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Review

Developing climate-smart agriculture to face climate variability in West Africa: Challenges and lessons learnt

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ABSTRACT

This paper reviewed the prospects for climate-smart agriculture (CSA) development and promotion in West Africa as well as lessons learnt and challenges with a focus on climate change and variability. It was evident from the literature that West Africa is vulnerable to climate change and variability, on account of its socio-economic and physical characteristics. As climate change and variability persists, the region's quest to use agriculture as the mainstream opportunity to deliver on set targets of the sustainable development goals will be strongly challenged without appropriate interventions. Adopting CSA seems to be a suitable strategy to achieving food security while also mitigating and adapting to climate-related risks. Among numerous CSA technologies, the review found (1) agroforestry (farmer-managed natural regenerations), soil and water conservation technologies (zai, half-moon, tie/contour ridges, conservation agriculture) and (3) climate information services as highly valued promising options for climate change adaptation and risk management in West Africa. In addition, institutional settings at the community, national and regional levels such as the establishment of multi-stakeholder innovation platforms, national science policy dialogue platforms on CSA in parts of West Africa and the formulation of the West Africa CSA Alliance were found to be crucial in promoting capacity development and awareness of CSA technologies and innovations in the region. The review found that CSA still faces a number of challenges, including: lack of clear conceptual understanding, limited enabling policy and financing. The prospects of CSA in West Africa hinge on the capacities of farming households and the region's national institutions to understand the environmental, economic and social challenges in the context of climate change, and consequently self-mobilize to develop and implement responsive policies at appropriate scales.

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1. Introduction

With climate change already compounding the socioeconomic and biophysical constraints to development in West Africa, the adoption of climate-smart agriculture (CSA) is one mainstream opportunity to improving food and livelihood security in the region. As an innovative approach, CSA may effectively achieve the development goals of vulnerable populations highly dependent on agriculture although this will depend on effective management of the synergies and trade-offs between the mitigation, adaptation and productivity goals of CSA. While CSA may be a new term for a set of agricultural innovations, tools and policies, the concept is already embedded in many indigenous practices, tools and approaches that have helped farmers produce food in the face of changing and varying climatic conditions. For instance, traditional fallow systems, crop rotation and water harvesting practices such as *Zai* in the Sahel allow for sustainable conservation of water and soils for improved crop productivity and livelihoods (Lahmar et al., 2012). Meanwhile, advances in CSA research has also led to the development and dissemination of relatively new approaches, tools and policies such as solar-powered drip irrigation systems, integrated tree-crop-livestock systems, high yielding and drought resistant seeds, agriculture insurance, climate information systems, development of national and regional climate change action plans and policies which open new vistas of opportunities for farmers and production systems to adapt and/or mitigate climate-related risks. With the concept of CSA still developing and the complexity of the socioeconomic, political, cultural and ecological environment of West Africa, getting farmers to adopt and practice CSA technologies may likely encounter challenges despite the tremendous benefits attached to its adoption. While greater emphasis in the literature has been placed on climate change and variability effects and projections for West Africa (e.g. Jalloh et al., 2013; Zougmoré et al., 2016; Roudier et al., 2011), there is limited attention to lessons learnt and challenges that confront the development and adoption of agricultural practices that counter climate change (Neumann et al., 2010). As policy makers and development experts attempt to help poor and marginal farmers adapt to climate change as an opportunity to deliver on the food security targets defined by the sustainable development goals, knowledge on agricultural innovations that deliver on the principles of CSA will be crucial for bringing CSA to scale in the region. In this paper, we discussed (1) the need for CSA in West Africa, (2) some notable agricultural innovations that deliver on CSA principles in the region, (3) institutional settings that could help scale up CSA, and (4) some challenges that must be addressed to improve understanding on CSA concepts and speed up its scaling up in the region. We used evidence from the literature to discuss the aforementioned areas to draw implications on the prospects for CSA development and promotion in West Africa.

2. Methodology

Earlier, we had carried out a participatory selection of CSA options for testing in 5 locations within 5 countries (Ghana, Mali, Niger, Senegal and Burkina Faso) with participants being the local farmers who would trial the options, researchers from national and international agencies, and policy makers. The selected options have then been under testing for 7 years. Initial results suggest that of the initial options, six have been prioritised for further development and testing – these are the six that informed the focus of this paper discussed in section 4. These include: (1) conservation agriculture, (2) climate information services, (3) agroforestry – farmer managed natural regeneration, (4) planting pits – zai and half-moon, (5) drip irrigation and (6) erosion control techniques – tie/contour ridges and stone bunds. For each of the six, we have searched for the appropriate literature relevant to West Africa. The review employed Scopus for literature identification. The compound field TITLE-ABS-KEY that searches abstracts, keywords, and article titles was used to identify CSA literature that were specific to West Africa. The search was narrowed to peer-reviewed and grey literature published in English and French on and after 2000. Search keys for each practice in relation to climate change are enumerated in Table 1. In order to review papers based on the 3 pillars of CSA (productivity, mitigation and productivity), search keywords for productivity, mitigation and adaptation were also included where applicable (Table 2). Search results were subjected to filtering by reading through abstracts and titles and removing duplicates. In Table 3, we provide a list of literature found to be most relevant to this paper and catalogued into the 3 pillars of CSA. Moreover, we established national science-policy learning platforms in the above-mentioned countries and these have been operating for 5 years. These multi-stakeholder platforms consisting of academics, the media, researchers, NGOs, policy makers, farmer-based organizations, traditional leaders, etc. are settings through which scientists and policy makers interact, and challenge each other's opinions to come up with jointly developed knowledge aiming at informing policy decision processes. From the discussions in such fora, we have distilled institutional options that would foster uptake of CSA and the on-going challenges to CSA in Sections 5 And 6 respectively.

3. Why promote climate-smart agriculture in West Africa?

The literature attests to West Africa as being vulnerable to climate change and variability, on account of socio-economic and physical characteristics (Baptista et al., 2013). Farmers have to cope with highly variable, short and unpredictable rainfalls. Yet, agriculture in this region is essentially rain fed. With increasing variability of climate change, water resources for agriculture may become more unpredictable. In addition, increased run-off frequency and soil erosion has rendered many agricultural lands degraded (Zougmoré et al., 2014). This therefore necessitates adopting agricultural innovations that improve the efficient use of green water (rain water available in soil for plant use) and offer the opportunity to improve soil productivity and mitigate climate-related risks.

