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Review

Climate-Smart Agriculture in African Countries: A Review of Strategies and Impacts on Smallholder Farmers

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Abstract: The agricultural sector contributes approximately 10–20% of the total anthropogenic greenhouse gas (GHGs) emissions. Consequently, climate change can negatively affect crop yields and livestock production thus threatening food security, especially in a vulnerable continent like Africa. This review provides an overview of climate-smart agriculture (CSA) practices and their impacts on smallholder farmers in five African countries (Algeria, Senegal, Benin, Nigeria and Zambia). A total of 164 published articles on CSA practices were reviewed. Analysis of extracted data showed that CSA practices are classified as follows: agricultural practices, restoration practices of degraded lands, forest and cropland regeneration practices, practices in the livestock sub-sector, water resources and use of weather and climate information services. Moreover, climate change effects differed alongside strategies adapted from one country to another. Adoption of these strategies was often influenced by financial means put in place by governments, the role of policy legislation, access to climate information and farmers' intellectual level. To address this deficiency, scientific-outcome-based research should be used to increase the effectiveness of climate adaptation management programs. In conclusion, to enhance the uptake of climate-smart agricultural practices in Africa, this review recommends the use of scientific-research-driven adaptation measures and prioritization of climate change in governments' agendas.

Keywords: climate change; smallholder farmer; impact; food security; adaptation strategies

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1. Introduction

Climate change refers to the increase in greenhouse gas emissions (GHGs) such as nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4) in the atmosphere causing irregularity, variability and unpredictability of rainfall, temperature increase, floods and drought. These effects will likely be "severe, pervasive, and irreversible" in the years to come, and the African continent seems to be one of the most vulnerable zones across the globe [1,2]. Many studies have shown the vulnerability of African countries to climate change in recent years. For instance, Hulme et al. [3] and the IPCC [1] both projected that by 2050, East Africa will experience warmer temperatures, a 5–20% increase in rainfall between December and February and 5–10% less rainfall from June to August. This change in climate will affect fishing in coastal and aquaculture systems and will cause a decline in crop production, particularly in maize [4]. Furthermore, in West, Central, Eastern and Southern Africa, drought and a rise in mean annual temperature were cited as the most prevalent climate variables that pose a high risk to rainfed crop production systems and the livelihoods of subsistence farmers [5].

The agricultural sector contributes approximately 10 to 20% of the total anthropogenic GHG emissions [6]. Consequently, climate change negatively affects yields of the crop, livestock and fishery production thus threatening food and nutrition security [7]. Moreover, globalization, urbanization, mechanization and population growth will accentuate and accelerate these effects. To deal with these effects, several research studies and technical reports have recommended the transformation of agriculture, food systems and generally our consumption models to more sustainable systems (decreasing the carbon footprint and greenhouse gas fluxes, replacing fossil fuels with renewable energy, genetic conservation and preservation of local breeds that are well adapted to the local environment, redeploying biodiversity) [1,2,8–14].

Climate-smart agriculture (CSA) has been identified as an important tool that can be used to overcome the challenges presented by climate change to agricultural systems and better incorporate agriculture in international climate negotiations [15]. Indeed, CSA enables farmers, key institutions and service providers to farmers build the capacity to adapt and effectively respond to long-term climate change as well as manage the risks that come about as a result of increased climate variability [5].

Using climate-smart agriculture (CSA), the agricultural sector has the potential to assist in mitigating climate change and increasing resilience by means of adaptation. According to the FAO [7], CSA was defined as agriculture that improves resilience, increases productivity in a sustainable way, reduces or removes greenhouse gases where possible and boosts attainment of national food security and development goals [16–18]. Furthermore, these strategies aim to mitigate and adapt to the climate change effects as well as provide a fair and stable income and good working conditions to smallholder farmers and vulnerable populations. CSA practices and technologies include a variety of integrated options that build on the diversity of Africa's farming systems and fisheries. These integrated options include agro-ecological approaches, sustainable natural resource management and ecosystem management that are central to climate change adaptation [19].

The CSA strategies could contribute significantly to social equity and local economies, especially, in southern countries [20–23]. A lot of interest has been shown in CSA in recent years and a number of actors such as governments, farmers, civil society organizations (CSOs), international organizations, the private sector and the research community have initiated different interventions in CSA [24]. In this paper, we assume that climate-smart practices are used in African countries and that their impact has been noted by smallholder farmers. However, the current status of the prioritization of climate change in the government agenda varies from one country to another. In Algeria, the climate change subject is not prioritized at all. The country is considered a "rentier state" (e.g., living on income from natural resource assets), and the extractive industry plays a key role in the country's economy, and therefore, climate change remains a very sensitive subject [25].

In Senegal, climate change presents a significant challenge. Hence, the country has prioritized adaptation actions and mainstream adaptation into development planning. This measure was taken to reduce greenhouse gas (GHG) emissions by 2030 and to increase the resilience of its ecosystems and populations to the impacts of climate change [26]. However, an implementation gap remains between adaptation plans and project realization. This could be due to financial constraints and limits in available, accessible and locally derived data on climate change and its impacts on various sectors and communities [27]. In Benin, in the year 2021, the government developed its national climate change adaptation plan [28]. The plan aims to reduce the impacts of climate change by developing resilience and adaptive capacity and facilitating the integration of climate change adaptation strategies into all planning projects. Moreover, it focused on eight most vulnerable sectors: energy, forestry, tourism, infrastructure, agriculture, water, health and the coast [29].

Nigeria conducted a review of its National Policy on Climate Change for 2021–2030 with the aim of defining a new holistic framework to guide the country's response to the development challenge of climate change. The document outlined sectorial and cross-sectorial strategic policy statements and actions for the management of climate change within the country's pursuit of climate-resilient sustainable development. The goal is to promote low-carbon, climate-resilient and gender-responsive sustainable socio-economic development [30]. The National Climate Change Learning Strategy was introduced in Zambia as a follow-up to the country's National Climate Change Policy of 2016 with the goals of increasing awareness and strengthening climate change knowledge, developing institutional and individual capacity for mitigating and adapting to climate change and mainstreaming climate change learning into national priority sector policies and systems [31]. The main objectives of this systematic review are to: (*i*) identify climate-smart agriculture practices used to improve resilience in five African countries, distributed from north to south (Algeria, Senegal, Benin, Nigeria and Zambia) (Figure 1), and (*ii*) assess the impact of these practices on smallholder farmers.

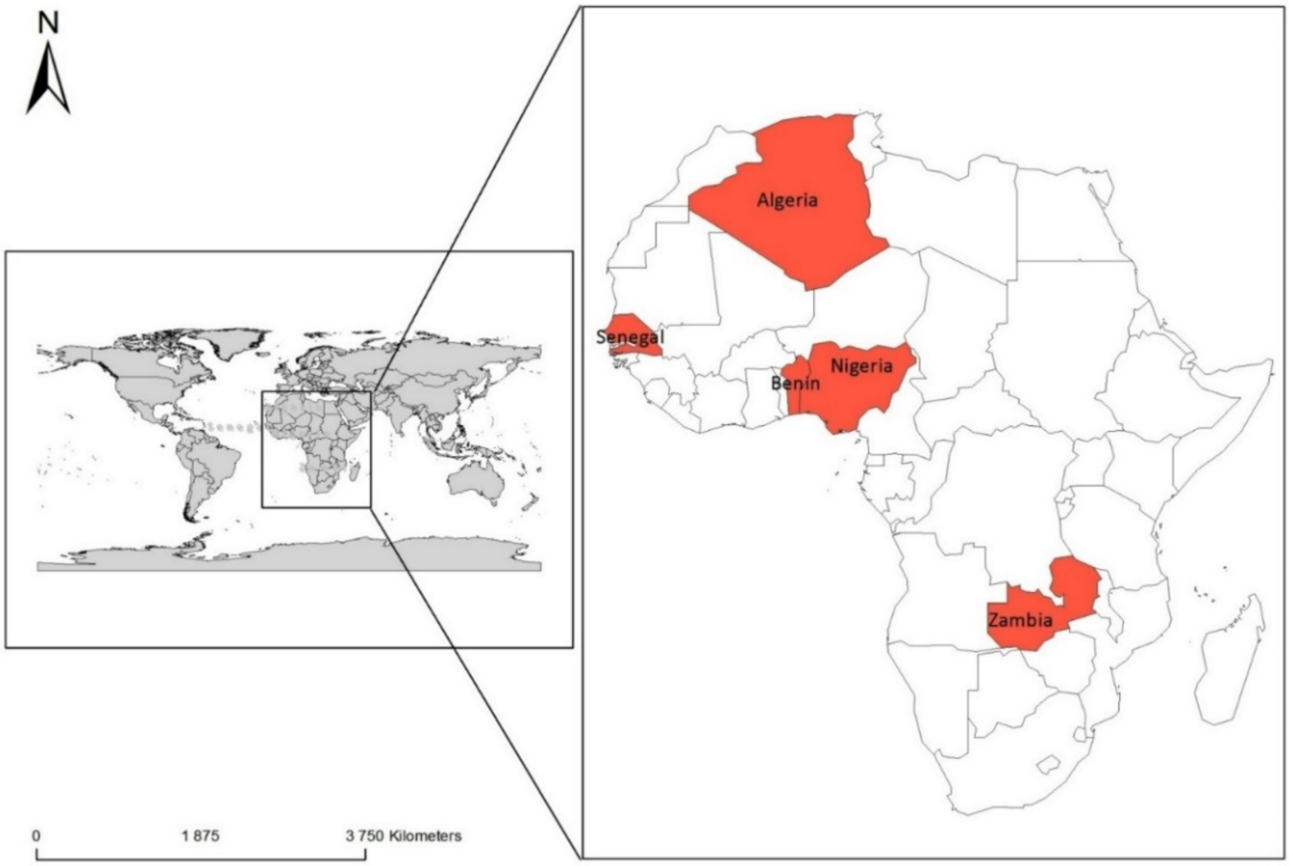

Figure 1. Location map of African countries involved in this review (Algeria, Senegal, Benin, Nigeria and Zambia) from which data concerning climate-smart agriculture during the last decade (2010–2022) were extracted and analyzed.

