Making smallholder farming systems in Nigeria sustainable and climate smart

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Abstract: *Agriculture is the predominant occupation among rural dwellers who are mostly smallholder farmers in Nigeria. Changes in the frequency and severity of droughts and floods, extreme temperatures, protracted rainy season as occasioned by recent climatic changes are leading to reduced food productivity of smallholders and thereby threatening food security. The sustainable productivity of smallholders, therefore, depends on their ability to adapt to climatic changes and variability hinged on holistic approaches to agricultural production. This paper sought to analyse and review farming systems in Nigeria, smallholders' understanding of climate change, climate change impact on agricultural productivity, and mitigation and adaptation strategies. Identifying and implementing climate-smart practises such as integrated soil fertility management, improved agricultural inputs, water, and nutrient management in interdisciplinary synergism with concepts such as decision support systems and scaled-up rural advisory services, potentially improves the sustainability of smallholder systems. This creates better livelihoods for farmers, accelerated rural development and food security. In addition, ensuring food security in Nigeria requires prioritisation of smallholder farming systems with appropriate measures of how climate change impacts will be mitigated, long before they are experienced.*

Keywords: *adaptation, climate change, food security, smallholders, sustainable productivity*

Introduction

In Africa, agriculture provides employment opportunities for about 60% of the economically active population and more than 70% of its poorest people (ADB, 2010; FAO, 2014). Smallholders produce more than 80% of food consumed in most parts of the developing world, thereby contributing meaningfully to poverty reduction and food security (IFAD and UNEP, 2013; HLPE, 2013). These smallholders often do not have access to affordable agricultural inputs, credit, and sufficient labour; they practise low-input subsistence agriculture and cultivate small areas of land, with crop yields and outputs well below global averages (Chauvin et al., 2012). They expend their income, often less than $2 per day, mostly on food (AGRA, 2014). The sustainable productivity of smallholders affects rural livelihoods, food security, and poverty status, and also depends on environmental components, including soil and climatic components of the ecosystem to provide support. The need to sustain farm productivity for better livelihoods often makes smallholders put pressure on the natural resource base through habitat modification, use of chemicals, excessive use of water and soil nutrients (IFAD and UNEP, 2013). Impacts of global warming and associated climatic changes, aggravated by poor resource-use, are a major problem facing the universe, with concerns of how climate vagaries can be adapted to and mitigated in the long term (Cooper et al., 2006). Therefore, it is imperative to intensify agricultural systems to mitigate global food crisis (Godfray and Garnett, 2014) and analyse agricultural systems in Africa, which are mostly rainfed (IFAD, 2011), because agriculture offers opportunities to deliver simultaneously on crucial issues affecting livelihoods and economies of sub-Saharan Africa (Thornton et al., 2011), including preservation of the natural resource base, food production, employment and income generation, poverty reduction, climate change adaptation and mitigation (Vermeulen et al., 2012). This paper, therefore, will highlight ways of ensuring sustainable and climate-smart smallholder farming systems in Nigeria.

Scope of the Problem

Increasing food demand, scarcity of natural resources, population explosion, volatile input and output prices, rising energy costs, administrative regulation and importantly, associated climatic changes are posing a threat to food production. The pace, scale, and direction of such changes are hardly predictable (Thompson and Scoones, 2009). Climate change affects agriculture more than other sectors because climate can be considered as the primary determinant of agricultural productivity (Apata et al., 2009; Ayanwuyi et al., 2010). The IPCC (2007b) defines climate change as a change in the state of the climate that can be identified by changes in the mean and or the variability of its properties, persisting for an extended period, typically decades, or longer. Climatic changes characterised by increased temperature and erratic rainfall distribution due to Green House Gas (GHG) emission have been reported at the global level in the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) (Stocker et al., 2013). Climatic patterns play a fundamental role in shaping natural ecosystems, human economies, and societies that depend on them. Therefore, a change in climate has implications on human livelihoods, animals, plants, and the ecosystem with a strong consensus among experts that climatic variability will have extreme, resultant impacts on agricultural production (Rosenzweig et al., 2013).

Sub-Saharan Africa's food production systems are mostly sectioned to tropical zones, making them vulnerable to extreme weather events and the continent's capacity to adapt to climate change uncertain (Thornton et al., 2009), also, poor soils and dependence on rainfed agriculture (IFAD, 2011) are preponderant. Although smallholders have considerable experience in dealing with climate variability, the unprecedented levels of variability associated with long-term climate change are beyond the domain of indigenous coping strategies (Pettengell, 2010). Jarvis et al., 2012 projected significant climate change impacts on beans, banana, and sorghum, which are major food crops in Africa. Based on the scope of climatic variability observed over the past four decades, the West African sub-region is very vulnerable to the impacts of climate change (IPCC, 2007; 2014). In Nigeria, agricultural production is predominantly rainfed, thus rainfall is the most important element of climate (Odekunle et al., 2007). Consequently, climate change will greatly affect both crop and livestock farming in the country.