Climate change impacts are already known to West African

Table 1
Search keys for CSA practices considered in the analysis.

CSA practice	Search key	Comments
Climate information services	"climate information" OR "climate information services" OR "weather information" OR "weather forecast" OR "seasonal forecast" OR "climate agro-advisories" AND "agricultur*" OR "livestock" OR "crop" OR "aquac*" OR "fish" OR "farm" OR "food" AND "climate change" OR "weather" OR "rainfall" OR "variability" OR "drought" OR "adapt*" OR "mitigat*" OR "resilience" AND "west Africa" OR "benin" OR "burkina faso" OR "cape verde" OR "cabo verde" OR "cote d'Ivoire" OR "ivory coast" OR "gambia" OR "Ghana" OR "guinea" OR " guinea bissau" OR "liberia" OR "mali" OR "Mauritania" OR "niger" OR "nigeria" OR "senegal" OR " sierra leone" OR " sao tome and principe" OR "togo"	We included search items for agriculture to filter out the use of climate information for other purposes rather than agriculture
Conservation agriculture	"Conservation agriculture" OR "no till*" OR "zero till*" OR "minimum till*" OR "reduced till*" OR "mulch" OR "cover crop*" OR "green manur*" OR "permanent soil cover" OR "soil amendment" OR "organic amendment" OR "organic resource" OR "crop rotation" AND "climate change" OR "weather" OR "rainfall" OR "variability" OR "drought" OR "adapt*" OR "mitigat*" OR "resilience" AND "west Africa" OR "benin" OR "burkina faso" OR "cape verde" OR "cabo verde" OR "cote d'Ivoire" OR "ivory coast" OR "gambia" OR "Ghana" OR "guinea" OR " guinea bissau" OR "liberia" OR "mali" OR "Mauritania" OR "niger" OR "nigeria" OR "senegal" OR " sierra leone" OR " sao tome and principe" OR "togo"	We included climate change search keywords to get papers where conservation agriculture has been used as a climate change adaptation or mitigation strategy
Drip irrigation	"drip irrigation" OR "irrigation" OR "micro irrigation" OR "solar-powered irrigation" AND "climate change" OR "weather" OR "rainfall" OR "variability" OR "drought" OR "adapt*" OR "mitigat*" OR "resilience" AND "west Africa" OR "benin" OR "burkina faso" OR "cape verde" OR "cabo verde" OR "cote d'Ivoire" OR "ivory coast" OR "gambia" OR "Ghana" OR "guinea" OR " guinea bissau" OR "liberia" OR "mali" OR "Mauritania" OR "niger" OR "nigeria" OR "senegal" OR " sierra leone" OR " sao tome and principe" OR "togo"	Applicable climate change search keywords were included to get papers where drip irrigation has been used as a climate change adaptation strategy
Agroforestry – farmer managed natural regeneration	"farmer managed natural regeneration" AND "climate change" OR "weather" OR "rainfall" OR "variability" OR "drought" OR "adapt*" OR "mitigat*" OR "resilience" AND "west Africa" OR "benin" OR "burkina faso" OR "cape verde" OR "cabo verde" OR "cote d'Ivoire" OR "ivory coast" OR "gambia" OR "Ghana" OR "guinea" OR " guinea bissau" OR "liberia" OR "mali" OR "Mauritania" OR "niger" OR "nigeria" OR "senegal" OR " sierra leone" OR " sao tome and principe" OR "togo"	We included climate change search keywords to get papers where agroforestry has been used as a climate change adaptation or mitigation strategy
Planting pits	"zai" OR "tassas" OR "half-moon" OR "demi-lune" OR "semi-circular bunds" OR "planting pit" OR "micro catchment" OR "rainwater harvesting" OR "soil and water conservation" AND "climate change" OR "weather" OR "rainfall" OR "variability" OR "drought" OR "adapt*" OR "mitigat*" OR "resilience" AND "west Africa" OR "benin" OR "burkina faso" OR "cape verde" OR "cabo verde" OR "cote d'Ivoire" OR "ivory coast" OR "gambia" OR "Ghana" OR "guinea" OR " guinea bissau" OR "liberia" OR "mali" OR "Mauritania" OR "niger" OR "nigeria" OR "senegal" OR " sierra leone" OR " sao tome and principe" OR "togo"	We included climate change search keywords to get papers where planting pits have been used as a climate change adaptation or mitigation strategy
Erosion control techniques	"tie ridge" OR "contour" OR "stone bund" OR "stoneline" OR "stone row" OR "stone barriers" AND "climate change" OR "weather" OR "rainfall" OR "variability" OR "drought" OR "adapt*" OR "mitigat*" OR "resilience" AND "west Africa" OR "benin" OR "burkina faso" OR "cape verde" OR "cabo verde" OR "cote d'Ivoire" OR "ivory coast" OR "gambia" OR "Ghana" OR "guinea" OR " guinea bissau" OR "liberia" OR "mali" OR "Mauritania" OR "niger" OR "nigeria" OR "senegal" OR " sierra leone" OR " sao tome and principe" OR "togo"	We included climate change search keywords to get papers where the techniques have been used as a climate change adaptation strategy

Table 2
Search keys for the three pillars of CSA: productivity, mitigation and adaptation.

Productivity	Mitigation	Adaptation/resilience
"grain yield" OR "crop productivity" OR crop "production" OR "kg per hectare" OR "harvest" OR "harvest index" OR "land equivalent ratio" OR "biomass yield" OR "shoot yield" OR "water productivity" OR "water use efficiency" OR "soil fertility" OR "nutrient enrichment" OR "nutrient uptake" OR "nutrient use efficiency" OR "agronomic efficiency" OR "carcass weight" OR "liveweight" OR "feed consumption" OR "feed conversion rate" OR "weight gain" OR "growth rate" OR "willingness to pay" OR "profit" OR "gross margin" OR "cost" OR "cost effective" OR "benefit"	"greenhouse gas" OR "emissions" OR "trace gas*" OR "carbon dioxide" OR "CO2" OR "enteric fermentation" OR "nitrous oxide" OR "N2O" OR "methane" OR "CH4" OR "atmospheric carbon" OR "soil carbon" OR "carbon stock" OR "soil carbon sequestration" OR "biomass carbon"	"adapt*" OR "adaptive capacity" OR "risk management" OR "risk mitigation" OR "vulnerability" OR "food security" OR "nutrition" OR "malnutrition" OR "household" OR "food access" OR "crop diversification" OR "improved breeds" OR "improved varieties" OR "soil restoration" OR "soil and water conservation" OR "soil productivity" OR "drought-tolerant" OR "livelihood" OR "income" OR "total expenditure" OR "poverty reduction"

Table 3
Relevant literature from search results used to analyze how the CSA practices discussed in the paper addressed one or more of the three pillars of CSA.