2. Materials and Methods

2.1. Method of Literature Search

As shown in Figure 2, publication search and article selection were conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [32]. A literature review of published research articles and technical reports regarding CSA practices from five African countries, distributed from north to south (Algeria, Senegal, Benin, Nigeria and Zambia) was conducted (Figure 1).

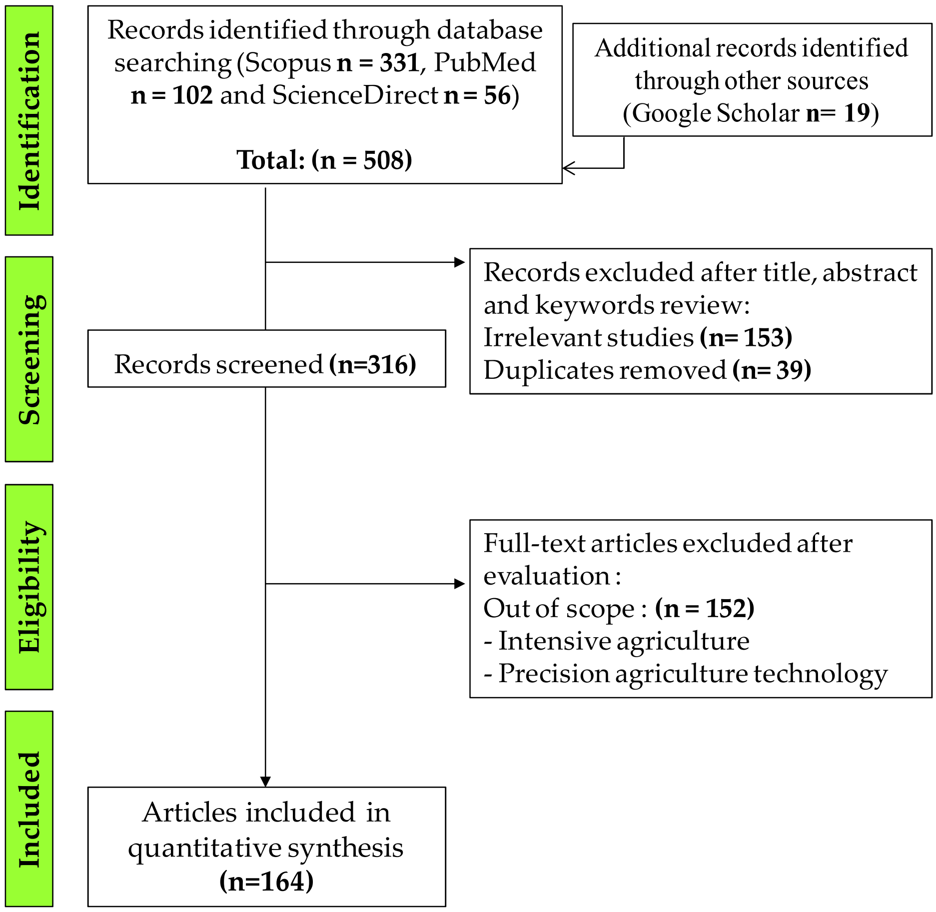

Figure 2. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram showing the detailed selection process of studies in the systematic review.

In order to conduct an effective search for systematic reviews, it is essential to combine multiple databases since it eliminates or drastically reduces the possibility that qualified papers on a certain topic would be overlooked [33]. During the identification phase, several keywords and their synonyms, related terms and variations were combined using Boolean operators "OR" and/or "AND": "Climate-Smart agriculture", "Climate-Smart agriculture AND Africa" and "Climate-Smart agriculture AND Country (Algeria OR Senegal OR Benin OR Nigeria OR Zambia)" (Table 1). The initial search in the scientific literature was carried out on different databases: ScienceDirect, Scopus and PubMed. Our research was limited to papers published within the last 12 years (from 2010 to 2022).

Table 1. Search string used for the systematic review process.

Database	Keywords Used
Scopus and PubMed	("Climate-Smart agriculture" OR (("Climate-chang*" OR "global-warmin*") AND Agriculture) AND (Algeria OR Senegal OR Benin OR Nigeria OR Zambia))
ScienceDirect	"Climate-Smart agriculture" AND (Algeria OR Senegal OR Benin OR Nigeria OR Zambia) "Climate-Smart agriculture" AND Africa

The Endnote X software (version 5, Thomson ISI ResearchSoft, Philadelphia, PA, USA) was used to import found references. Moreover, the references part of imported articles was checked to retrieve other related studies even in other databases such as Google Scholar. Duplicate articles were deleted, and only articles with further details were kept.

2.2. Relevant Screening, Inclusion and Exclusion Criteria

Two researchers conducted the review independently (S.B. and N.S.D.). No restrictions were imposed based on the publication's source. To make sure the articles were appropriate for inclusion, a preliminary screening was performed by reading the titles and abstracts. The full text of the retrieved articles was then downloaded.

Based on the review of published summaries, we excluded reviews, opinion pieces, book chapters, conference abstracts, letters to the editor and research articles that: (1) were published before 2010; (2) recorded data from other countries outside of Algeria, Senegal, Benin, Nigeria and Zambia; (3) recorded data from intensive agriculture; or (4) covered scientific articles and technical reports not published in the English or French languages. Moreover, duplicate articles were deleted, and only detailed articles were kept.

Data concerning CSA practices in participating countries were extracted from the selected qualitative and quantitative documents. The main criterion was the capacity to improve agricultural productivity and build resilience. More precisely, CSA practice efficacy was measured through the capacity of agriculture to achieve adaptation to and/or mitigation of climate change effects and to ensure food security. The selected articles were thoroughly reviewed, and the required information that was extracted was as follows: first author, year of study, provincial and geographical information and detailed description of agricultural and livestock innovative practices implemented at a small and large scale, in one or many countries.

2.3. SWOT Analysis

SWOT analysis is a method of strategic planning used to assess the strengths, weaknesses, opportunities and threats (SWOT) in many different fields [34]. Here, from data concerning CSA practices in participating countries, the SWOT methodology was used to determine CSA internal factors consisting of strengths and weaknesses influenced by a local ecosystem, on the one hand, and the CSA external factors consisting of the opportunities and threats that are affected by an external ecosystem, on the other hand.

3. Results

3.1. Characteristics of Eligible Studies

From the first stage of the PRISMA methodology which served to identify documents in the "topic" section using pre-defined search strings, document types (research articles and technical reports), language (English and French) and within the year range from 2010 to 2022, a total of 508 publications were found (Algeria: 46, Senegal: 73, Benin: 45, Nigeria: 174 and Zambia: 151). During the second stage (screening), an examination of the title, abstract and keywords was carried out, and 192 articles were excluded because they were found to be duplicates or did not meet the inclusion criteria.

Among the 344 qualified documents for the third stage (eligibility screening), 152 documents were excluded after full-text analysis, as those studies were related to intensive agriculture and precision agriculture technology topics.

In the long run, we identified 164 research publications that matched our objectives (Algeria: 30, Senegal: 48, Benin: 22, Nigeria: 39 and Zambia: 25). (A flowchart illustrating the choice of studies is shown in Figure 2).

3.2. Algeria

Algeria is located in the north of Africa (Figure 1), with an area of 2,381,741 km^2 and a rapidly growing population, which has gone from 25.911 million people in 1990 to 42.008 million people in 2018. Despite this growth, the rural population remains stable; it represented 27.4% of the total population in 2018 [35]. Sahara represents about 85% of the landmass, characterized by an entirely arid climate, with extremely low levels of surface water availability and less than 9% of the total population [36].

Algeria is located in an area considered to be particularly vulnerable to climate change [37–39]. A number of studies have reported a future decrease in total annual rainfall by 15–30% [40] and an increase in the desert climate with the loss of the temperate northern zone, which is demonstrated by both an increased temperature and a decrease in precipitation [37,41]. Moreover, in this region, the climate is dry, and most agricultural soils comprise a limited organic matter content of less than 1% coupled with poor soil aggregate structure. The prevalent practices of tilling the land, overgrazing and exposing bare soils have always worsened the situation. The long-term effects are severe degradation of land and ultimately desertification, as observed in several parts of the region [42]. Due to these effects, agriculture production is not stable and presents severe fluctuations. For that reason, more adaptive agriculture with regard to climate change must be implemented, and the use of more advanced technological solutions must be enhanced to limit the climate change effects on agricultural productivity.

3.2.1. CSA Practices

Smallholder farmers in Algeria are currently required to raise agricultural production while using fewer resources (such as less energy and more water) and under more constraints (e.g., an increase in temperatures, soil salinity and desertification). A number of CSA practices have been initiated and implemented, such as water saving, construction of dams and hill reservoirs, fight against erosion and desertification, anti-drought programs, protection and rehabilitation of steppe lands and preservation and extension of forests [43–48]. Here are some examples of climate-smart innovations in the agricultural, livestock and forestry sectors, financial resources and policy evolution.