2. The State of Agriculture in Nigeria

Nigeria has about 98.3 million hectares of land and 74 million useful for agriculture (Opara, 2011). Cultivated lands in Nigeria occupied about 44.7% of land area in 2011, with 37.3% and 7.4% consisting of arable lands and permanent crops, respectively (FAO, 2015). Agriculture plays an important role in Nigeria's economy, as it contributes more than 40% of the GDP and generates about 70% employment opportunities (Yakubu and Akanegbu, 2015). Smallholders control 80 to 90% of Nigeria's farmland (Fig 1), contributing immensely to food production; they live in areas with limited access to inputs and other productive resources. About 66% of Nigeria's farmlands are located in the north, and the rest distributed between the middle belt and the south, with less than 1% of irrigated farmlands (FAO, 2015). Farming systems differ between the north and south due to precipitation patterns. Changes in climatic patterns are adversely affecting farm outputs (Lebel and Ali, 2009), increasing severe crop failure due to incessant dry periods and early stoppage of rains during the planting seasons (Adejuwon, 2008), coupled with crop flooding, rising temperatures, and pest infestations.

Before independence in 1960, over 75% of Nigeria's yearly merchandise export commodities were from the agricultural sector (Okoruwa et al., 2003). In 2013, cassava, yam, and cereals such as maize, sorghum, millet, and rice, accounted for 70% of production in the agricultural sector (FAOSTAT; FAO, 2015), with cassava and yam production at 53 and 40 million tons respectively. Sorghum and maize are the most important cereal crops in Nigeria in terms of harvested area (FAO, 2015). Millet cultivated majorly in northern Nigeria, and rice, which is cultivated in all the agro-ecological zones are also important cereals. However, rice production has emerged as the fastest growing sub-sector and the most required commodity in the Nigerian food basket. Rainfed production of lowland rice is predominant, it accounts for about 50% of rice grown in Nigeria (Mereu et al., 2018).
Dwindling oil prices, reduced demand for non-renewable energy, possible depletion of fossil fuel deposits and incessant domestic problems in the oil-producing areas of Nigeria, positions the agricultural sector as an obvious substitute to drive a diversified economy based on agriculture, technology, and human resources, rather than a mono-commodity driven economy based majorly on crude oil. Although the government is making an effort to restore the sector to its former status by initiating policies and programmes (Adama et al., 2016) which promote investment and diversification away from the oil sector, food imports still make up only 10% of Nigeria's total imports (NBS, 2010).

2.1 Farming systems in Nigeria

Farming systems encompass all components of a farm enterprise, including cropland, cropping systems, livestock, common grazing land and woodlots managed by several farmers in a community and off-farm activities, within a framework of markets for land, labour, production inputs, farm products, credit and knowledge (Fairhurst, 2012). Farming systems in Nigeria involve diverse cropping systems, including intercropping, which entails growing two or more crops simultaneously on the same field. It is common among subsistence farmers who practice low-input agriculture (Ntare, 1990) and those who lack adequate farm hands (Hildebrand, 1976). Intercropping ensures greater yield stability and is effective in reducing pest and disease damage (Andrews, 1974). There are several traditional cropping systems in Nigeria, evolving from responses to existing soil, climatic and social conditions (Kang, 1986). Major food crops in the humid tropical zone are plantain, banana, rice and root crops such as cassava, yam, sweet potato, and cocoyam; sorghum, maize, and cowpea in the sub-humid zone with millet and cowpea in the semiarid zone (Okigbo, 1980), combined with minimal external inputs and livestock integration. Consequently, farm productivity is low and the cycle of low input, low yield, and low income perpetuates poverty (IITA, 1998). As a result of the traditional farming systems, crop production tends to less fertile land, thus poor productivity and emergence of unsustainable farming systems pose a threat to food security (Woomer et al*.,* 2001).

Dixon et al., 2001 highlighted some farming systems suited to Nigeria, including the tree - crop farming system which is largely practiced in the humid zones. The system is characterised by the production of industrial tree crops; notably, cocoa, coffee, oil palm, and rubber. Food crops are inter-planted between tree crops and are grown mainly for subsistence with a few cattle kept. There are also commercial tree crop holdings for crops like oil palm, providing services to smallholder farmers in out-grower schemes. The root-crop farming system is also common in the moist sub-humid and humid agro-ecological zones with cultivated crops like cassava, cocoyam, and yam. Likewise, the cereal - root crop mixed farming system is commonly practiced in the middle-belt region of Nigeria. This system shares climatic characteristics with the maize mixed system, but is characterised by lower altitude, higher temperatures, lower population density, abundant cultivated land and higher livestock numbers per household. Cervigni et al., 2013 estimated that production of crops such as cocoa, yam, and cassava in the south, and sorghum and millet in the north dominate agricultural production and exports (up to 65%,) followed by groundnut, oil palm produce and maize.