CSA practice	Productivity	Adaptation	Mitigation
Conservation agriculture	Giller et al. (2009); Buah et al. (2017); Lahmar et al. (2012); Bayala et al. (2012).). Kermah et al. (2017); Partey et al. (2016); Ndah et al., 2014).	Obalum et al., 2012; Buah et al. (2017); Ndah et al., 2014).	Dossou-Yovo et al. (2016); Soler et al. (2011); Crews and Peoples (2004); Dick et al. (2008)
Climate information services	Roudier et al. (2016); MacCarthy et al. (2017)	Roudier et al. (2016); Lodoun et al. (2014); Tarhule and Lamb (2003). Wanders and Wood (2018); Fitchett and Ebhouma (2017); Westermann et al. (2015); Zare et al. (2017); CCAFS (2015); Etwire et al. (2017); Ouédraogo et al. (2015); Ouédraogo et al. (2018); Oyekale et al. (2015)	–
Planting pits – Zai and half-moon	Wouterse (2017); Sawadogo (2011); Lahmar et al. (2012); Masse et al. (2011). Slingerland and Stork (2000); Barro et al. (2005); Clavel et al. (2008); Schuler et al. (2016); Zougmoré et al. (2014); Wildemeersch et al. (2015a); Fatondji et al. (2006); Adekalu et al. (2009)	Schuler et al. (2016); Sidibé (2005); Wildemeersch et al. (2015b); Sawadogo (2011)	–
Agroforestry practices – farmer managed natural regeneration	Tougiani et al. (2009); Garrity et al. (2010); Sendzimir et al. (2011); Neate (2013); Martin et al. (2016); Binam et al. (2015)	Sinare and Gordon (2015); (Bayala et al., 2012); Tougiani et al. (2009); Garrity et al. (2010); Binam et al. (2015); Weston et al. (2015)	Luedeling and Neufeldt (2012)
Erosion control techniques - Stone bunds and tie/contour ridge	Zougmoré et al. (2003); 2014); Traore et al. (2017)	Baffour et al., 2012; Mashi et al., 2015); Gigou et al., 2006). (Sawadogo, 2011). Aune et al., 2017).	–
Drip irrigation	Burney et al., 2010	Wanvoeke et al. (2016); Burney et al. (2010); Maisiri et al. (2005)	–

farmers. Using Scopus, 121 peer-reviewed journals confirmed large proportions of farmers (between 71 and 95%) in West Africa were aware of climate change and already facing its impacts (Limantol et al., 2016; Yéo et al., 2016; Koura et al., 2015). The observations by farmers are consistent with the numerous scientific assertions from models and empirical evidence. The fourth and fifth assessment reports of the Intergovernmental Panel on Climate Change (IPCC) estimate 5% decline in rainfall by 2050 (IPCC, 2014) while simulations by Jalloh et al. (2013) also projected 1.5 °C–2.3 °C increases in temperature by 2050. Reduced crop yields due to intense drought as well as negative consequences of climate change and variability on aquatic ecosystems and productivity of fish and livestock are also reported (Omitoyin and Tosan, 2012; Niang et al., 2014; Rhodes et al., 2014). The paper by Zougmoré et al. (2016) already gives a comprehensive coverage of climate change and variability impacts and projections for West Africa. The empirical evidences and future projections of West Africa's climate suggest that without sustainable intervention mechanisms to curtail the risks posed by climate on agriculture, most countries in the region will fail to meet set targets of the sustainable development goals. The adoption of climate-smart agricultural practices and technologies is viewed as one mainstream opportunity. FAO (2010) defined climate-smart agriculture to encompass agricultural innovations that achieve (1) increased productivity for improved food security, (2) improved adaptation and resilience to climate change and variability, and (3) reduced greenhouse gas emissions (mitigation) where possible. Recently, the concept of CSA has been introduced to cover technical and institutional options for dealing with climate change (Lipper et al., 2014). With strong regional partnerships involving non-governmental organizations, civil society organizations, the private sector, governments and farmer-based organizations, it should be possible to design and implement the most applicable CSA interventions in different economic regions of West Africa for wider promotion of best practices.

4. What agricultural innovations in West Africa have the potential to deliver on the principles of climate-smart agriculture?

Evidence from the literature suggests that farmers are using several agricultural innovations developed from indigenous knowledge or introduced technologies to improve their adaptive capacity to climate change and variability. Some of these practices are ex ante, meaning they are based on pre-informed climatic events while others are ex post (measures adopted after a climatic event has been realised) (Burke and Lobell, 2010). Below, we used evidence from the literature to discuss how six agricultural innovations selected through participatory testing in 5 locations within 5 countries (Ghana, Mali, Niger, Senegal and Burkina Faso) have been promising in achieving one or more of the three pillars of CSA: productivity, mitigation and adaptation.

4.1. Conservation agriculture

Conservation agriculture (CA) is a common practice in West Africa with soil and water conservation attributes. Building on conventional slash-and-burn agricultural systems, CA approaches involve: (a) minimum or zero-tillage; (b) maintenance of soil cover through cover cropping or mulching; and (c) crop rotation (Giller et al., 2009). Since its introduction by the Food and Agricultural Organization of the United Nations, CA has been accepted as one key agricultural innovation that delivers on one or more of the three pillars of climate-smart agriculture. The use of CA is driven by increased soil degradation in West Africa (particularly in the arid and semi-arid regions) where crop yields are relatively low due to low soil organic matter, limited use of fertilizer inputs and recurrent droughts (Buah et al., 2017; Lahmar et al., 2012).