- *Agricultural practices*

During the 1980s, the Biskra region in the southeast of Algeria's Sahara experienced quick changes in agriculture which resulted in the transformation of the terrain. Production of horticultural crops in greenhouses coupled with the development of irrigated agriculture has resulted in a noticeable agricultural boom [44]. However, water- and land-use efficiency remain very weak, and these problems are exacerbated with: low-cost water which is pumped free, low annual precipitation estimated at <250 mm and an intermittent transfer of greenhouse construction to escape problems with soil-borne diseases [48].

To avoid these problems and to enhance investment and trade in a modern, sustainable horticulture sector, Algeria has collaborated with the Netherlands to realize a practical greenhouse system best suited to the local harsh arid environment. Adaptive greenhouse systems are based on what is called the SmaSH concept of GHI, which stands for smart sustainable horticulture and aims to optimize greenhouse designs to one specific setting, climate conditioning, greenhouse climate control, substrates and nutrition control [49–51]. Since then, farmers have widely used this mode of production (using greenhouses) which has allowed them to increase their yields in a very significant way.

Another strategy developed by smallholder farmers, especially in the semi-arid regions of Algeria is the integration of crop–livestock systems (ICLSs). This system is centered around interactions between animal and crop activities which are temporal and spatial [52]. This strategy is considered a conservative farming practice based on minimum mechanical soil disturbance and the permanent cover of soil using crop residues and/or cover crops. This is also coupled with the diversification of crops using a crop rotation system [53]. ICLS practices under conservation agriculture principles have contributed positively to growth yield and the reduced climate vulnerability of farmers, promoted more diverse on-farm crops and reduced market fluctuation vulnerability (in terms of fuel, seeds, feed resources, labor, seeds, etc.) [53,54].

- *Forest and cropland regeneration practices*

In 1972, the *green dam (le barrage vert)* was launched to protect watersheds against erosion and manage the use of forests, rangelands and other dryland natural resources in a sustainable way. This project played a key role in adapting and mitigating climate change thus improving the food security and livelihoods of the people in Algeria [55]. From east to west, it extends over a strip of 1000 to 1500 km long and about 20 km wide and over an area of 3000 ha [56]. The project has produced significant positive results such as the replenishment of pastures and species diversification (Atlas pistachio, Acacia, Arizona cypress (*Cupressus arizonica*), Aleppo pine (*Pinus halepensis*) and Atriplex (*Atriplex halimus*, *A. nummulaira*) almond). However, human overexploitation and agricultural expansion caused negative effects [55].

- *Practices in the livestock sector*

A scientific project was launched in 2018 in collaboration with smallholder farmers to bring together African nations (Algeria and Tunisia) and European nations (Greece) to implement CSA practices through biodiversity restoration and more sustainable livestock establishment [22]. Algerian autochthonous bovine populations resemble the Brown Atlas, and it is segmented into subpopulations, namely Guelmoise, Cheurfa, Krouminiène, Chelifienne, Sétifienne and Djerba. These subpopulations are well adapted to the local harsh arid and semi-arid environment. The size of these populations has been estimated by the "*Recensement National des Exploitations Agricoles et d'élevage RGA*" [57] at nearly 896,287 subjects. Moreover, these animals are characterized by good rusticity, which represents an essential socio-economic element thus largely contributing to the nourishing of the rural people. However, the introduction of exotic livestock breeds in Algeria has led to a profound mutation in the genetic structure of the dairy animal. This has resulted in a drastic decrease in the local cattle population. Consequently, the proportion of local breeds has decreased from about 82% in 1986 to 48% in 2016 [58].

In northeastern Algeria, local breeds were identified and tracked [11,14]. Products (such as milk and traditional cheese) were researched because consuming milk and its derivatives from these breeds is historically a very old eating practice [59]. The studies found that the products could contribute significantly to the local economies as they could easily be associated with contemporary food trends such as "local" and "slow food" [22]. Results show that among the ecotypes studied, the Sétifen ecotype will be very beneficial for a genetic selection program [11]. Concerning products, a large certification program is underway.

- *Water resources management*

Farmers in the Algerian Sahara devised a number of techniques to combat the effects of drought, on the one hand, and the pressures on water resources from other sectors such as the extractive industry, on the other hand [25]. A good example is the widespread practice of sustainable use of water in potato crop production in the El Oued region (southeast of Algeria). In this region, an enormous Sub-Saharan Aquifer occurs close to the surface; thus, agriculture has developed on a substantial scale over an area of more than 30,000 hectares of sand used for potato cultivation of two harvests yearly. Currently, the smallholder potato producers (approximately 2000) in El Oued continuously irrigate the potatoes using center-pivot irrigation. These practices have been reported to be unsustainable, and there is room for improvement in terms of water use efficiency, fertilizer and pesticide applications, CO_2 footprint, field layout, the choice of appropriate varieties, the quality of the starting material and prevention of postharvest losses [60].

To avoid these problems, and to make potato production more sustainable, several strategies have been tested on five-hectare demonstration farms. These strategies include smart irrigation using complex scheduling, innovative equipment and precision techniques and the introduction of new (climate-smart) potato varieties. Results show an estimated water saving of more than 50% by introducing underground drip fertigation. Moreover, tuber yields have slightly increased in autumn (9.2 tons/hectare to 11.5 tons/hectare using center-pivot irrigation and subsurface fertigation, respectively). The new potato varieties, i.e., Arizona, Manitou and Rudolph, had better yields than the traditionally used Spunta [45]. Despite being a relatively simple installation, in which planting and installation of driplines can be carried out at the same time, subsurface fertigation is not yet widely used in Algeria, probably due to the current costs of water (fully supported by the authorities), investment costs, knowledge gap on technology and lack of skills to get it running.

- *Access to credit and financial resources*

For the past 20 years, Algeria has adopted national policies for increasing investment in CSA to provide a fair, stable income and good working conditions to smallholder farmers and to contribute to social equity and rural economies. This policy has been implemented through various national plans, including the National Agricultural Development Program (PNDA: *Programme National de Développement Agricole* from 2000 to 2010), the Agricultural and Rural Renewal Policy (PRAR: *la Politique de Renouveau Agricole et Rural* from 2010 to 2014) and the FILAHA Plan from 2014 to 2020.

The PNDA is the most important program which aims to counter the problems arising due to challenges and constraints which are natural, technical, organizational and institutional. These problems have been the cause of weak national food security, degrading natural resources and reducing cohesion and social peace in rural areas. Results from these reforms show a growth rate of total factor productivity which recorded significant annual growth from 1.6% per year over the 1991/2000 period to 6.6% per year over the 2008–2013 period [61].

3.2.2. Impact on Smallholder Farmers

The impact of CSA practices on smallholder farmers in Algeria is poorly documented when compared to other African nations. Here, we included data collected for Maghreb countries (Tunisia and Morocco) which present similarities in terms of climatic conditions and CSA practices [62,63].

CSA practices using conservation agriculture principles have shown very beneficial results on farmers' finances. In the region of Sétif (northeastern Algeria), a comparative study of two cropping systems used on 28 farms namely no-till and tilled wheat showed that the no-till system had the best economic results (in terms of the average annual costs and returns per hectare) with a difference in gross margin of 84 USD/ha compared to conventionally tilled wheat. Additionally, no-till was shown to need less labor and fuel, with 241 min/ha and 42 L/ha compared to 624 min/ha and 99 L/ha for conventional tillage [64].

In addition, with regard to the development of crop diversification in Sahara regions in Algeria, palm tree monoculture and tunnel greenhouses have dramatically expanded on the margins of traditional oasis and horticultural production under greenhouses, and the expansion of irrigated agriculture experienced very significant growth [44]. In the city of El Ghrous in the region of Biskra, data collected from a survey of 100 farms specializing in early tomatoes under greenhouses showed the comfortable profitability of this activity. With an average cost price per kilogram of tomato of 26 DZD/kg and an average selling price of 61 DZD/kg, the average gross margin of the producer amounted to 35 DZD/kg, i.e., 57% of the sale price [65].

A study conducted in Morocco in 2013 which covered 21 major wheat-producing provinces (representing 79% of the total number of wheat producers) analyzed the impacts of the conservation agriculture adoption. Results show that the adoption of zero tillage, crop rotation and crop residue retention led to higher yields of 307 kg/ha (35%), higher gross margins of 99 USD/ha (44%) and 23 kg/capita/year (38%) more consumption of wheat relative to the conventional system [66].

Moreover, the non-adoption of CSA strategies by farmers can lead to economic losses. In Tunisia, a study was carried out to assess the overall economic loss caused by the inefficient use of irrigation water. About 724 farms producing the main 20 crops were randomly sampled with respect to the type of farm, bioclimatic area and system of production. Results show that the total direct economic losses of both types of water inefficiencies were valued at around TND 470 million (≈USD 150 million) [67]. Another study, also carried out in Tunisia, evaluated the economic viability of two tree-based adaptation strategies (cactus intercropping and olive tree plantations) in the rangelands of central Tunisia. The results show that whereas rainfed plantations were not at all profitable, the cultivation of irrigated olive trees was advantageous for farmers and society as a whole. Additionally, intercropping with cactus to supplement livestock food and watering was a very effective approach to boost farmers' revenues without increasing agricultural water consumption [68].

3.3. Senegal

Senegal is a West African country (Figure 1), which covers 196,712 km^2 and has more than 16,000,000 inhabitants. The main economic activities are livestock production and agriculture, which account for 17.5% of the country's GDP (gross domestic product). These sectors employ 69% of the country's population [69].