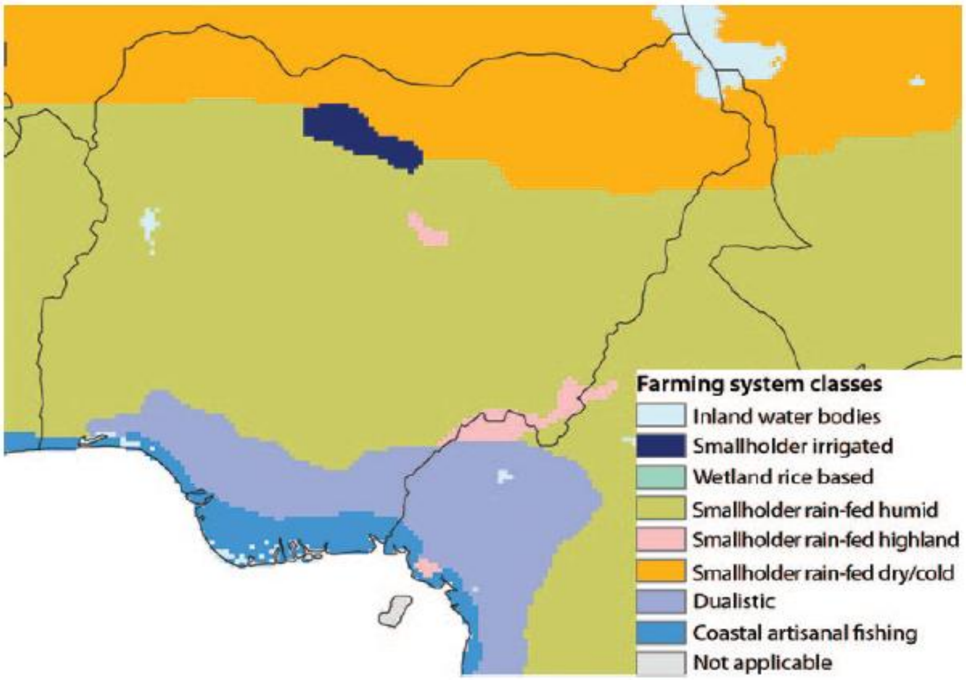

Figure 1: Spatial Distribution of Farms by Classes in Nigeria.
Figure highlighting the influence of smallholder farming on Agriculture in Nigeria.
Source: (Cervigni et al., 2013)

2.1.1 Importance of Smallholders to Sustainable Livelihoods

Approximately 2.5 billion people in the world earn their source of living directly from agricultural production systems, either as full or part-time farmers or as members of farming households that support farming activities (FAO, 2008a). Smallholders produce food and non-food products on a small scale with limited external inputs, cultivating field and tree crops as well as livestock, fish and other aquatic organisms. Most smallholders live in rural areas, although urban and peri-urban smallholdings are becoming important sources of supply for developing urban areas (IFAD, 2011). Women play an important role in the smallholder system and are commonly in charge of food crop production, especially where the farming system includes both food and cash crops (Koohafkan, 2011).

Smallholder farming systems are very diverse and contribute considerably to the global agricultural output of a variety of crops, producing the bulk of food in developing countries, and in many instances, their contribution is vital (IAASTD, 2009a). They produce an estimated 80% of the food consumed in Asia and sub-Saharan Africa (Dan-Azumi, 2011). Smallholder farmers characterise Nigeria's agricultural systems (Fig 1); they operate on small farms, family owned, rented, or leased, utilising family labour often augmented with the minor hiring of labour and labour exchanges with other farmers at peak seasons. The major staple foods produced are sorghum, yam, millet, cassava, and maize coupled with livestock rearing. The system does not make adequate use of modern farming techniques, capital input, advisory services and market information; also, there are inadequate infrastructural facilities for maximising production (Mgbenka et al*.,* 2015).

2.1.2 Sustainable Intensification of Smallholder Farming Systems

Sustainable intensification is often broadly described as production of more food, feed, fuel and/or fibre per unit of land, labour, and/or capital used, preservation of ecosystem services, including those governed by healthy soils, and resilience to shocks and stresses, including climate change (Pretty et al., 2011). Sustainable intensification requires soil and land to be managed sustainably, including avoidance of negative nutrient balances and soil erosion, the build-up of soil carbon, and the retention of soil biological diversity thresholds to preserve essential functions managed by soil biota. Also, external agro-inputs require efficient use to minimise possible negative environmental consequences.