In terms of productivity and adaptation, empirical evidence confirm CA increase the biological yield of major food crops such as maize, sorghum and millet even on poor soils and offer economic benefits from diversified crop rotation systems (Giller et al., 2009; Bayala et al., 2012). Meta analyses in the dry areas of Burkina Faso, Senegal and Niger attributed this to improved soil fertility, reduced soil erosion and improved soil water retention influenced by the maintenance of soil cover through the growing of cover crops; application of green manures and mulching (Bayala et al., 2012). As climate change and variability manifest as unpredictability of rainfall, recurrent droughts, increased run-off, rising temperatures etc., minimizing tillage activities and maintaining adequate soil cover through mulching offer multiple benefits to the farmer in dealing with climate-related risks. This includes reduced run-off, increased water infiltration, improved soil organic matter and improved soil moisture retention (Obalum et al., 2012). In addition, N fixation from legumes such as mucuna (*Mucuna pruriens*), cowpea (*Vigna unguiculata*), common bean (*Phaseolus vulgaris*) employed in CA markedly improve soil nitrogen availability and increase grain yield of cereals (Kermah et al., 2017). The encouragement of zero or minimum tillage in CA also minimizes labour costs in land preparation and enables early planting to synchronize the onset of rainfall. Furthermore, with crop diversification and use of varying intercropping approaches in CA, there is significant reduction in the risks of crop failure providing farmers important safety nets in the event one crop fails to perform as expected (Buah et al., 2017).

In terms of climate change mitigation, the quantification of net fluxes of greenhouse gases and carbon sequestration in CA is considered a major knowledge gap even in the global literature. Measurements of greenhouse gases with CA are normally related to the application of fertilizers rather than the key principles underpinning CA (Soler et al., 2011). In West Africa, few studies covering this area of research have concentrated on soil carbon. Generally, the return of organic residues and minimum disturbance to soil has been thought to be an option for reducing or balancing carbon emissions on arable fields. On upland rice fields in northern Benin, Dossou-Yovo et al. (2016) reported that the application of 3 Mg dry matter ha^{-1} of rice straw and 60 kg N ha^{-1} of fertilizer could compensate for the emission of carbon from organic matter decomposition. Using a simulation approach based on empirical datasets, Soler et al. (2011) also found that in Burkina Faso the application of nitrogen fertilizer and manure improved biomass production of crops which when incorporated into soils significantly reduced carbon loss. Despite concerns legumes used in crop rotations may contribute to nitrous-oxide emissions (Crews and Peoples, 2004), studies from Mali confirmed that growing N-fixing crops in rotation did not significantly increase N_2O emissions (Dick et al., 2008). While the application of CA techniques markedly improves crop productivity, dealing with the trade-offs between crop residue use as mulch in CA and as livestock feed has been a major concern among CA advocates as it constrains the adoption of the practice among farmers in West Africa (Giller et al., 2009; Ndah et al., 2014).

4.2. Planting pits - zai and half-moon techniques

In the Sahel areas of West Africa, farmers (particularly in Mali, Niger and Burkina Faso) are using planting pits (such as zai or tassas) and half-moon structures (Fig. 1) as water harvesting techniques to retain water for sorghum and millet production (Wouterse, 2017; Sawadogo, 2011). Developed from indigenous knowledge, the techniques are being promoted as climate-smart soil and water conservation technologies (Lahmar et al., 2012; Masse et al., 2011). Both Zai and half-moons involve digging pits (at 20–40 cm diameter and 10–15 cm depth for Zai and about 2 m in diameter for half-moons) to accumulate water before subsequent planting with or without the application of organic resources such as compost, plant residues and animal manure (Sawadogo, 2011). Farmers use the techniques mainly on bush fields, on dry eroded valley soils as well as on normal and degraded bare lands to maintain soil moisture, reduce soil erosion, and improve soil fertility (Slingerland and Stork, 2000). Zai and half-moons remain common among many smallholder farming communities in the Sahel despite their strenuous manual labour requirements (about 300 man-h ha^{-1}) during the dry season; unpredictable rainfall patterns and high temperatures (Barro et al., 2005; Clavel et al.,

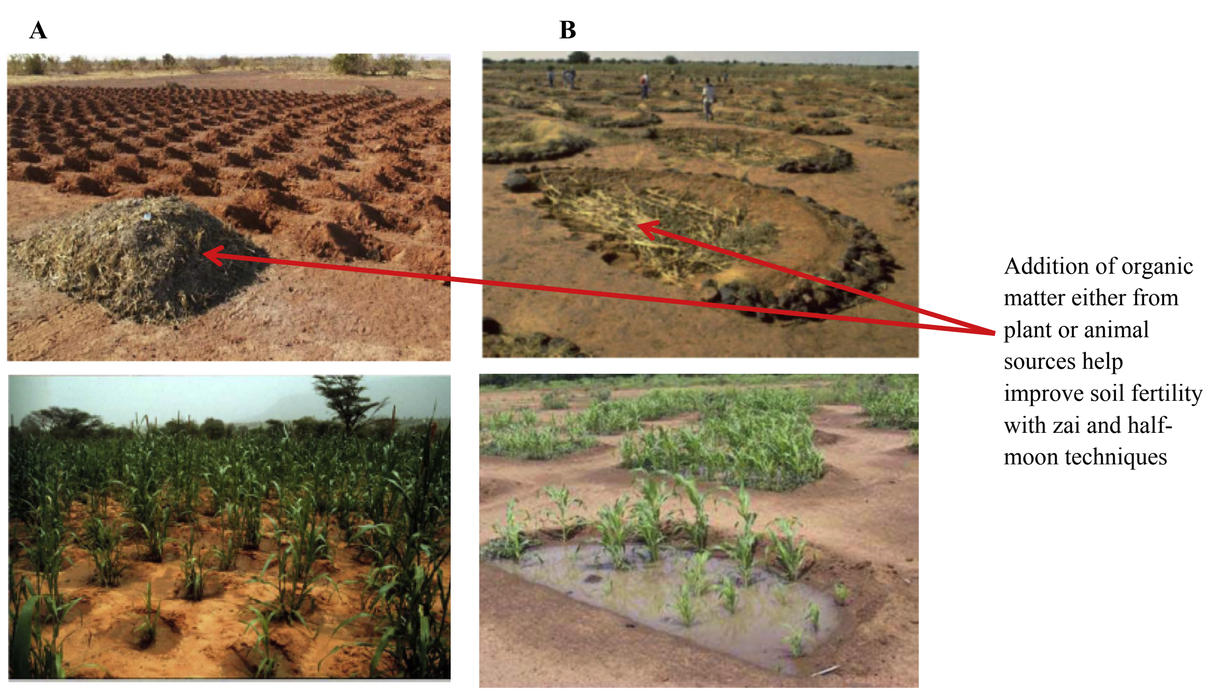

Fig. 1. Zai (A) and half-moon (B) rain water harvesting techniques for soil and water conservation in the Sahel zones of West Africa. Picture by Djibril S. DAYAMBA, ICRAF-Mali.