The agriculture sector is dominated by smallholder farmers who grow millet, sorghum, maize and rice for subsistence purposes [70]. The ecosystems, society and the economy of Senegal are all extremely vulnerable to climatic changes. The main climate challenges to the nation are increasing temperatures and unpredictable precipitation that cause drought, more frequent pluvial flooding and associated health problems [71]. A concerning scenario amid remote regions is made even worse by a raise in the frequency and severity of floods, droughts, cyclones and the increase in sea level. Due to the huge reduction in harvests, water shortages and escalating health challenges brought on by these natural calamities, the populace is becoming increasingly vulnerable to food insecurity [72]. Senegal has experienced eight (8) severe droughts since 1977, with the droughts happening periodically for several decades. Around 800,000 people were reported to have experienced food insecurity as a result of the drought in 2011, which resulted in a 20% drop in grain production and a 31% drop in groundnut production. Most of the affected people relied on agriculture to meet their daily necessities. In addition, Senegal experienced floods frequently, affecting an average of 400,000 to 600,000 people per year, between 1980 and 2008 [73]. Rainfall is the principal determinant of farmers' activities because more than 70% of the agricultural production is rainfed and irrigation covers less than 5% of all arable farmland [74]. According to the report of some studies, low-input rainfed agriculture will be severely damaged by climate change, with yields for sorghum and millet dropping by about 50% by the year 2080. Depending on the type of crop, high-input rainfed agriculture's production will decline more gradually, from 2–3% in the 2020s to 15–40% in the 2080s [75].

Since then, many initiatives have been taken by both development partners and the State to enable producers to cope with the effects of climate change. Among these initiatives is the promotion of CSA to improve food security and people's livelihoods [17]. Senegal has undertaken significant initiatives to encourage resilience through the adoption of climate-smart practices [76]. The nation is making huge strides in creating a political landscape that will strengthen CSA programs [74]. Although the term "climate-smart agriculture" (CSA) may be new for a set of agricultural innovations, tools and policies, the concept is already ingrained in many indigenous practices, tools and methodologies that have assisted farmers in producing food in the face of rapidly changing climatic conditions [17].

3.3.1. CSA Practices

In Senegal, good agricultural practices related to CSA have been identified [26,72,77–79]. Results from the previously cited literature show that CSA practices can be divided into six groups: agricultural practices, restoration practices of degraded lands, forest and cropland regeneration practices, practices in the livestock sub-sector, water resources and weather and climate information services.

- *Agricultural practices*

These methods are used by smallholder farmers to mitigate the effects of climate change. These include the adaption strategies used in the agricultural sector to increase productivity [72]. The practices are:

- Erosion control practices;
- Development of stone bunds;

- Stabilizing of gullies by filtering dikes;
- Fixing the dunes;
- Using improved varieties. For the countries of Gambia, Mali, Senegal, Burkina Faso, Ghana and Guinea in particular, the International Rice Research Institute (IRRI) published 28 climate-resilient high-yielding rice cultivars that are also iron and salinity tolerant [80];
- The application of novel cultivation techniques adapted in farmer field schools (FFS) for the subsequent extension to producers.

- *Conservation agriculture*

It is also recognized that land degradation reduces the productive capacities of cultivated soils [81]. The use of CSA is driven by increased degradation of soil in West Africa, especially in the dry and semi-arid regions, where crop yields are relatively low due to low soil organic matter, insufficient fertilizer use and frequent droughts [82]. The main practices used in Senegal are composting, the organic manure technique and the manure pit, Zaï, desalination of mangrove rice fields and restoration of salty soils [72].

- *Forest and cropland regeneration practices*

Some practices have also been promoted by researchers and are related to the regeneration practices of forests and cultivated lands and the integrated management of water resources. Farmers used: assisted natural regeneration (ANR); agroforestry; defending; crops of recession; and use of neem pesticides. A total of 11 million *Faidherbia albida* trees were reported to have been planted on 27,000 acres of degraded land in the Kaffrine region of Senegal [19].

- *Practices in the livestock sector*

To combat the effect of climate change, breeders in the livestock sector currently employ the following strategies: practice of haymaking; treatment of straw with urea; agricultural pastoralism; and pastoralism. Livestock keepers are reportedly likely to be impacted by a drop in the availability of animal feed and water, changes in the severity and distribution of pests and illnesses that affect both livestock and pasture and smallholders' mixed crop–livestock systems [83,84].

- *Water resources management*

According to long-term observational data and climate projections, freshwater resources are vulnerable to climate change and may be significantly influenced, with significant consequences for Senegal's human communities and ecosystems [85]. When that happens, managing water resources becomes a prerequisite to coping with the effects of climate change. All efforts taken to promote effective and efficient management of water for profitable agriculture are considered water resources: construction of anti-salt dikes and stormwater retention; practice of micro-irrigation; storage of runoff by micro retention; rainwater harvesting; and integrated management of water resources.

- *Weather and Climate Information Services (WCIS)*

Improved weather and climate information services (WCIS), or the packaging and distribution of downsized and useful weather and climate information (WCI) that satisfies end users' needs, have received a lot of attention in recent years [86–91]. Particularly in Senegal, several studies have shown that the use of WCIS has become very popular among farmers, fishermen and livestock breeders in recent years [17,70,92–94]. Millions of Senegalese farmers have been receiving simplistic forecasts since 2011 as part of climate information services. The National Weather Agency has been empowered by partners such as the USAID, CCAFS/ICRISAT, WFP FAO, etc., to develop climate information for producers, breeders and fishermen. More specifically in the field of agriculture, consultations and meetings have been organized before to identify the needs for climate information with the different categories of users. The National Meteorological Service (ANACIM) then started producing tailored climate information. To ensure proper understanding and better use of

CIS, training sessions were organized with producers to share with them the content of the messages transferred but also the likely decisions for each type of information received. Partners responsible for disseminating climate information (community radio stations, private companies, etc.) have also been trained to better convey information [5,70,95]. The forecast data offered include the total amounts of rainfall, the beginning and end of the rainy season, as well as a 10-day prognosis for the duration of the rainy season [5]. Farmers are better prepared to deal with global climatic change by receiving pertinent and understandable climate information [24]. Documented evidence from Ghana and Senegal reported a great potential in improving the adaptive capacity of smallholder farmers to climate variability and extreme weather events [96].

Moreover, ANACIM formed Multidisciplinary Working Groups (the Multidisciplinary Working Group (MWG) was an initiative of the Agro-Hydro-Meteorology (Agrhymet for the Sahel) national committee. More than 27 MWGs have been created in Senegal. Members of MWGs include all relevant state extension technical services and relevant local organizations within the districts. The mission of the MWG is to ensure the close monitoring of the climate phenomena and to alert timely, competent structures in order to prevent potential risks. They receive meteorological information such as the seasonal, weekly and instant forecasts from the meteorological office and tailor the information using the updates from the actual ground reality with regard to the areas of competency of each participating service. They meet three times a month during the cropping season to discuss and take action for better planning of the farming activities within the district for the next 10-day period. Each MWG should have a legal status and be led by the prefect of the district [71]) (MWGs) in partnership with other technical services (agriculture, livestock and environment) for the dissemination of WCIS to farmers. The MWGs served as a forum for interaction where meteorologists and stakeholders from other industries, including agriculture and water, could work together to develop early warning information [97].

Additionally, "Participatory Integrated Climate Services for Agriculture (PICSA)", a new strategy for expanding climate information services, has been launched. Using historical climate records, participatory decision-making tools and seasonal climate forecasts, this method helps farmers identify and better plan livelihood options suitable to their circumstances and climatic conditions [98]. Together with local government extension officers, the Senegalese Institute for Agricultural Research (ISRA) and CGIAR World Agroforestry Center (ICRAF) adopted this strategy.

Furthermore, crop insurance has received extensive partner promotion and has emerged as a promising risk transfer tool. However, caution is advised about its integration into a more comprehensive risk management strategy. The viability of pricing agricultural insurance products in Senegal at rates that are both affordable to impoverished farmers and profitable for insurance providers, without the need for significant, ongoing subsidies by the government or outside donors, is a particular challenge that deserves to be explored in the upcoming years [72].

The analysis points out opportunities to create the political will to build an environment that is conducive to the widespread adoption of CSA. The analysis identifies prospects to create and channel CSA needs from the perspective of public opinion [76].

3.3.2. Impact on Smallholder Farmers

In this section, we provide evidence from the literature regarding the effects of CSA use in agricultural production. However, Senegal continues to have a relatively low adoption rate for climate-smart behaviors and technologies [99]. Researchers have criticized the linear approach for its dominance in knowledge generation and its restrictive perspective of innovation, but it is nevertheless used in many programs and organizations [77].

Regarding forest and cropland regeneration practices, a study involving 1080 households in the Sudano-Sahelian ecozones of Burkina Faso, Niger, Mali and Senegal's Sahelian revealed that farmer-managed natural regeneration can be a crucial safety net for farmers in the event of crop yield and livestock underperformance brought on by climate variability.

The study reported that by planting and maintaining multipurpose trees on farmlands, a community of 1000 households may improve its income by USD 72,000 [100]. Nyasimi, Amwata, Hove, Kinyangi and Wamukoya [19] showed that trees provide a source of fuel and feed and that replanting has decreased the amount of time women spend gathering firewood from 2.5 h per day to 0.5 h today. In addition, the tension between farmers and herders has been reduced by 80% as a result of regreening the land.

