soil and water resources, and adaptive management of natural resources at both farm and landscape levels (Torquebiau, 2015). Landscape-level approaches will make sure that heterogeneity in land-use and cropping systems is favored, in order to contribute to synergy between climate change adaptation and mitigation (Torquebiau, 2015). Technologies/practices that need to be tailored to farmers' different socio-ecological circumstances and generate context-specific CSA innovations could include agroforestry, water harvesting and soil and water conservation in rainfed and irrigated systems; development and adaptation of stress tolerant crops and livestock breeds; innovations for combining conservation agriculture and integrated soil fertility management technology components; and diversification in crop-livestock production systems (Partey *et al.*, 2016; Zougmoré *et al.*, 2014). In the highlands of East Africa, improved fallow agroforestry technologies are options to increase soil fertility and crop yields. Adopters have witnessed a massive economic boost. A survey in Western Kenya revealed that 500 farmers using calliandra shrubs for short-term agroforestry fallows increased their annual net income by between US$ 62 to 122 depending on whether they used shrubs as a substitute, or as supplement, and depending on where they were located (Franzel and Wambugu, 2007). These options could be applicable (although with different species) for other parts of Africa.

3.3 Southern Africa

Apart from the projected reduction in rainfall and an increase in frequency of drought for a region that is already largely semi-arid, Southern Africa has some of the most infertile and unproductive soils on the continent (Mapfumo *et al.*, 2017). Similar to East Africa, increasing crop productivity through intensification options is a priority for the region. The sub-region also has some of the least diversified cropping systems and a critical challenge in addressing chronic food and nutrient insecurity as well as land degradation is: "how to get the region's smallholder communities out of the *Maize Poverty Trap*" (Mapfumo *et al.*, 2014). This entails ensuring household self-sufficiency in staple maize through production or alternative access mechanisms before communities can invest and/or diversify into other agricultural and non-agricultural livelihood options. Overall, integrated soil, water, nutrient and organic matter management techniques hold potentials for CSA in Southern Africa (Mapfumo *et al.*, 2017). CSA, especially if it targets soil carbon and organic matter, offers a credible entry point for managing these changes in the context of climate change, particularly if interventions can be integrated to address problems at the interface of agricultural productivity, natural resources management and social safety nets. This can be achieved through systematic and intensive legume cereal rotational systems coupled to inorganic fertilizer use and integrated conservation agriculture and integrated soil fertility management systems that respond to farmer circumstances. The use of tree legumes (via agroforestry) is popular in Southern Africa and considered an agroecologically sound CSA practice for improving and sustaining soil fertility (Mbow *et al.*, 2014). It is estimated that about 20,000 farmers are now using *Sesbania sesban*, *Tephrosia vogelii* and *Cajanus cajan* in two-year fallows followed by maize rotations for two to three years. Impressive root growth explains the success of these short term agroforestry fallows (Torquebiau and Kwesiga, 1996).

4 What enabling CSA policies and plans exist for climate risk management in sub-Saharan Africa?

With increasing concerns about the negative consequences of climate change and variability on livelihoods, regional, sub-regional and national climate change policies and plans targeted at mitigating climate change and improving adaptive capacity of the African people have been developed (Zougmoré *et al.*, 2016). In 2014, African leaders endorsed the inclusion of CSA in the New Partnership for Africa's Development (NEPAD) programme on agriculture and climate change and established the African Climate Smart Agriculture Coordination Platform which is expected to enable the NEPAD Planning and Coordinating Agency (NPCA) to collaborate with Regional Economic Communities (RECs) and Non-Governmental Organisations (NGOs) in targeting 25 million farm households by 2025. The NEPAD Heads of State and Government Orientation Committee at its 31st session on 25 June 2014 in Malabo, Equatorial Guinea, also welcomed the new partnership between NPCA and major global NGOs to strengthen grass-root adaptive capacity to climate change and boost agricultural productivity. The meeting requested NPCA in collaboration with the Food and Agriculture Organization of the United Nations (FAO) to provide urgent technical assistance to the African Union (AU) Member States to implement the CSA programme and that the African Development Bank (AfDB) and partners should provide support to African countries on investments in the CSA field (African Union, 2014). In addition, COP22 saw the Adaptation of African Agriculture initiative ("AAA"), launched by the Moroccan Government to transform African Agriculture through:

- sustainable and resilient soil management;
- improved agricultural water management;
- climate risk management.