2008). 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 (Schuler et al., 2016). For half-moons, manure or compost application rate of about 14.6 t ha^{-1} could be expected while about half to one-third of that could be used in Zai (Zougmoré et al., 2014).

In terms of productivity, sorghum grain yields obtained using half-moons in Burkina Faso reportedly vary from 1400 to 2000 kg ha^{-1} (Lahmar et al., 2012). Smallholder farmers practicing these techniques have witnessed substantial improvements in yields of major food crops such as sorghum, millet and maize (Wildemeersch et al., 2015a). In Niger, a comparative study between zai and flat planting showed zai improved water use efficiency of millet by a factor of about 2 (Fatondji et al., 2006). In addition, grain yield with zai increased in 3- to 4-folds compared with flat planting which demonstrated the yield effects of improved water harvesting in zai alone (Fatondji et al., 2006). When combined with the application of cattle manure and millet straw, Fatondji et al. (2006) reported an increased yield of millet by 2–7 times compared with the control (with no amendments) due to improved nutrient uptake (43–64% for N, 50–87% for P and 58–66% for K) with zai. Similar observations have been reported by Wildemeersch et al. (2015a). In the savannah belt of Nigeria, Adekalu et al. (2009) also confirmed that zai and half-moons were suitable run-off water harvesting techniques for dry spell mitigation for cowpea production. Notwithstanding the benefits of zai and half-moons, large scale landscape adoption remains a concern in West Africa. In Niger, Wildemeersch et al. (2015b) reported low adoption rate of zai. This has been attributed to manure shortage and a lack of specific erosion knowledge. Similarly, Sidibé (2005) found that in Burkina Faso, variables such as education and perception of soil degradation significantly influences adoption of zai. The onus is on governments and development experts to promote farmer education and extension on the causes, effects and mitigation of land degradation and improve awareness and training on zai and half-moon techniques.

Generally, studies on the economics of using zai and half-moons are limited. In northern Burkina Faso, a study by Schuler et al. (2016) revealed that although labour costs can be higher, a net positive effect of applying zai on overall farm productivity can be expected. The study reported a significantly higher gross margin of using zai relative to conventional systems with net farm profits of 101,085 FCFA and 23,030 FCFA respectively. Moreover, there is limited evidence in the literature as to how these water harvesting techniques may contribute to climate change mitigation although emissions from the use of decomposable organic matter and nitrogen fertilizers can be expected. Empirical studies are needed to substantiate these facts.

4.3. Erosion control techniques - stone bunds and tie/contour ridge

Although rainfall is important for farming activities, excess rains cause flooding and erosion on farmers' fields causing crop destruction and removal of top soils (Baffour et al., 2012; Mashi et al., 2015). The use of innovative approaches such as stone bund and contour/tie ridges for reducing erosion and collecting run-off water for farming activities have become popular among farmers in West Africa, particularly in the dry areas of Burkina Faso, Mali, and Niger (Gigou et al., 2006). Stone bunds also called stone lines or contour lines involve pilling stones at close spacing along the natural contours of the land to slow down the speed of run-off water thereby reducing erosion and improving water infiltration (Sawadogo, 2011). As a climate-smart approach, stone bunds markedly improve the adaptation of cropping systems to climate change and variability due to its ability to reduce the impacts of flood and drought extremes on farmers' fields. Stone bund is also classified as a precision agriculture technique in the Sahel because it contributes to concentrating water to the reach of plants (Aune et al., 2017). Studies on farmers' field in the Sahel areas of West Africa have shown that using stone bunds as erosion barriers have the propensity to increase crop yields by 59% (Zougmoré et al., 2003, 2014). In addition, the combined effects of integrated soil fertility management techniques and stone barriers could increase crop yields by 84% (Zougmoré et al., 2003, 2014). In Burkina Faso, applying compost on fields with stone bund structures reportedly increased the grain yield of sorghum by 142% with a resultant economic gain of 145,000 to 180,000 FCFA per hectare per year in the rainy season (Zougmoré et al., 2014).

Similar to stone buds, tie/contour ridges are used by farmers to reduce erosion and improve water use efficiency on farmlands. As a micro-catchment system, they serve as climate-smart rain water harvesting techniques during water limiting conditions. They are widely used in the arid and semi-arid areas of West Africa and remain one of the most highly adopted soil and water conservation techniques (Sawadogo, 2011; Zougmoré et al., 2014). Unlike stone bunds, contour ridges are earthen structures, normally between 15 and 20 cm above the soil surface. Distance between ridges varies considerably but normally between 0.5 to about 10 m which is decided based on rainfall characteristics of farmers' field. In West Africa, integrated soil fertility management approaches such as application of compost, organic manure and fertilizers may be combined with contour ridging for increased productivity. In Mali, Traore et al. (2017) reported 56%–60% increase in the yield of improved millet and sorghum varieties with contour ridges relative to control fields.

4.4. Drip irrigation

Agriculture in West Africa is mostly rainfed; increasing the vulnerabilities of production systems to climate change and variability. While the potential for irrigation can be enormous, areas equipped with irrigation hardly exceed 5% of total agricultural area (Burney et al., 2010). Developments in improving water availability on farmlands are seen in the investments in drip irrigation facilities as a climate-smart option in West Africa particularly for the production of 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). Evidence from the literature shows farmlands equipped with drip irrigation could record up to 100% increase in yields relative to control fields (Maisiri et al., 2005). In addition, significant savings in water use, up to about 80% could be realized compared with conventional irrigation practices (Maisiri et al., 2005). This notwithstanding, government programs and support of non-governmental organizations will be needed to confront some major challenges (such as lack of reliable water supply; relatively high initial investment costs, limited access to fertilizers and limited access to improved seeds etc.), that frustrate farmers from adopting this useful technology. The consequential effects of water abstraction for irrigation on the local water table and water supply capabilities need thorough investigation in the quest to scale up drip irrigation in West Africa.