Moreover, with regard to weather and climate services, a study carried out by Diouf, Ouedraogo, Ouedraogo, Ablouka and Zougmoré [93] showed that the adoption of seasonal forecasts (SF) has a considerable impact on Senegalese farmers' ability to produce their principal crops and earn a living from farming. Depending on the type and sex of the crops, this effect varies. For millet and rice crops, the users (men and women) of the seasonal prediction gained an average of 158 kg/ha and 140 kg/ha, respectively, more yield than the non-users. Men are more affected by the application of SF on rice (321.33 kg/ha vs. −25.3 kg/ha) and millet (202.7 kg/ha vs. 16.7 kg/ha). The rise in agricultural production was the most notable result of improved seasonal forecasts for farmers in Senegal [101]. The initiative developed test farms that rigorously followed forecasts and related agricultural recommendations and matched them to control farms employing conventional techniques to test yield increases. Similar information was provided for groundnut flowers and souna, demonstrating increases in yields of 50% and 15%, respectively [24]. Seasonal predictions were being distributed to 7.4 million rural Senegalese as of August 2015 using 102 rural community radio stations and short messaging services (SMS) [92]. Climate data are now regarded as agricultural inputs in Senegal, alongside the fundamental production inputs of seeds, fertilizer and machinery [70]. According to an impact assessment study, the use of CIS in Senegal increased household income by between 10% and 25% [96].

The usage of weather and climate information services, particularly seasonal forecasts, has been found to alter farmers' attitudes and strategies, according to some authors, including Hassan and Nhemachena [97] and Ingram et al. [102]. Additionally, Chiputwa, Wainaina, Nakelse, Makui, Zougmoré, Ndiaye and Minang [94] researched the effects of the Multidisciplinary Working Group in Senegal. Results show that depending on the type of information provided, MWGs are positively related to farmers' awareness, access to and adoption of WCI, leading to farm management responses. Farmers' knowledge of WCI normally rises by 18%, their access improves by 12%, and their adoption rises by 10% when MWGs are present.

Furthermore, a study conducted by Bonilla-Findji et al. [103] discovered that although 159 male and 110 female farmers adopted the CSA techniques promoted in Kaffrine, the adoption rate was lower for households headed by women than for those headed by men. Higher acceptance rates for agroforestry and reduced tillage were reported (70%), medium adoption levels for manure (40%), organic matter plus micro-dose of artificial fertilizers and FMNR (about 23%) and low acceptance rates (15%) for micro-dose (NPK plus urea) and drought-tolerant varieties. Approximately 90% of farmers who adopted CSA techniques reported positive results in terms of providing substantial incomes, trying to improve food access and diversity, enhancing climate resilience and not increasing agricultural labor time. From 8 to 88%, different CSA practices and gender differences were assessed to impact yield improvement.

Evidence suggests that PICSA specifically encouraged farmers to consider and then implement a number of innovations, such as (i) adjusting the timing of activities such as sowing dates, (ii) implementing soil and water management practices, (iii) choosing crop varieties, (iv) managing fertilizer and (v) adapting their season plans (farm size, etc.) to the actual resources available to them [98].

3.4. Benin

Located in West Africa at latitudes 6°30′ and 12°30′ north and meridian 1° and 30°40′ east, it is in the tropical region between the equator and the Tropic of Cancer (Figure 1). Africa's coastline developing nation of Benin is subjected to the harmful consequences of climate change [104]. Significant disturbances have been a feature of climate change since the 1960s. In the same way, future predictions have been made on increased drought, late and violent rains, floods and temperature rise. By 2100, the temperature is expected to rise by +2.6 to +3.2 °C. In addition, rainfall in the southern part of the country will continue to be higher (+0.2%), but it will decrease by 13–15% in the northern part of the country by 2100 [105–107]. Without taking any action to adapt to climate change, agricultural productivity will suffer more under these scenarios and is predicted to fall by 5 to 20% by 2025 [108,109]. Since 80% of the population relies on agriculture for livelihood, this will have a negative effect on their quality of life [110].

3.4.1. CSA Practices

In Benin, to assess climate change farmers' perception, as well as the adaptation strategies put in place, several CSA practices have been initiated, conducted and implemented:

- *Agricultural practices*

Farmers have created some climate-smart agriculture techniques in the Zou Department of southern Benin, including the diversification of crops and livestock, the use of improved varieties, chemical fertilizers and pesticides to combat diseases and pests and agroforestry and perennial plantations (oil palms, orchards, forest species). Additionally, to diversify their sources of income, several farmers have adapted small ruminant and poultry husbandry [111].

Maize is one of the major staple foods of the municipality of Zè, which is located in the sub-humid Guinean zone in the southern part of Benin. It is cultivated by 85% of the country's farmers, and the government of Benin has made it one of its key areas in its effort to combat extreme poverty and hunger [112]. Consequently, maize yield is anticipated to decline by 5 to 25% by 2050 in the absence of proactive measures to develop adaptation strategies [113]. Beninese maize farmers have therefore established some adaptation strategies to deal with it and lessen the negative effects of climate change, such as adjusting the cropping calendar by changing planting dates and sowing times, using improved crop varieties, integrating crops and livestock and planting trees to naturally shade crops during prolonged dry seasons [112].

Arouna et al. [114] showed that the best strategies developed by Beninese farmers were the adoption of short-cycle varieties, the adjustment of the sowing period, staggered sowing, agroforestry and the construction of cages for animals to fight strong winds. In addition to these strategies, other farmers have developed additional strategies such as the practice of transhumance of herds in search of fresh grass and water points. Diversification of income-generating activities is another strategy developed by farmers in the commune of Banikoara to adapt to climate variability [115]. Farmers in northern Benin have implemented intercropping, crop rotation, field relocation, altered cropping patterns and water and soil conservation measures [116].

- *Conservation agriculture*

In northern Benin, the adoption of conservation agriculture principles on upland rice soil showed significant results in soil carbon storage. The emission of carbon from the decomposition of organic matter is counterbalanced with the use of manual tillage, 3 Mg ha of rice straw and 60 kg/ha of fertilizer [117].

Additionally, a study was conducted in the Boukombé watersheds of Benin to evaluate the agricultural practices, soil conservation techniques and river erosion-prone areas. A standardized questionnaire was used to conduct interviews with a total of 250 farmers. According to the findings, the following agricultural methods were used: a combination of crops (100%), rotation system (70%), monoculture (66%) and cultivated fallow (100%) [118].

- *Forest and cropland regeneration practices*

In the Department of Zou (southern Benin), 120 farmers were interviewed to evaluate the CSA strategies that they adopted to fight against global warming. Results show that

35.5% of surveyed farmers adopted "agroforestry and perennial plantation (oil palm, orchard, tree species)", which is considered as being the most promising strategy as it can protect the soil, improve biodiversity and participate in carbon sequestration [111]. In the municipality of Zè (in southern Benin), maize farmers also adopted an improved crop variety, change in sowing time and crop and livestock agroforestry (integration and tree planting) CSA strategies [112].

- *Practices in the livestock sector*

Idrissou, Assani, Baco, Yabi and Alkoiret Traoré [104] reported that to cope with climate change, cattle farmers integrated livestock and crop husbandry, developed transhumance, used concentrated feed, reduced herd size and forage cropping and diversified livestock. In northeastern Benin, herdsmen have developed practices and herding strategies to manage both their herds and space using changing regional and seasonal movements of herds to better deal with the available natural forage [119].

Moreover, in the watershed of the Sota at Malanville municipality in the far northeast of Benin, Zakari et al. [120] showed that agro-pastoralists (livestock and crop husbandry) have used numerous strategies to combat climate change, such as compliance with vaccination campaigns (85%), watering in the river (37.50%) and spatial mobility (59.50%). In the periphery of Cotonou in Benin, Koura et al. [121] showed that herders faced difficulties in feeding their animals and have adopted different feeding strategies such as moving animals to other areas, including peri-urban and rural, or abandoning breeding activity.

- *Water resources management*

In order to examine the effectiveness of water management, rice farmers from the inland valleys of Koussin-Lélé, Bamè and Zonmon in South Benin were interviewed. Results show that the long-term lowland variety IR-841 with "rice-straw" mulch at 10 Mg/ha enables farmers to use their water resources more efficiently and boost yields in their upland plots [122]. Moreover, in northern Benin, vegetable production was observed in inland valleys and around agro-pastoral dams, and rehabilitation and optimized utilization of these resources have been encouraged in light of climate change uncertainty to increase agricultural production and ensure food security [123].

- *Use of Weather and Climate Information Services (WCIS):*

Crop yield can be optimized with the use of weather and climate information services. The use of a GIS-based technique that evaluates and integrates biophysical factors (climate, hydrology, soil and landscape) in the Tossahou inland valley in central Benin (mostly including the hydromorphic zones) showed that 52% of the area is suitable for irrigated farming, 18% for farming under natural flood and 1.2% for rainfed bunded rice [124].

3.4.2. Impact on Smallholder Farmers

The profound effects of climate change on agriculture, coupled with the low resilience and high vulnerability of populations to shocks, could considerably reduce the capacity of smallholder farmers in Benin to manage natural resources and thus alter their livelihoods, their food security and their well-being. It is becoming imperative to comprehend the actions taken by farmers to combat climate change [107].

According to Issifou Moumouni et al. [125], the fluctuation in mean daily temperature and the minimum temperature of the coolest month are the two most crucial factors for forecasting the geographical and temporal dynamics of soybean-producing areas. By 2050, climate change will significantly alter the agro-ecological zones that produce soybeans. These changes will be marked by an increase in non-adapted soybean production areas.

Moreover, Danvi, Jütten, Giertz, Zwart and Diekkrüger [124] assessed the viability of rice production in a central Benin valley. Rainfed dike farming (RB), farming under irrigated farmland (IR) and natural flooding (NF) are rice farming systems based on soil and landscape suitability. For all cropping systems, rainfall and temperature were limiting factors. The naturally flooded crop was most constrained by flooding, whereas irrigated and rainfed dike cropping were primarily constrained by steep slopes and soil texture, respectively.