Sustainable intensification among smallholders can be achieved by employing practises such as conservation agriculture, which refers to a collection of technologies including crop rotation and no-tillage. This technique has not been maximised in Nigeria and will likely require trials in various settings to determine both agronomic parameters and socioeconomic preferences of farmers, as there may be implications related to labour and use of chemicals to reduce pests and weeds, and also how willing farmers are to change their entire farm production system (Cervigni et al., 2013). Further, Water harvesting, which could be a no-cost, small-scale and on-farm activity can enhance sustainability. It can substitute for irrigation and increase the efficiency of water use on irrigated farmland. Pits can be dug, surrounded with dikes to hold water in the soil. Furthermore, integrated soil fertility management which entails combining organic and inorganic fertilisers in strategic amounts, based on certain combinations of crops and agro-ecological zones can help farmers adapt to climate variability*,* achieve sustainable intensification while contributing to soil health and better yields (Vanlauwe et al., 2010). Organic fertilisers are sourced from manure, mulch, crop residues, or nitrogen-fixing trees and legumes (Cervigni et al., 2013).

Agroforestry is also vital to sustainable intensification. It is characterised by natural regeneration of tree cover and other agroforestry practices, such as live fencing, shelterbelts, and woodlots. The adoption of agroforestry helps maintain shade canopies in plantations, increase productivity and help mitigate climate change by reducing expansion of cultivation to natural forests and also sequester carbon. Replanting of lost vegetation and depleted pasture by adopting some form of irrigation rather than totally depending on rain can bolster livestock production. Also, burning of grassland land must be abated by farmers; rotational grazing and establishment of grazing reserves are essential for sustainable intensification (Cervigni et al., 2013). The diversity of farming systems, agro-ecological conditions, farm household resources and socio-economic conditions are also consequential to achieving sustainable intensification. Overall, various means of reducing poverty among smallholders must be employed to break its vicious cycle (Tittonell and Giller, 2013).

3. Climate as an Important Component of Farming Systems

About 9% of Sub-Saharan Africa's population depend on rainfed agriculture for food production (FAO, 2006). A decline in precipitation has been observed in West Africa since the end of the 1960s, ranging from 20-40% between the periods of 1931-1960 and 1968 -1990 (IPCC, 2007), signalling danger to food production in the region.

Figure 2: Rainfall Anomaly in Nigeria
A figure representing data on recorded rainfall distribution from the Nigerian Meteorological Agency (NIMET) and showing distorted patterns of distribution from 1952 – 2012
Source: NIMET; In Adegoke et al., 2014

The National Adaptation Strategy and Plan of Action on Climate Change for Nigeria (NASPA-CCN) predicted a general increase in both rainfall and temperature extremes but with more uncertainty where rainfall was concerned (BNRCC, 2011). Among smallholder farmers, rainfall is the most important climatic factor critical to their survival, particularly for their crop growth and livestock herds. A period of low rainfall portends a period of scarcity of both feed and water, and increased grazing distances for pastoralists. However, in the sub-humid parts of Nigeria, Fabusoro et al., (2014) found that the mean monthly rainfall increased by 65 mm per month per decade from 1982 to 2010.

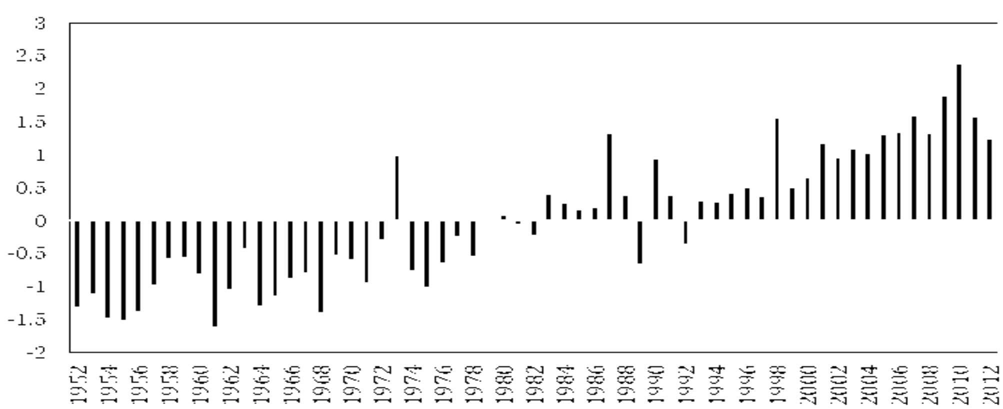

Figure 3: Temperature Anomaly in Nigeria
A figure representing data on observed patterns of temperature ranges from NIMET with irregularities over 6 decades (1952 - 2012).
Source: NIMET; In Adegoke et al., 2014

The authors also found that the pattern of rainfall and temperature appeared to be going in the same direction, with temperatures rising at about 0.4^{0}C per month per decade in Southwest Nigeria. As temperatures rise (Fig 3), rainfall patterns change and variability increases (Fig 2).