4.5. Agroforestry practices – farmer managed natural regeneration

In West Africa, evidence suggests that diversifying agroecosystems with integrated approaches such as agroforestry that combine tress with crops and/or livestock may improve resilience to climate-related risks (Sinare and Gordon, 2015). These farming systems have the potential to improve food security, reduce the magnitude of climate change, and increase resilience (Bayala et al., 2012). As a widely developed land use system worldwide, agroforestry is increasingly acknowledged as a component of climate-smart agriculture (FAO, 2013). With trees occupying 10% of about 50% of the world's agricultural fields, agroforestry is certainly a widespread land use system (FAO, 2010). Agroforestry technologies disseminated and practiced across West Africa are achieving tremendous impacts for climate change adaptation, mitigation and improved food security. One notable practice that has recently gained high adoption in the arid and semi-arid areas of West Africa is the farmer managed natural regeneration (FMNR). Despite its introduction before the evolution of the climate-smart agricultural concept, adoption of FMNR is viewed as a huge step to improving food security and contributing to climate change adaptation and mitigation, Historically, FMNR evolved out of an Integrated Development Project in the Maradi region of Niger in 1984 where tree stumps from trees such as *Faidherbia albida*, *Ziziphus spina* and *Z. mauritiaca, Bauhinia reticulata*, *Guiera senegalensi etc.* were naturally regenerated to reduce desertification and improve soil productivity (Tougiani et al., 2009). In Niger, FMNR has led to the planting of about two hundred million trees (Tougiani et al., 2009) with soil fertility benefits and providing substantial amount of biomass for household energy (such as charcoal and firewood) and contributing to food security for about 2.5 million people (Garrity et al., 2010). The benefits on bioenergy and food are valued at US$56 ha^{-1} yr^{-1}, or a total annual value of US$280 million (Garrity et al., 2010; Sendzimir et al., 2011; Neate, 2013). With the trees also serving as windbreaks and shelterbelts, cultivated fields are now resilient to wind storms posed by climate extremes. Where fodder species such as *Vitellaria paradoxa*, *Parkia biglobosa*, *Khaya senegalensis*, *Adansonia digitata* and *Faidherbia albida* etc. are used, their leaves are harvested and fed to livestock (Martin et al., 2016) particularly in periods of drought and grass scarcity. A study involving 1080 households in the Sahelian and Sudano-Sahelian ecozone of Burkina Faso, Niger, Mali and Senegal showed FRMR can be an important safety net for farmers in the event of shortfalls in crop yields and livestock due to climate change or variability. The study revealed that a community of 1000 households could increase income by US$ 72,000 per year by planting and protecting multipurpose trees on farmlands (Binam et al., 2015). In Ghana, Weston et al. (2015) showed FMNR could increase household income by US$ 887 per year which is substantial for a country with a gross national income per capita of US$ 1410. Although, quantification of soil carbon sequestration and emission of greenhouse gases with FMNR has received limited attention, the potential for climate change mitigation can be expected like analogous parkland systems (Luedeling and Neufeldt, 2012).

4.6. Climate information services

One of the major constraints to development of sustainable agriculture in West Africa is the high dependence of farming systems on rainfall. Recurrent droughts and unpredictability of rainfalls make farmers very vulnerable to climate-related risks (Boansi et al., 2018). Climate information services (CIS) is therefore seen as one mainstream strategy for climate risk mitigation strategy (Lodoun et al., 2014; Tarhule and Lamb, 2003). With the availability of CIS from either indigenous knowledge systems or meteorological information, farmers are well-informed about rainfall distribution patterns; intensity and frequency; wind storms and extreme events like droughts which enable them plan their agricultural activities effectively and efficiently (Wanders and Wood, 2018; Fitchett and Ebhouma, 2017). Critical planning decisions such as when to start land preparation, when to plant, crop variety selection, schedules for fertilizer application are all tied to receiving downscaled seasonal forecast information (Westermann et al., 2015; Zare et al., 2017). Fig. 2 shows different forms of climate information that help farmers make decisions.

Studies on the adoption of CIS in West Africa are limited. In the arid and semi-arid areas of Senegal, Mali, Niger, Burkina Faso and Ghana West Africa, over a million farmers are reported to be using CIS delivered through mobile phones and rural radios to effectively manage their farm operations (CCAFS, 2015; Etwire et al., 2017). Bringing together stakeholders in research institutions and the media, farmers receive agro-advisory services that enable them interpret information received and adopt the most suitable climate-smart agricultural practices based on local conditions. While studies on the costs and benefits of using climate information services are limited, studies by Ouédraogo et al. (2015) showed farmers using CIS used fewer inputs (e.g. organic manure, fertilizers) in cowpea and sesame production systems compared with those who do not. This is expected to reduce cost of production and increase profits from high yield of crops and reduced risk of crop failure that would have been caused by climate-related damages. With CIS becoming significant to farmers, many are now willing to