This initiative supported by all African governments is expected to enable farmers and the agri-food system to simultaneously increase productivity, improve resilience and manage natural resources more sustainably, thereby contributing to national, regional and global food security and nutrition (CCAFS, 2016). The 4‰ initiative "Soils for food security and climate", launched at COP 21 and which has now developed into a full-size international program, also targets climate change mitigation and adaptation through an increase of soil carbon content (Soussana *et al.*, 2017).

5 What CSA technologies and approaches are helping farmers in sub-Saharan Africa deal with climate-related risks?

As climate change and variability continue to threaten agriculture and livelihoods in sub-Saharan Africa, it is important that actions are taken to reduce risks and capitalize on opportunities. The past years have seen the promotion of CSA technologies and enabling agricultural policies and investment plans as a stepping up approach to improving farm productivity, rural livelihoods and adaptive capacity of farmers and production systems. In this section, we discuss how developments in agricultural technologies that achieve one or more of the three pillars (productivity, mitigation and adaptation) of CSA are helping farmers deal with climate-related risks.

5.1 Resilient cultivars

In the crop production sector, there are improvement efforts in the development of crop cultivars that are resilient to drought, pest, weeds, salinity, flooding, etc (ICRISAT, 2015). Various research centers within the CGIAR and elsewhere have announced the release of climate resilient crop varieties. For instance the International Center for Tropical Agriculture (CIAT) developed 30 new heat-resistant bean varieties for Africa that remain productive even beyond the critical 19 °C tolerance level at which most beans falter (Beebe *et al.*, 2011). The International Rice Research Institute (IRRI) released 28 climate-resilient high-yielding varieties of rice for the Gambia, Mali, Senegal, Burkina Faso, Ghana and Guinea which are also tolerant to salinity and iron (Lafarge *et al.*, 2016). In rice, the adaptation of flowering processes to heat is crucial since high temperature can cause flower sterility. Research is on-going for varieties which can escape (early anthesis time), avoid (panicle cooling through transpiration) or tolerate (presence of genes of interest) heat at flowering (Lafarge *et al.*, 2016). Despite the "climate-smartness" and high productivity levels reported for improved crop varieties in Africa (Lacape *et al.*, 2016), there are concerns on increased emissions associated with the use of fertilizers and also the high input costs (e.g. from fertilizers) and supply costs (from seed companies) to the farmer which often dwindles the adoption potential of small scale farmers. This has been reported in the maize-growing regions of Kenya and Mozambique, where farmers are rejecting new hybrid maize varieties in favour of existing traditional varieties due to difficulties of obtaining the necessary inputs for growing hybrid seed. Research is on-going to develop crop varieties with other traits for resilience e.g. improved root growth to withstand long drought, e.g. for cotton (Lacape *et al.*, 2016). The costs and benefits of various climate-informed improved crop varieties remain a major gap for research in the region (Zougmoré *et al.*, 2016).