One of the key basic foods in Benin is maize, which is also one of the government's top priorities for reducing poverty and food insecurity. It is one of the government's priority sectors and is produced by around 85% of farmers. Changes in the climate, temperature, rainy season and drought have an impact on maize production [112].

Livestock farmers in the dry and sub-humid tropics of Benin perceive climate change. Concerned livestock farmers have highlighted the negative consequences of climate change on animal fertility, health and output [104].

3.5. Nigeria

The population of Nigeria is projected to be over 200 million inhabitants, and this makes it the most populated African country [126]. The country covers about a 923,768 km^2 area. Uniquely, the geography of Nigeria (Figure 1) provides a climate that varies from tropical rainforest in the south to semi-arid and arid in the north and thus allows the production of different crop varieties. With a south–north gradient, the average monthly temperatures vary from 22 °C to around 38 °C. Nigeria is also the biggest economy in Africa with the agriculture sector contributing around 30% of the gross domestic product (GDP), with over 70% of the residents directly involved in farming and the food supply chain [127,128], making it a significant proportion of the country's economy [129]. Nigeria is characterized by diverse contexts and heterogeneous production environments [130]. Agricultural production systems in Nigeria are principally dependent on rainfall with around 69% of the less-privileged engaged mostly in rainfed agriculture, which exposes their living conditions to unpredictable climatic fluctuations, with grave implications for food security [131]. More so, being a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), Nigeria is accountable to reduce its national GHG emissions as a fair contribution to the global efforts to mitigate climate change [132]. The impact of climatic variations on Nigeria's many ecological zones is having a negative effect on the country's ability to feed its increasing population [126].

3.5.1. CSA Practices

Nigeria faces varying degrees of climate risk such as rising temperature, changing rainfall patterns, distribution and volume and extreme climate events such as floods, droughts and desertification [130]. Sea levels have been reported to steadily increase along with the coastal areas of Nigeria, and it is predicted that a 1 m rise in water levels could cause a loss of about 75% of the total landmass in the Niger Delta region, which has led to coastal erosion and the loss of some villages (e.g., Erstwhile Village in Delta State) [133]. Using time-series data that spanned 43 years and an econometric analytical technique, Olayide et al. [134] assessed the differences between rainfall and irrigation's effects on total production and its sub-sectors (all crops, staples, livestock, fisheries and forestry), and they found that irrigation had a favorable and significant impact on both. The results indicate the necessity for CSA approaches that would incorporate the complementing development of larger arable land areas under irrigation in Nigeria in order to reduce the impact of climate-induced production risks [134]. Practices under CSA are relevant in increasing farm yield or productivity, reducing vulnerabilities or enhancing climate adaptations, as well as improving carbon sequestration [135]. This among other reasons is why the Government of Nigeria in conjunction with civil society organizations developed a National Adaptation Strategy and Plan of Action on Climate Change (NASPA-CCN) in 2011 [136].

- *Conservation agriculture*

This approach has been widely reported in most farming communities in Nigeria. Giller et al. [137] noted that conservation agriculture involves three approaches which include minimum or no-tillage, maintaining soil cover via cover cropping or mulching and crop rotation. In the northeast regions of Nigeria, soil degradation is high, and conservation agriculture is being used to combat reduced crop yields due to the low percentage of soil organic matter, limited use of fertilizer inputs and persistent droughts [138,139]. Reports have shown that the practice increases the productivity of primary food crops such as maize, sorghum and millet even on poor soils and offers economic benefits from diversified schemes of crop rotation [137,140]. Mulching provides adequate soil cover which has led to lower rates of run-off, better water infiltration, improvements in soil organic matter and moisture retention. Using zero or minimum tillage grants advantages such as reductions in costs expended on land preparation and early planting, which matches the onset of rainfall. This CSA practice appears promising to the farmers whose objective is to maximize production outcomes [130].

- *Agricultural Practices*

The usage of improved crop varieties has been found to be prevalent among cereal growers in Nigeria as an adaptation approach to coping with the impact of climate change due to high pest/disease resistance, low water requirement and early maturity. In Kwara State, rice farmers planted a local variety of rice crossbred in Kebbi State which matures in 12 weeks while some other farmers are still cultivating older varieties that are ready for harvest in 4 months and above [141].

Rainfall is important for farming activities; however, excess rains cause flooding and erosion of cultivated fields causing crop loss and disintegration of top soils, with about 40% of sampled farmers indicating that gully erosion had affected their crop production [142]. The techniques used by farmers are mixed cropping, tied ridging, mulching and tree planting [143,144]. In the southern and northern parts of Nigeria, to combat flooding and erosion caused by excess rains, farmers use "*terracing*", which consists of constructing ridges and channels across the slope [145].

Moreover, in the Sahel areas of Yobe, farmers adopt the use of water harvesting techniques called "*Zaï*", which are planting pits to retain moisture for sorghum and millet production [146]. It involves burrowing pits (20–40 cm wide and 10–15 cm deep) to accumulate water before planting which is often done with the application of biological materials such as compost, crop residues and animal dung. It includes tedious manual labor requirements (about 300 men/hectare) during the dry season due to unpredictable rainfall patterns and high temperatures. The crops that have been successfully planted by employing other conservation agriculture techniques such as the application of animal manure or compost include sorghum, millet and cowpeas [138,139].

The use of "*sack farming*" as a conservation practice where storage materials (sack, nylon) which are considered to no longer have use for the original purposes are filled with soil and used for vegetable farming, rather than allowed to waste on dumpsites [147]. The practice of farming in sacks involves growing seedlings in large sacks filled with soil [148].

- *Practices in the livestock sector*

Zougmoré, Partey, Ouédraogo, Omitoyin, Thomas, Ayantunde, Ericksen, Said and Jalloh [5] opined that the measures for climate change mitigation in the livestock sub-sector could include technical and management opportunities that promote the reduction in greenhouse gas (GHG) emissions through efficient feeding systems, balanced feed rations and efficient manure management. These actions work by maximizing feed resource use efficiencies which would increase livestock productivity and decrease emissions per unit of product. Adaptation activities due to extended dry periods include seasonal migration in search of fresh forage and water by pastoralists, which is common with handlers of cattle, sheep and goats [149], forage preservation as fodder for off-season utilization [150], feed formulation with alternative feed resources [151] and use of resistant breeds, increased spacing and routine vaccination [152].

- *Use of Weather and Climate Information Services (WCIS)*

Services that provide weather and climate data can be a vital tool in building the resilience of farmers in addressing the increasing threats associated with climate variability in Nigeria. Studies conducted by Ajaero and Anorue [153] reported that Nigerians have not given sufficient attention to climate change information. Similarly, another study captured that the degree of information available is capable of influencing the level of awareness of climate change issues [154]. Having access to specific weather information such as early warning and forecast technologies is capable of helping farmers to develop and readjust coping or adaptation strategies [155].

Consequently, Nigeria's National Determined Contributions of COP21 Paris Agreement call for climate-smart agriculture, with weather and climate information services serving as primary safety nets [156]. Hence, access to timely weather forecasts and other adaptive mechanisms is required in ensuring food sustainability in Nigeria.

According to reports from Nigeria, giving cassava and yam farmers information about climate change through extension agents dramatically raises the possibility that they will engage in climate-smart actions such as planting early-maturing crop types and planting trees [157]. However, this information was not available, as Tarhule and Lamb [158] showed that 60% of respondents (farmers included in their study) received no information on how to prepare for drought or what to do during and after a drought. Moreover, 30% of respondents received little information during the same period, mostly through non-governmental organizations or bilateral projects. However, only 8% of the 30% implemented the recommendations received.

3.5.2. Impact on Smallholder Farmers

Rural households in many communities of Sub-Saharan Africa are continuously modifying the existing practices in farm management as an attempt to mitigate the climate change effects, the majority of which are autonomous [145]. A survey conducted on maize–poultry value chains by Liverpool-Tasie et al. [159] in two Nigerian states (Kaduna and Oyo) showed that economic actors with more direct exposure to climate events (such as women, poultry farmers and maize farmers) are more likely to perceive these events than those whose exposure is more indirect such as men, feed millers and maize traders. The correctness of climate change perception could be attributed to the fact that farmers recall production rather than the climate itself [160].

In Nigeria, scientists and policymakers in the area of agriculture and sustainable development have pushed for the implementation of climate-smart agricultural practices over the last decade [126]. According to a study conducted by [161] in Ondo State, Nigeria, 57% of 120 farmers interviewed were unwilling to pay for extension services due to their smallholdings and other socioeconomic constraints such as low farm income and inconsistency in government policies, while the remaining 43% were willing to pay for limited extension services on improved seed varieties and funding sources.

The findings of Oyawole et al. [162] reported the percentage of farmers adopting CSA practices in northern Nigeria such as green manure (17.0%), crop rotation (29.0%) and zero/minimum tillage (37.0%). The study also recorded that refuse retention was adopted on 45.0% of the maize farms sampled while organic manure and agroforestry were adopted on 43.0% and 42.0% of the maize farms, respectively.