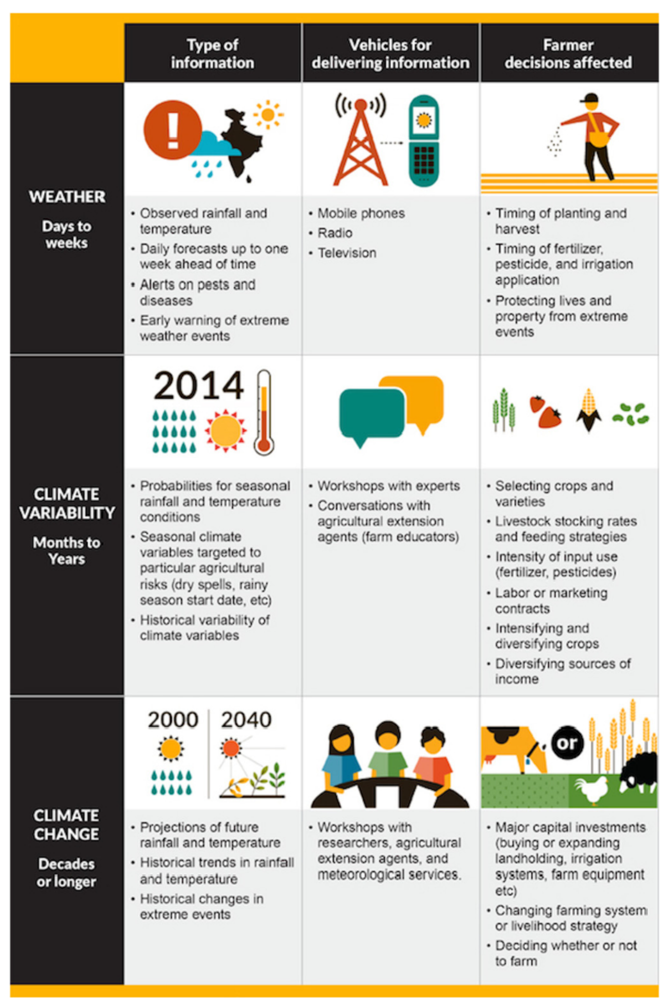

Fig. 2. How farmers around the world are making decisions based on weather and climate information (Hansen et al., 2016).

pay. A study involving 170 farmers in Burkina Faso showed 63% farmers were willing to pay (WTP) for CIS with an annual predicted value of XOF 3496 for seasonal forecast, XOF 1066 for 10-day forecast, XOF 1985 for daily forecast and XOF 1628 for agro-advisories (Ouédraogo et al., 2018). Similarly, a study by Oyekale et al. (2015) in South-Western Nigeria reported 68.1% of farmers were willing to pay N126.32 per year for CIS with factors such as access to CIS, years of farm experience, level of education, rainfall variability etc. as major determinants of WTP. An ex-ante approach used by Roudier et al. (2016) also showed that millet farmers in Niger using 10-day forecasts may increase farm incomes by 1.8%–13%. However, the results are shown to be more significant for farmers with access to farm inputs and larger farm sizes. In relation to productivity, studies linking CIS access and use to agricultural productivity are very uncommon. In the northern regions of Ghana, MacCarthy et al. (2017) showed that the combined use of CIS and integrated soil fertility management practices such as manure and fertilizer applications improved water and agronomic efficiency of maize.

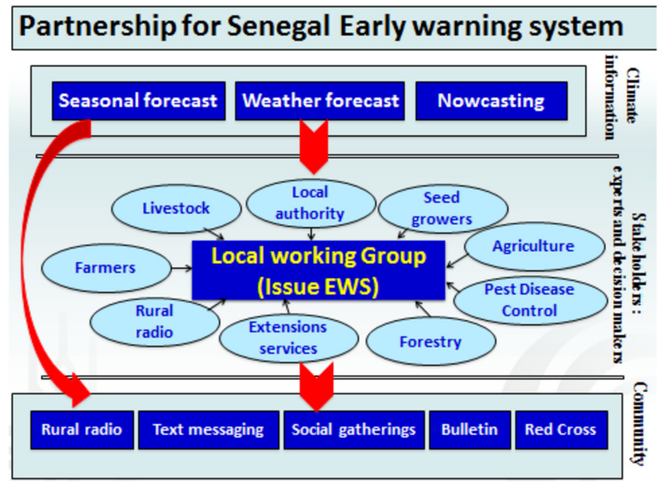

Fig. 3. Flow chart between stakeholders from generation up to dissemination (Zougmoré and Ndiaye, 2015).

5. What institutional settings could foster the promotion of CSA in West Africa?

As an innovative approach to achieving the sustainable development goals, CSA attracts a lot of actors at the village, community, national and regional levels. These actors are part of local, national and regional institutions which are key to promoting CSA. At the village and commune levels, the establishment of innovation platforms is viewed as a mechanism to develop and promote CSA technologies and practices. According to Homann-Kee et al. (2013) an innovation platform is a space for learning and change involving a group of individuals (who often represent organizations) with different backgrounds and interests: farmers, traders, food processors, researchers, government officials etc. It also brings together external actors such as technicians, administrative staff, local elected officials, researchers and members of associations, local organizations and savings and loans schemes (Sanogo et al., 2017). The importance of innovation platforms in promoting the goals of CSA is already felt in many parts of West Africa although further studies are still necessary to quantify the extent to which they are influencing CSA development and adoption on a large scale. In Daga-Birame in Senegal, Sanogo et al. (2017) reported how innovation platforms contributed to promoting economic activities (such as baobab fruits processing, market gardening), managing protected areas and improving farmers' accessibility to loans and insurance as part of a local development initiative in promoting CSA. Furthermore, the establishment of multi-disciplinary working groups played an important role in disseminating climate information and advisories (Fig. 3) which significantly influenced farm management decisions and other livelihood activities (Zougmoré and Ndiaye, 2015).

Scaling up CSA requires policies and political commitment. Countries have to be supported in putting in place policy; institutional, technical and financial means to mainstream climate change considerations into agricultural sectors and provide a basis for operationalizing sustainable agricultural and food systems under changing conditions (Dinesh, 2016). At the national level, the use of district and national science policy dialogue platforms can lead the mainstreaming of climate change into agricultural policies and national development plans (Essegbey et al., 2015). In Ghana, National Climate-Smart Agriculture Action Plan (2016–2020) was developed under the technical and scientific auspices of the Ministry of Food and Agriculture and a Ghana science-policy dialogue platform on climate change, agriculture and food security (Essegbey et al., 2015). In Burkina Faso, a national science-policy dialogue platform on climate change, agriculture and food security contributed to mainstreaming climate change into the national plan for the rural sector (PNSR - Programme National du Secteur Rural) (Palazzo et al., 2016). Similar initiatives have been undertaken by national platforms in Senegal for two key national policies - Programme for Accelerated Agricultural Development (PRACAS) and the Emerging Senegal Plan (PSE)) to mainstream climate change. The lessons learnt from the aforementioned multi-stakeholder district and national platforms suggest hope for future uptake of CSA practices in West Africa. However, this will depend on the continual capacitation of the policy platforms, the political will of governments and appropriate financial schemes. At the regional level, an intervention framework of CSA for the Economic Community of West African States (ECOWAS) and the creation of the West Africa Climate-Smart Agriculture Alliance (WACSAA) serve as springboards for promoting the mainstreaming of CSA in West Africa (ECOWAS, 2015; WACSAA, 2015).