5.2 Water management techniques

As water resources for agriculture are becoming more unpredictable due to increased climate variability, soil and water conservation approaches that improve the efficient use of green water have been prioritized for the region (ICRISAT, 2015). In the Sahel areas of West Africa, farmers have successfully used *zaï* or *tassas* (improved traditional planting pits), contour bunds and half-moon structures to capture water. Crops such as sorghum, millet and cowpeas are successfully planted with these techniques by employing other conservation agriculture techniques such as the application of animal manure or compost (Zougmoré *et al.*, 2014) with grain yields exceeding 200% relative to control fields in Burkina Faso and Niger (Wildemeersch *et al.*, 2015). The use of intermittent irrigation for flooded rice has seen water efficiently utilized and yields increasing significantly. The system of sustainable rice intensification (SRI) has seen high adoption as a climate-smart option in about 20 African countries (Nyasimi *et al.*, 2014). Up to 4–5 million smallholder farmers are expected to have benefitted from the system since 2013 (Nyasimi *et al.*, 2014). In Madagascar alone, 65% of rice fields are thought to be under SRI with 45,248 farmers adopting the technique between 2005 and 2012 (COSOP, 2012). Similar adoption levels and success stories of SRI as a climate-smart option have been reported in Rwanda, Mali and Burundi (Uphoff, 2012). Moreover, there are also increased investments in irrigation in the quest to meet the water requirements of cropping fields in Africa particularly for high value vegetables (Wanvoeke *et al.*, 2016). Solar powered drip irrigation facilities are in particular being promoted in the Sudano-Sahel zones of West Africa due to their cost-effectiveness and significant correlation to increased household income and nutritional intake in the region (Burney *et al.*, 2010). In addition, the promise of distributed irrigation has led to recent momentum around smallholder irrigation in contrast to large-scale centralized irrigation projects require specific institutional arrangements for successful adoption and support (Burney *et al.*, 2013). In Cape Verde, traditional irrigation techniques that maximize water use through fog water collection are also recognized as climate-smart options for smallholder agriculture (Hiraldo, 2011).

5.3 Agroforestry

Adoption of agroforestry has been slow, although the proclivity for climate risk management and adaptation has been established. In Niger and in the Sahel, an African alliance to combat desertification has improved food security through farmer-managed natural regeneration, i.e. the protection of useful trees naturally germinating in farmers' fields (Neate, 2013). This approach has not only yielded climate change mitigating benefits but also improved soil fertility and household fodder, food and fuelwood needs (Nyasimi *et al.*, 2014). However, the existence of many traditional agroforestry practices (e.g. parklands, homegardens) does not suffice to convince farmers who are used to conventional monocultures to shift to mixed cropping or agroforestry. Supporting policies or other incentives are necessary. In the highlands of East Africa and in Southern Africa nevertheless, adopters of improved fallow agroforestry technologies witnessed improved income (Mbow *et al.*, 2014). Many options exist to increase the prevalence of trees on farms, ranging form multilayer agriculture, to hedges, contour lines hedgerows, fodder trees in rangelands, trees in homegardens, etc.

5.4 Climate information services

Climate information services (CIS) remain a valuable asset to vulnerable farming populations in Africa. The use of seasonal forecast information to predict the expectation of rains has a long tradition in Africa with even pastoralists in Ethiopia and northern Kenya still using indigenous forecasting methods to reduce climate-related risks (Luseno *et al.*, 2003). With CIS, farmers are able to plan their planting and make projections about rainfall distribution patterns and temperature variations (Giorgi *et al.*, 2009). Application of climate information services is new to many farmers in Africa but evidence from Ghana and Senegal demonstrates great potential in improving the adaptive capacity of smallholder farmers to climate variability and extreme events (CCAFS, 2015). In these countries, an approach was successfully implemented:

- to design tailored CIS;
- to communicate the results appropriately to farmers for their farm management decision making (CCAFS, 2015).