The use of improved variety with good management has increased the production yield of cereal farmers. A case study of three cropping seasons reported by the FAO and ICRISAT [138] showed a better harvest of 900 kg/ha with planting the improved SOSAT millet cultivar compared to 550 kg/ha using the local Gwagwa millet variety, which increase farmers' income. Moreover, intercropping with sorghum and cowpea gave a yield that is 64% higher than the traditional local variety, while limiting the intercrop to cowpea yielded an 88% advantage. Leveraging on the early maturity of improved varieties, Aderinoye-Abdulwahab and Abdulbaki [141] observed that rice farmers planted a locally crossbred variety that matures in 3 months and provides farmers with an opportunity to plant and complete production cycles twice in one growing season, particularly when the farmer leveraged on early-planting strategy.

A report by the FAO and ICRISAT [138] showed that the average yields recorded from terraced farms for sorghum and maize were 47% higher when compared to non-terraced farmlands in the areas sampled. Terracing as a soil-water conservation technique has also been reported in the South-Western region of Nigeria [160], and a study conducted by Danso-Abbeam, Ojo, Baiyegunhi and Ogundeji [145] reported that 67% of sampled farm households utilize the technique along with planting trees along slope contour, watershed management, irrigation and water harvesting to combat climate change.

The merits of micro-dosing fertilizer usage in comparison with the broadcasting method of application include a reduction in quantity (saving cost) and wastage of fertilizer. Ayanwale et al. [163] conducted a study using the method on underutilized vegetables and observed that the innovation had economic viability of between 32 and 50% and an expected adoption rate of 25%. In another report, the adoption rate of micro-dosing was up to 80% in areas with a general awareness of the benefits of the practice, recording cereal yields of about 2000 kg/ha compared to broadcasting which gave a yield of 1200 kg/ha [138]. However, the method is labor intensive.

Olawuyi and Mushunje [130] concluded that farmers with a high propensity to participate in collective action have a high likelihood to adopt climate-resilient farming practices compared to their counterparts with a lower propensity to participate in collective action. The determinants of climate-smart agriculture in southeast Nigeria from the report of Onyeneke, Igberi, Uwadoka and Aligbe [135] include farmers' schooling attainment, revenue, credit, extension services, livestock ownership, experience in agriculture, size of cultivated land, proximity to the market, distance to water resources, leadership position, risk orientation of the farmer, gender, land ownership, family size and exposure to information. Designing policies that will enhance these factors that determine the adoption of climate-smart agriculture in smallholder farming systems has great potential to increase the use of these practices.

Agricultural extension systems play a crucial role in providing information and educational programs on new technologies to farmers. Olorunfemi et al. [164] reported that although the extension agents were currently involved in the dissemination of some CSA initiatives, they were still not involved in the dissemination of a wide range of practices that are prominent among which are the irrigation-related water management initiatives, conversion of waste to compost, agroforestry and land reclamation initiatives, use of resource conservation and agro-weather-related initiatives. The study observed that the significant factors influencing the involvement of extension agents in disseminating CSA initiatives are educational qualification, participation in CSA training, years of experience and the number of communities covered.

3.6. Zambia

Zambia covers an area of about 752,618 km^2 and is alienated into three agro-ecological zones which are based on climatic, geo-physical and soil type parameters. The country is located in southern Africa and lies between 8° and 18° south of the equator, largely on a plateau area (Figure 1). The climate is sub-tropical, and 95% of the precipitation falls between November and April [165]. Zambia has a total population estimated at 16.6 million out of which 69% are found in rural areas and more than 84% of the population work as subsistence farmers [166,167]. From a global warming point of view, Zambia is a minimal contributor to GHG emissions. However, an increasing number of climate-related vulnerabilities are being faced by the country's agricultural practices [168,169]. Agriculture in Zambia is dominantly rainfed which means climate change poses a considerable challenge [170].

According to climate trends in Zambia, the average yearly temperature increased by 0.34 °C every decade between 1960 and 2003. Since 1960, the average annual rainfall has declined by 2.3% every decade, or 1.9 mm/month. In Zambia, climatic extremes include drought, extremely high temperatures, seasonal and flash floods and dry periods which are frequent occurrences. The frequency, intensity and magnitude of several of these have all increased [171].

After simulating 32 weather sequences drawn from historical climate data, Thurlow et al. [172] reported that accumulated agricultural losses related to climate variability in Zambia would reach USD 3.1 billion over the next 10–20 years. The disastrous effects that result from these are primarily brought on by flooded fields, a lack of water, crop devastation and an increase in agricultural and livestock illnesses [173]. Several initiatives have focused on the promotion of climate-smart agriculture (CSA) methods in Zambia in order to lessen and adapt to the consequences of climate change [165].

3.6.1. CSA Practices

The Republic of Zambia's government and collaborating partners have been pushing the adoption of CSA methods in order to sustainably raise agricultural productivity, strengthen farmers' resistance to the effects of climate change and eliminate or lower greenhouse gas (GHG) emissions [174]. The commonly promoted practices have been as follows:

- *Conservation agriculture*

As already mentioned, conservation agriculture is an agricultural method that aims to conserve, improve and use natural resources more effectively in the production of food through integrated management of available soil, water and biological resources as well as external inputs [175]. Conservation agriculture in Zambia has mainly been promoted by non-governmental organizations for over 20 years. There are currently 250,000 farmers in the estimated reach out of the 1,200,000 smallholder farmers in the country [176]. The practices under this category include minimum soil tillage, continuous soil cover and crop rotation. The specific technologies under minimum soil tillage include hand-hoe basins, ox-drawn ripping and tractor ripping [177].

Kuntashula et al. [178], investigated the impact of minimum tillage and crop rotation on maize yields for farmers who adopted the strategies across six districts in Zambia. They recorded that using low tillage and crop rotation increased maize productivity by 26 to 38 percent and 21 to 24 percent, respectively.

- *Forest and cropland regeneration practices*

Several studies conducted on a small scale in Zambia have clearly shown how agroforestry can increase crop yields, soil fertility and a host of other advantages for smallholder farmers [179]. Moreover, a variety of rural development goals connected to bettering land use and farmer livelihoods can be accomplished with the support of agroforestry activities, which are usually regarded as a longer-term sustainable land-use approach [180,181]. In Sub-Saharan Africa, planting nitrogen-fixing trees has been regarded as a crucial technique to fight widespread reductions in soil fertility and diminishing food production [182]. An indigenous, nitrogen-fixing acacia species of trees commonly known as Musangu (*Faidherbia albida*) is widely promoted for agroforestry practices in Zambia. However, adoption rates have typically been low, and this has been attributed to a lack of interest and low availability of seedlings [183]. It is also important to note that a study by Kafwamfwa [184] reported that the use of *Faidherbia albida* in agroforestry tends to acidify the soil in the long run compared to the use of eucalyptus trees which neutralizes soil acidity.

- *Practices in the livestock sector*

Climate-smart agriculture practices and technologies in the livestock sector in Zambia include: (i) micro-level adaptation such as shifts in species, breeds and/or production systems; (ii) institutional changes (policy) such as the development of animal breeding policy; and (iii) technological development such as breeding animals for high resistance to drought, heat and other harsh environmental conditions [174].

Agroforestry integration into crop–livestock production systems, enhanced housing and feeding approaches and improved management of grazing, forages, animal waste and other practices [169,174].

- *Water resources management*

Over 90% of Zambia's smallholder agriculture is rainfed, and this makes farmers more vulnerable to climate shocks such as droughts and floods. Irrigation is therefore promoted as a way of building resilience and adaptation to the climate change effect [185,186]. According to research conducted by Chisola et al. [187], the main stressors on water availability in Zambia were growing rainfall variability, protracted dry periods, decreased rainfall intensity, rising reservoir percentages and irrigated croplands. They also suggested certain adaptation measures, such as more effective agricultural water use and farmer-aided natural regeneration of forest patches, as they are essential to enhancing landscape hydrological processes that increase seasonal water availability.

3.6.2. Impact on Smallholder Farmers

Long-term welfare effects on Zambian households have been observed for the majority of climate-smart agriculture strategies. The short-term advantages are ambiguous and could be limited by insufficient access to financing, input and product markets and capacity building [169].

Several studies have documented the impact of varying climate-smart practices on smallholder farmers in Zambia. Arslan, McCarthy, Lipper, Asfaw, Cattaneo and Kokwe [166] investigated the effect of reduced tillage, crop rotation and legume intercropping, combined with the use of improved seeds and inorganic fertilizer on maize yields in Zambia. The study found that CSA practices (legume intercropping) increased significantly maize yield and reduced the probability of low yields even under critical weather stress, which improve farmers' income. The study of Mupangwa et al. [188] is in agreement with data reported by Arslan, McCarthy, Lipper, Asfaw, Cattaneo and Kokwe [166]: intercropping of maize with cowpea produced significantly greater yields when compared to the conventional ridge-tillage system in eastern Zambia. The yield benefits for smallholder farmers were higher in dry spells from conservation agriculture systems than from conventional practice. However, crop performance was also dependent on seasonal rainfall distribution regardless of the cropping system used [188]. Additionally, a study by Omulo et al. [189] showed that mechanized conservation agriculture among small- and medium-scale farmers had significant short-term economic advantages over conventional methods, but it also made note that smallholder farmers would need access to capital markets in order to hire equipment and purchase inputs. In the dry season, maize gross margin was highest in farms using direct seeding plots (zero tillage) (790 USD/ha) compared to farms using conventional practices (746 USD/ha). These effects are more pronounced in soybean crops: direct seeding had the highest gross margins compared to conventional practices in both seasons dry and wet (537 USD/ha and 392 USD/ha, respectively).