6. Challenges for CSA development in West Africa

Notwithstanding the benefits of CSA, it faces a number of challenges including lack of proper understanding of CSA concepts, limited financial investments, the uncertainty of how farmers and policy makers manage trade-offs among the 3 pillars (productivity, mitigation and adaptation) of CSA etc. Below, we discuss some of the challenges faced by CSA in West Africa:

6.1. Limited understanding of CSA concept and framework

First and foremost, the definition and description of CSA by FAO (2010) remains popular among stakeholders of agriculture and development experts worldwide. However, uncertainties still remain as to what technologies and practices should be categorised as CSA and what among the three pillars: productivity, adaptation and mitigation has to be prioritised in a given context. In West Africa, farming systems and practices are diverse and with the variations in agroecological zones it is unclear whether a particular practise deemed CSA may remain so in all agroecologies with the same level of success (Williams et al., 2015). As scientists and development experts advocate for the mainstreaming of CSA into agricultural policies and rural development plans, policy makers would need better understanding of the context-specificity of CSA to influence initiatives that promote investments into the scaling up of CSA.

6.2. Setting priorities right between farmers and policy makers — how should trade-offs be managed?

During COP 21 in Paris, all West African countries developed mechanisms by which they can reduce greenhouse gas emissions. With the quest to meet the food requirements of its growing population, agricultural systems may be intensified, the result of which will see destruction of forests, intense use of chemical fertilizers which all contribute to emission of greenhouse gases. As farmers' priority will be on increasing productivity to meet market requirements, policy makers and governments would have to strife for a win-win situation. With the growing consensus of achieving food security and environmental sustainability in West Africa, a multi-stakeholder approach in generating empirical evidence that generates new knowledge and decision-making processes will be crucial to identifying technologies, practices and policies that result in a win-win situation under varying contexts.

6.3. Limited investments due to the lack of adapting and broadening a number of appropriate technologies or technological packages to underpin CSA

As it stands, it remains unclear what set of practices, technologies underpinning CSA are achieving great success in West Africa. In the literature, there is lack of documentation of successful CSA practices and under what context, for whom and for how long. Until now, conservation agriculture and agroforestry remains the most widely documented practices deemed to conform to the objectives of CSA (Kassam et al., 2009; Garrity et al., 2010). Meanwhile, the economic implications of these practices are limitedly studied. In addition, agroforestry and conservation agriculture faces many challenges regarding adoption (Giller et al., 2009; Sylla et al., 2012) making the business case for investment blurred. Improving documentation of successful CSA practices and developing a business case for investment is crucial for attracting investments from governments and the private sector for large scale adoption in West Africa.

6.4. Marginality of agro-ecological regions in West Africa

Most of West Africa's farming systems are located in arid to semi-arid environments and to lesser extent sub-humid zones. Most have severe soil fertility limitations, in addition to water constraints. With projections of increased frequency of droughts and worsening intra-seasonal rainfall variability (IPCC, 2014), exceptional innovations are required to ensure sustainable agricultural productivity. It is reported that improved soil fertility management coupled with other agronomic practices including appropriate choices of planting dates, crop types and varieties, and water harvesting techniques at field level, can increase crop yields and in some cases compensate for anticipated climate change impacts (Rurinda et al., 2014). Research findings also point to the critical role of integrated crop-livestock systems in enhancing adaptive capacity of smallholder farmers to climate change (Mapfumo et al., 2014). Investments that provide multi-dimensional solutions to challenges of access to water and soils, including options for infrastructure development (e.g. irrigation) may widen the scope for provision of CSA solutions.

6.5. Fitting CSA into the existing policy frameworks

With CSA becoming one mainstream opportunity to adapt and mitigate climate change and variability, existing national and regional level policies, programs, plans and strategies on agriculture and/or environment may have to mainstream CSA. Giving that the initial formulation of such policies, strategies, plans and programs were not informed by CSA, countries would have to conduct a thorough review of existing policy frameworks to inform appropriate revisions. This is expected to improve the robustness of existing policies to future uncertainties posed by climate change. However, Williams et al. (2015) reports that compatibility challenges posed by the mainstreaming of CSA into already existing policy frameworks have constrained such reviews and revisions. For instance, it is reported that many countries within ECOWAS are yet to link climate change adaptation into their national agricultural investment plans (Williams et al., 2015). It is in this context that new or improved policies may be required which will inform (and be informed) by CSA.

7. Conclusions

The aim of this paper, was to use evidence from the available literature to discuss (1) the need for climate-smart agriculture (CSA) in West Africa, (2) some notable agricultural innovations that deliver on CSA principles in the region, (3) institutional settings that could help scale up CSA, and (4) some challenges that must be addressed to improve understanding on CSA concepts and speed up its scaling up in West Africa. From the scholarly literature reviewed, CSA seems to be a suitable approach to address the challenges of building synergies among climate change mitigation, adaptation and food security which are closely related within agriculture, and minimizing their potential negative trade-offs. Among numerous CSA technologies, the review found (1) agroforestry (farmer-managed natural regeneration, rotation woodlots), soil and water conservation technologies (zai, half-moon, conservation agriculture) and (3) climate information services as highly valued promising options for climate change adaptation and risk management in the region. In addition, institutional settings at the community, national and regional levels such as the establishment of multi-stakeholder innovation platforms, national science policy dialogue platforms on CSA in parts of the region and the formulation of the West Africa CSA were found to be instrumental in promoting capacity development and awareness of CSA technologies and innovations in the region. This notwithstanding, the review found that CSA faces a number of challenges, including: lack of clear conceptual understanding, limited enabling policy and financing, thus needing critical attention and interventions. The prospects of CSA in West Africa hinge on the capacities of farming households and the region's national institutions to understand the environmental, economic and social challenges in the context of climate change, and consequently self-mobilize to develop and implement responsive policies at appropriate scales.

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