A collaboration between scientists, the national meteorological agencies and information and communications technology (ICT)-based service providers facilitated the development of more accurate and specific seasonal rainfall forecasts, and raised the capacity of partners to do longer-term analysis and provide more targeted information for farmers. The use of ICT (radio, mobile phones) and associated agro-advisory services is becoming increasingly important in order to reach more farmers and overcome the high transactions costs incurred by face-to-face interaction associated with conventional extension services (Etwire *et al.*, 2017). The forecast information provided includes the total seasonal rainfall, the onset and end of the rainy season, plus a 10-day weaher 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, a partnership with 82 rural community-based radio stations is promoting economic development through communication and local information exchange, and the seasonal forecast is now reaching about 750 000 rural households across the 14 administrative regions (CCAFS, 2015). In Ghana, through a private ICT-based platform, market price alerts, agro-advisories, weather forecast and voice messages on climate-smart agricultural practices are sent out to farmers in the North of the country in the language of their choice. This platform has so far trained about 835 farmers (of which 33% are women) giving them, through mobile phones, access to and use of downscaled seasonal forecasts and agro-advisories (ICRISAT, 2015). Furthermore, the agricultural value chain programs in Burkina Faso and Senegal have also disseminated seasonal forecast information and climate-smart agricultural advisories to farmers from various agricultural sectors (Ouédraogo *et al.*, 2015). A cost-benefit analysis in Burkina Faso by Ouédraogo *et al.* (2015) 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. A Participatory integrated climate services for agriculture (PICSA) approach is also being tested in Ghana to equip agricultural extension staff and other intermediaries to work with groups of farmers to understand climate information and incorporate it into their planning. The PICSA approach involves agriculture extension staff working with groups of farmers ahead of the agricultural season to analyze historical climate information and use participatory tools to develop and choose crop, livestock and livelihood options best suited to individual farmers' circumstances (Dorward *et al.*, 2015). Then, before and during the season, extension staff and farmers consider the practical implications of seasonal and short-term forecasts on farmer plans. PICSA was initially piloted in Zimbabwe, where more than 1200 extension officers were trained, and has since been incorporated into climate service capacity development initiatives in Tanzania, Malawi, Burkina Faso, Mali, Niger, Senegal, Ghana, Lesotho, etc. (Dinesh, 2016). Despite the many benefits CIS can bring to farmers its adoption faces many constraints related to legitimacy, salience, access, understanding, capacity to respond and data scarcity (Hansen *et al.*, 2011).

5.5 Agricultural insurance

With changing climate and unpredictable weather conditions, agricultural insurance is an important tool to managing climate-related shocks (Adiku *et al.*, 2017). Major steps to promoting agricultural insurance are evolving in Africa. In Ghana, a weather-index based crop insurance concept was developed through collaboration between the University of Ghana and the German International Cooperation (GIZ). The Ghana National Insurance Commission (NIC) is seeking to link various agricultural stakeholders such as weather technical persons, farmers, agricultural extension officer, input dealers and other aggregators, and financial institutions as well as the insurance industry, for a participatory farmer led approach to insurance (Adiku *et al.*, 2017). In Malawi, a packaged loan and index-based insurance (measured as a water requirement satisfaction index, as a weighted sum of cumulative rainfall during a 130-day growing period, with individual weights assigned to decadal (10-day) rainfall totals) developed in 2005 saw several thousands of farmers subscribing to agricultural insurance as it allowed acquisition of funds to purchase high yield varieties of groundnut (Meze-Hausken *et al.*, 2009). However, many uncertainties and challenges surround insurance posing high risk to its large scale adoption. Among them: doubts about the appropriateness of indices for payment, clear definition of risks, difficulties for implementation in the absence of public funds, farmers' perception and the unwillingness of some private financial companies.

6 Conclusion

Historical statistical studies and integrated assessment models provide evidence that climate change will affect agricultural yields and earnings, food prices, reliability of delivery, food quality, and poverty in sub-Saharan Africa. Responses need to come quickly, with salient and tailored risk management strategies that can limit disasters on agricultural productions and infrastructures. In this review paper, we demonstrated that technologies and practices such as agroforestry, conservation agriculture, crop diversification, climate information services, etc., are emerging CSA options to improving farm productivity, rural livelihoods and adaptive capacity of farmers and production systems in sub-Saharan Africa. Indeed, their potential in transforming and reorienting agricultural systems to support food security under the new realities of climate change show their novelty to agricultural and rural livelihood development. The sound implementation of these CSA options requires the definition of innovative policies and appropriate financial mechanisms to catalyze new initiatives that will ensure large-scale CSA adoption.

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