Farmers will need to grow different crops, plant at different times, use different inputs, raise different animals, and be prepared for concurrent changes (Nelson et al., 2014). The absence of a significant reduction in mean annual rainfall does not imply a lesser probability of occurrence of drought. The indirect effects of climate change are prevalent in socioeconomic aspects and evident in household income and savings, cost of food, poverty level, health and welfare issues, gender disparity, conflict over natural resource use, technology transfer and social inequality (AGRA, 2014).

3.1 Impacts of Climate Change on Agriculture in Nigeria

Smallholders play a significant role in agriculture, particularly in developing countries (Wiggins and Keats, 2015), despite the enormous climate change problems they face. It is projected that climate change will cause a decrease in rainfed crop yields of up to 50% by the year 2020 (IPCC, 2007). However, there are uncertainties of how climate change will continue to influence weather and climate in terms of definite locales around the world (Otto, 2015). The (5th) IPCC report also reveals that the impacts of climate change are more urgent, intense and devastating than previously projected (IPCC, 2014). In Nigeria, there has been an observed increase in CO_2 emission from agriculture (Fig 4), over two decades.

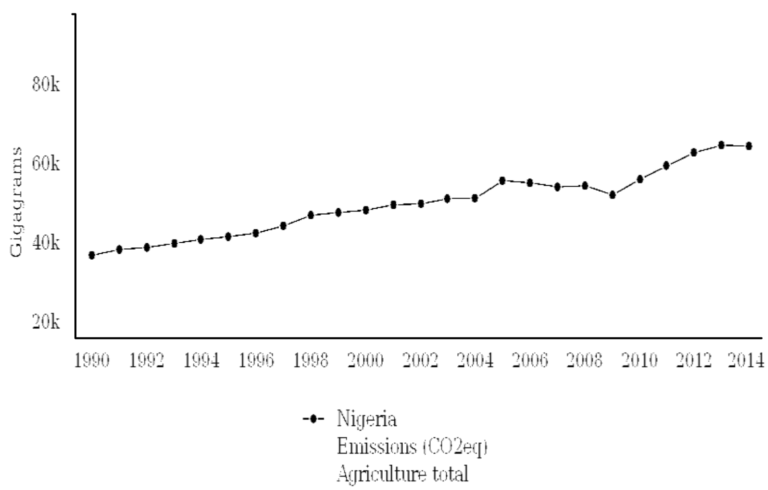

Figure 4: Trend of Increasing CO_2 Emission from Agriculture in Nigeria
This figure presents an observed increase in the trend of CO_2 emission from agricultural activities in Nigeria from 1990-2014.
Source: http://faostat3.fao.org/browse/area/159/en

The production of crops such as groundnut, rubber, coffee, cocoa, and palm have declined in magnitude since the drought of 1972-73, which is assumed the first evidence of climate change impact on agriculture in Nigeria (Ajetomobi et al., 2011). Evidence of erratic rainfall distribution in the south and increasing temperatures in the north, crop failures, hunger, poverty, malnutrition, diseases and abandonment of farm holdings are some climate change effects in Nigeria (Bello et al., 2012), with projected decrease in yield of cereals and possible increase in root crops production by 2050 (Fig 5).

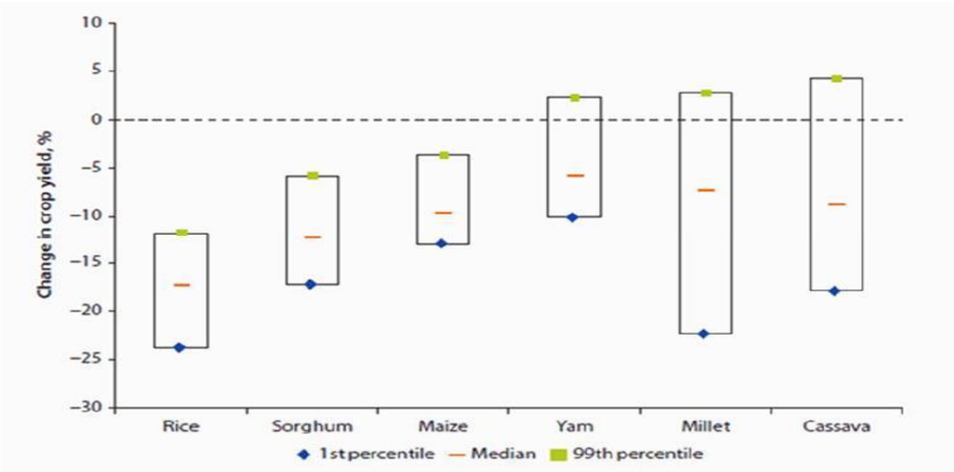

Figure 5: Aggregate Percent Change in Crop Yield in Nigeria by 2050.
Figure created from numerous data sources and designed by different climate models showing percentile changes in projected yields of major food crops in Nigeria. It reveals possible increases in yield of yam, millet, and cassava but otherwise for rice, sorghum and maize by 2050.
Source: (Cervigni et al., 2013).