Despite being a leader in Sub-Saharan Africa when it comes to promoting conservation agriculture measures, Zambia has generally had poor adoption rates among smallholder farmers. Cash and resource shortages, lack of access to agricultural inputs, incompatible land management practices, such as land preparation by fire and livestock browsing, insecure tenure rights and disincentives brought on by cultural practices, such as matrilineal inheritance, all contribute to low adoption [179]. There is a need for tailoring CSA practices in Zambia toward site-specific, considering the different conditions in the three agro-ecological regions to enhance adoption.

4. General Discussion

From the analyzed literature, it is glaring that topics on the impact and perception of CSA practices on smallholders are being documented in recent years; however, more efforts are needed for more evidence. In Africa, as well as other countries in the world, such as Myanmar [190], Nepal [191], Pakistan [192], Colombia [193], Brazil [194], China [195] and India [196], several studies investigating farmers' perception on climate change and adaptation strategies have been conducted. Moreover, all these studies emphasized the necessity to determine the factors that can hinder climate change information services and help farmers in implementing the most appropriate adaptation strategies.

In the Southern African region (Malawi and Botswana), Simelton et al. [197] recorded huge differences between what farmers perceived and meteorological data regarding rainfall, rainfall variations and changes (onset, duration or cessation, amount, frequency, intensity or inter-annual variability), and this lag is probably related to the confusion with changes in farming system sensitivity. In the South-West region of Nigeria, smallholder rice farmers' perception of climate change intensity (temperature and precipitation) is often influenced by farm size, farming experience, marital status and educational level [160]. The same results were reported in Ghana where farmers' climate change perception is influenced by their level of education and farming experience. Moreover, deforestation as an anthropogenic factor seems to be the most important determining factor [198].

Depending on their perception, farmers adopt strategies to fight against the climate change effects, and these adaptation strategies are context- and locality-dependent [112,199–201]. It was observed that the effect of climate change and vulnerability were not the same in the countries we covered in this review. Since 1975, Algeria has experienced a decline in rainfall and an increase in the frequency of flooding. The country, which is ranked 18 out of 184 countries most vulnerable to drought, is experiencing a spread of the desert, and nearly 10% of its population (3,763,800 people) is at risk. A record heat wave in June 2003 that featured three weeks of high temperatures exceeding 40 °C is estimated to have caused 40 deaths [37,202,203].

The same disasters were observed in Senegal, but at very different levels and intensities, floods occurred more frequently than droughts. In Gambia and Senegal rivers, heavy rains can provoke floods, but droughts had more consequences affecting more people per event. Moreover, sea-level changes and increased intensity of storm surges lead to coastal erosion and pose a major threat to the population and economy. Sea-level rise is exacerbated by the country's geology (including sediment deficits, natural instability of slopes and surface runoff) and threatens 74% of households living in coastal areas [202,204]. In Benin, sea-level rise threatens the southern coastal region where over 50% of the population (over 3 million) reside on the coast and in the city of Cotonou. The coast of Benin has been eroded for more than 400 m in certain areas over the last 40 years. Moreover, floods and recurrent droughts are becoming increasingly severe and more destructive, which has an impact on the spread of infectious diseases, such as malaria, which accounted for around 40% of all visits to health facilities [202,204].

Like in Benin, Nigeria has experienced recurrent floods that have become more frequent all over the country. This has negatively affected agriculture, health, infrastructure and the economy. Sea levels have been rising by the side of the coast of Nigeria, causing erosion. Studies estimated that a 1 m rise in sea level could cause the loss of 75% of the Niger Delta land. Furthermore, desertification has been occurring in Nigeria, and desert conditions have been expanding southward [202,205]. In Zambia, between the years 2000 and 2007, the number, intensity and frequency of droughts and floods increased, affecting 41 districts of the nine provinces. Consequently, the size of the affected population has also increased (from about 1.23 million in 2004-05 and 1.44 million in 2006-07) [202].

Data extracted from our database and the literature demonstrated that CSA practices can be classified into six categories: agricultural practices, restoration practices of degraded lands, forest and cropland regeneration practices, practices in the livestock sub-sector, water resources and use of weather and climate information services [86,97,104,111,157].

From the SWOT analysis (Table 2), we can emphasize that among the constraints in the implementation of adaptation practices and strategies against climate change and global warming in African countries included in this review, the financial factor remains the most important [1,2]. It is also noted that the involvement of donors is decisive in the access and use of CSA. This is in agreement with data from the literature, where a significant difference was recorded between the local farmers who had access to credit and those who did not [206,207]. Moreover, the implementation level of CSA practices can be influenced by information campaigns (public discourse and/or the media). In Zimbabwe, the effectiveness of climate CSA practices, as reported in newspapers, was assessed using quantitative data on crop production, animal production, fisheries, postharvest management, food safety, value addition, marketing and administration as they relate to climate change. According to the analysis of 469 articles on food security, climate change was discussed in 22.6% of the articles, while 77.4% of the articles dealt with other food-security-related topics [208]. These deficiencies in the dissemination of information were also recorded in European countries. In Romania, Marinescu et al. [209] showed that journalists covering sustainable food-related themes frequently lack a thorough understanding of the subject and thus utilize sources insufficiently, leading to the spread of erroneous information. The media's coverage of sustainable food is severely limited as a result of this deficiency in aspects relating to the consumption of fresh fruit and vegetables. This attitude of the actors in the communication sector regarding CSA is probably due to the general policy of the country in question. For instance, in Algeria, which is considered a "rentier state" (e.g., living on income from natural resource assets such as oil and gas), the extractive industry plays a key role in the country's economy, and therefore, climate change remains a very sensitive subject [25].

In addition, other factors may also influence the choice of adaptation strategies such as cultural and policy factors [157,200] and access to information on adaptation methods [210,211]. Using results from 1800 Bangladeshi rice farm households in eight groundwater-depleted and drought-prone districts of three climatic zones, Alauddin and Sarker [212] reported that inadequate and/or limited access to climate change information (20.1%), appropriate knowledge of adaptation measures (18.0%) and information about drought-resistant rice varieties (16.8%) represents a major barrier to climate change adaptation strategies. To address this deficiency, scientific-based outcome research was used to increase the effectiveness of climate adaptation management programs [213].

Table 2. SWOT factors affecting CSA practices in African countries involved in this review (Algeria, Senegal, Benin, Nigeria and Zambia).

STRENGHTS	WEAKNESSES
• Agriculture is among the largest sectors of the African economy • Traditional and extensive farming practices maintain local livelihoods • Biodiversity protection, ecosystem services improvement and habitat and landscape conservation • Agriculture sector contributes significantly to the rural economy • Off-farm employment opportunities • Strong tourism sector (agritourism) • Downstream multiplier effect on employment in other sectors such as the forestry sector	• Climate change (irregularity, variability and unpredictability of rainfall, floods and drought) • Poor access to credit and financial resources • Low funding of scientific-based outcome research on CSA • Inadequate institutional support and policy • Gender inequality (i.e., labor force vs. productive asset ownership) • Low income in agriculture and livestock sectors compared to other sectors • Increase in input costs (fertilizers and pesticides, water, equipment, etc.) • Non-existence or low number of PDOs/PGIs or other product certifications • Lack of diverse employment opportunities compared to large urban centers • Lack of information campaigns concerning CSA practices, in public discourse or in the media
OPPORTUNITIES	**THREATS**
• Improved access to credit and financial resources • Increasing demand for safe, sustainable, local and healthy food • New and innovative technology use to increase efficiency • Increase farmers' knowledge of management tools • Further development of circular economy • Introduction of legislation to protect smallholder farmers • Changing climate allows diversification of crop type • Advances in crop breeding and plant genetics • Increased opportunities for rural women	• Effects of climate change on farmers' lives, crop and livestock yield. • Necessity for generational renewal to increase uptake of new technology • Loss of small-scale family farms and extensive farming practices • Rural exodus: current age profile of farmers/herd owners and succession planning • Market volatility, price variations and input costs • Concurrence with imported agricultural products • Increased disease and pest pressures introduced through weak biosecurity measures • Agricultural activities impact on the environment (deforestation, water quality) • Inappropriate land-use/soil management • Habitat loss due to changes in land uses

5. Conclusions

The review explored the climate-smart agriculture practices adopted in five African countries and the factors that can influence farmers' choices in terms of strategies adopted, as well as their perception of the effects of climate change. From north to south and from west to east, the effects of climate change are not the same; consequently, the adopted strategies are equally not the same. Data analyzed showed that CSA practices can be classified into six categories: agricultural practices, restoration practices of degraded lands, forest and cropland regeneration practices, practices in the livestock sub-sector, water resources management and use of weather and climate information services. Moreover, CSA adaptation strategies are often influenced by many factors such as financial resources mobilized by the governments, policy legislation, accessibility to the information on adaptation methods, climate change information and the intellectual level of the farmers.

To enhance the adoption of climate-smart strategies and practices in Africa, this review recommends, among others, the use of scientific-research-driven adaptation measures and the incorporation and prioritization of climate change in the governments' development agendas. Moreover, it is necessary to strengthen public agricultural extension services, provide climate services to farmers, implement policies to guarantee food security and enhance the human capital of farm households to reduce their vulnerability to climate change.

In order to develop resilient terrains for sustainable agriculture in Africa, future research should be designed for and oriented toward the most adapted CSA practices in the areas studied as well as the constraints to their funding by governments. It is a promising future topic area to develop new measurements and assessment methods with regard to their suitability for covering not only biophysical (productivity, yields, etc.) but also socio-economic (food security, poverty, gender) CSA practices, focusing on the smallholder household level in CSA pillars (adaptation and mitigation).

Last but not least, strategies for CSA promotion should be reconsidered by using both institutional support policy and technology packages utilized to boost productivity. This could result in opportunities for CSA alternatives to be scaled up effectively.

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