4. Farmers' Understanding of Climate Change

Farmers' understanding of climate change is crucial in order to put up effective responses in adaptation and mitigation. In Nigeria, a series of research findings (Tologbonse et al., 2010; Idrisa et al., 2012) has sought to evaluate farmers' understanding of climate change. In a study by Ologeh et al., (2016) in the Guinea Savannah belt of Nigeria, a majority of the smallholders surveyed perceived climate change as increase or decrease in temperature, rainfall, and humidity. They alluded to experiencing erratic rainfall, and about 56% reported a significant increase in temperature as a result of climate change. The farmers identified crop failure, pests and diseases and drought as the most visible effects of climate change on farm activities

4.1 Indigenous Responses by Smallholders in Nigeria

Indigenous responses to climate uncertainties require intensification, to ensure climate-smart systems among resource-poor farmers, with limited access to scientific, technical and cost-incurring methods of climate change adaptation. Adaptation to climate change refers to the adjustment in ecological, social, and economic systems as well as responses to climatic conditions and their effects (Tol, 1998). The capacity of farmers to adapt to climate change can be significantly influenced by the level of awareness. Tol, (1998) suggested that awareness about climate change has a great capacity to drive farmers to improvise local technologies to aid adaptation.

4.1.1 A Case Study of the Guinea Savannah Belt of Nigeria

In a survey of about 500 smallholder farmers in the guinea savannah belt of Nigeria by (Ologeh et al., 2016), 59% of the farmers adopted indigenous methods of climate change adaptation, such as swamp farming, to cushion periods of delayed rains during the planting season, and thus ensured continued cropping activities in the absence of rainfall. Likewise, 23% made use of irrigation systems to support rainfed agriculture which is the common system of agriculture among smallholders in Nigeria. Further, farmers explored diversification of cropping patterns to mitigate climate change effects. About 76% practiced mixed cropping systems, anticipating good and bad in terms of potential crop failure, 64% used crop substitution techniques by planting cassava which seems to be climate resistant instead of crops that require much water for proper growth. The results of the study also indicated that 19% of the respondents adopted land fallowing as a means of adaptation. This is not a popular practice among smallholders due to land pressures and minimal access to land. In another study by the author, farmers irrigated their fields with water from rivers or wells. Farmers also adopted the use neem seed extracts as pest control measures; they claimed the seed extracts were more efficient and cheaper than pesticides (Ologeh, et al., 2018).

4.1.2 Bottlenecks in Climate Adaptation by Smallholders in Nigeria

Although smallholders in Nigeria are putting up responses to climate vagaries, literature highlights some predominant constraints due to poor information and extension services, and government policies. Nzeadibe et al., (2011) Idrisa et al., (2012) Otitoju and Enete, (2016) identified poor extension services, unavailability of improved crop varieties, zero subsidies on planting materials, low institutional capacity, and absence of government policies on climate change as constraints. Lack of information on appropriate adaptation option and credit to buy necessary resources and technologies hinders climate change adaptation (Onyeneke and Madukwe, 2010) since adaptation to climate change is costly (Deressa et al., 2008). Shortage of labour, land pressures and poor market access are also prevailing constraints. Oyekale, 2009 views smallholders with a low resource base as more vulnerable to climate change, with less likelihood of accessing weather information or capacity to develop technologies on their own.

5. Climate-Smart Agriculture

Climate-Smart Agriculture (CSA) is a form of agriculture that sustainably increases productivity, resilience (adaptation), reduces or removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals (FAO, 2010). The concept encompasses improved practises along agricultural value chains, appropriate institutions, and policy, adequate financing and investment. Strengthening farmers' capacity to adapt involves making adaptation options available and accessible, as well as providing training and extension services and access to credit (Zorom et al., 2013) and markets.

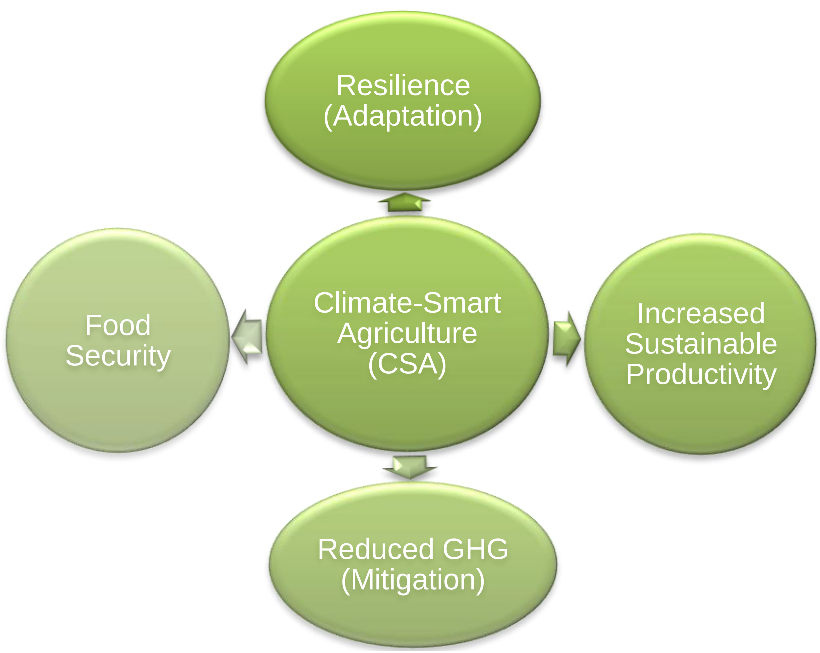

Figure 6: An overview of Climate-Smart Agriculture (FAO, 2010).

(Table I) highlights some climate-smart agriculture practises, including conservation practises, the spatial arrangement of crops, agroforestry, integrated soil fertility management and intensive animal care systems (AGRA, 2014). Land use management practises such as reduced tillage, manure, and waste management enhance the integration of soil biodiversity and accumulation of carbon in the soil (Wassmann and Pathak, 2007). Also, development and widespread use of new varieties which are tolerant to heat, salinity and resistant to floods and drought should be adopted by farmers, especially in sub-Saharan Africa. Technologies hinged on improved water management, crop diversification, improved pest management, decision support systems and weather information are strategies necessary for climate change adaptation. Energy-smart practises such as energy saving cooking stoves can help to reduce deforestation. Efficient food utilisation is also desirable, as almost 35% of food produced globally is wasted (Gustavsson et al., 2011).

Table I: Climate-Smart Agriculture Techniques

Nutrient-smart	**Water-smart**	**Carbon-smart**	**Energy-Smart**	**Weather-smart**	**Knowledge-smart**
Integrated soil fertility management	Water harvesting	Agroforestry	Green/renewable energy	Weather agro advisory services	Contingency crop planning
Green manuring	Intelligent Irrigation	Concentrate animal feeds	Use of energy saving stoves	Crop/livestock insurance	Indigenous knowledge systems
Intercropping with legumes	Land levelling	Fodder/manure management	Reduced/zero tillage	Weather smart livestock housing	Seedbanks
Biochar/ Anaerobic digestate	Planting across slopes	N-fixing trees	Biogas	Hydroponics	Agricultural Waste transformation/re-use
Rotational grazing	Alternate wetting	Hedgerow planting	Improved feeding techniques	Timely/Delayed planting and harvesting	Integrated pest management
Composting	Planting cover crops	Planting energy crops	Agroforestry	Crop diversity	Improved crop varieties
Site-specific nutrient application	Mulching	Biochar			Crop rotation/ Improved fallow

Source: AGRA, 2014; Khatri-Chhetri et al., 2017; Authors' perspective

6. Simulation models as Tools for Climate-Smart Agriculture

Most natural systems are complex, without defined boundaries. It is laborious to produce a simple, operational representation as part of reality which corresponds to the essential elements and mechanisms of a real-world system when associated with environmental management (Murthy, 2002). The variability in our climate and associated weather extremes is currently a global concern (Murthy, 2002). Climate change deals with existing and future issues, therefore, the use of simulation models presents a dynamic approach for evaluating the impact of climate change on agricultural production and world food security. Climate change impact assessments in agriculture are usually based on crop simulation models, as the crop level is the basic level at which climate directly affects agriculture (Rosenzweig et al*.,* 2014). Recently, efforts have gone into the improvement of crop and economic models and their coupling (Nelson et al., 2014). Crop growth simulation models (Table II) can be used to understand the effects of climate change such as elevated CO_2 levels, changes in temperature and rainfall on crop development, growth and yield. In reality, a change in weather may lead to the rapid development of a plant disease, loss in crop yield and consequent financial loss for farmers. The application of simulation models to study the potential impact of climate variability provides a link between models, agro-meteorology and societal concerns. Models have been used to evaluate the possible impacts of climate variability on crop production, especially to analyse crop yields relating to climate sensitivity under different climate scenarios.

Further, climate change places pressure on water availability and crop water productivity. Water plays a vital role in all areas of agricultural productivity and human endeavours. Water availability is not only important for sustaining human life, biodiversity, and the environment, it is also helpful for water administrators and farmers to determine agricultural water management and water allocation. Water availability is under threat from possible precipitation decrease in some regions of the world. It is imperative to take drastic measures to efficiently utilise water and develop new water resources. Simulation models can assist in water management in eventualities of water shortages and unavailability in relation to agricultural production. Changes in the pattern of pests, diseases and weed life cycles due to climate change might also impact on agriculture (Estay et al., 2009). It is necessary to understand the drivers of change and design strategies that can minimise the impact of climate change. Strategies like improving plant resistance to biotic stresses, agricultural practises, chemical control and simulation models can be used. The farmer's adaptation to climate change, through changes in farming management practises, cropping patterns, and use of new technologies informed by results from simulation models will consequently ease the impact of climate change. The proper understanding of the effects of climate change helps scientists to guide farmers in making crop management decisions such as selection of crops, cultivars, sowing dates and irrigation scheduling to minimise risks through simulation and scenario analysis using models. The improvement and use of simulation models will help in finding possible solutions to crop production under climate change conditions, especially in the developing world.

Table II: Simulation Models Useful in Agriculture

Model	Description	Author
APSIM	Simulation of biophysical processes in cropping systems	Keating et al., 2003
AQUACROP	Crop net irrigation, soil evaporation and crop response to different climatic variables simulation	Steduto et al., 2009
CropSyst	Cropping system simulation model	Stöckle et al., 2003
DSSAT	Crop growth, water, and nutrients dynamics	Jones et al., 2003
STICS	Crop growth, water, and nitrogen balance simulation	Brisson et al., 2003
WOFOST	Crop growth, Water, and nutrient use simulation	Diepen et al., 1989

7. Linkages between Extension Services, Smallholders, and Climate-Smart Agriculture

Agricultural extension plays a critical role in agricultural development by bringing farming communities information on new technologies, providing a framework for farmers to be organised into functional groups and channels for farmer problems to be identified for research and policy modifications (Annor-Frempong and Msuya, 2013). Agricultural extension is also a series of embedded communicative interventions which helps to resolve challenges facing agriculture (Leeuwis, 2006); therefore, it has to accommodate the issue of climate change (Ozor, 2009) including adaptation and mitigation.

In response to the changing nature of agriculture and farmers' needs as occasioned by climate change, the focus of extension in the past three decades has shifted away from transferring skills, technologies and knowledge related to the production of crops, livestock and forestry products from research outcomes to farmers, to developing technologies with farmers and facilitating innovation processes. This shift in focus is in alignment with the need for site-specific assessments to identify suitable agricultural technologies and practices needed for climate-smart agriculture. Extension providers in many countries have recorded successes in using participatory methods and approaches such as participatory technology development, enabling rural innovation and innovation platforms to develop and disseminate technologies, and also encourage innovation through multiple stakeholder engagements (Nederlof and Pyburn, 2012).

Furthermore, need areas to intensify agricultural extension efforts in assisting smallholders with information on how to be climate-smart include developing closer linkages between agricultural researchers and extension providers because of the strong need for researchers to tap local knowledge, having a clear understanding of farmers' needs and problems as well as obtaining feedback on how technological interventions are performing. Climate change adaptation entails changes in managing natural resources at the landscape level. Natural resource management will require changes in the institutional set-up of public extension, different from the system of traditional separate extension services for agriculture, forestry, fisheries and environment found in most countries, to a unified system between sectorial extension services provided by public and private sectors. Farmers also need to be more open to synergism between indigenous and scientific knowledge, sharpen their observational and experimental skills and improve their critical thinking and problem-solving abilities, in order to make their own decisions about appropriate practices, diversified and resilient income opportunities from several options.

Non-formal education and experiential learning approaches such as farmer field schools and climate field schools need scaling-up to further enhance farmers' experimentation and problem-solving abilities and encourage decision making regarding knowledge intensive agricultural practises (Waddington et al., 2014). Farmer Field School (FFS) is a participatory, non-formal extension approach based on experiential learning that puts farmers and their demands at the centre (FAO, 2002). It provides farmers with a low-risk setting to experiment with new agricultural management practises, evaluates their observations, develops new practical knowledge and skills, and also improves their individual and collective decision-making (Settle et al., 2014). Climate Field Schools (CFS) in parts of Asia have raised awareness of climate change and promoted solutions to cope with changing rainfall patterns, such as recording and interpretation of on-farm rainfall measurements and in-field water harvesting (Winarto et al., 2008).

Conclusion

This study aimed at evaluating ways of making smallholder systems in Nigeria sustainable and climate-smart, with an extensive review of relevant components and options vital for climate-smart agricultural systems. The paper reviewed the state of agriculture in Nigeria and the role of smallholders, their understanding of climate change, and adaptation strategies. In addition, it highlights the role of simulation models and scaled-up advisory services in ensuring climate-smart agriculture. It concludes that tilting agricultural research focus toward issues relating to climate-smart agriculture and associated catalysts such as sustainable intensification, natural resource management, and improved rural advisory services is central to realising more sustainable and climate-smart smallholder systems. Also, availability of subsidised inputs, use of decision support systems, and improved government policies are required. Further, communication of advances in climate-smart agriculture techniques should be championed by competent extension officers working closely with farmers, so as to monitor and evaluate their adaptation and mitigation strategies, and also keep farmers abreast of improved climate-smart practices related to their environment. Last, enabling environments which can sustain more functional channels for rapid, concurrent update and exchange of information from farmers to researchers can catalyse achieving climate-smart smallholder farming systems.

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