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Integration of Climate Smart Agro-Technologies and Efficient Post- Harvest Operations in Changing Weather Conditions in Nigeria

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Abstract

The purpose of this study was to examine the integration of climate smart agro-technologies and efficient post-harvest operations in changing weather conditions in Nigeria. Agriculture, which is the mainstay of most rural families in Nigeria, has faced several problems in recent times as a result of variety of factors such as post-harvest losses, climate change fluctuations, and high poverty level resulting in poor agricultural outputs and low income. Empirical studies have indicated that food production and income growth of farming households would be worse-off, if climate change is not properly mitigated. The combination of climate-smart agro-technologies and effective post-harvest management operations in this era of unfavorable climatic condition and post-harvest losses has become imperative. Climate smart agriculture consists of a three-win approach; for long-term food supply and security. It also comprises of three important goals such as mitigation, adaptation, and increased production. Agro-climate smart technologies includes solar energy techniques for drying agricultural product, green house technology for cultivation, climate resilient storage structures for storing harvested grains, and climate smart waste usage for agricultural waste management. Efficient post-harvest management operations such as proper harvesting, sun-drying, threshing, processing, packaging, and transportations were also explored. This study advocated the adoption of climate smart agro- technologies and efficient post-harvest management operations as an alternative measures for increased food production and farm income in the face of changing weather and climatic conditions.

Keywords: Agriculture; Climate smart techniques; Household farmers; Post-harvest operations.

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1. Introduction

Agriculture is the cultivation of crops and the practice of animal husbandry for the production of food, wool, and other items. Agriculture is fundamental to the economy of the majority of African nations, and its expansion has significant consequences for the region's food security and poverty reduction [1]. Its contributions to Nigeria's GDP have declined dramatically as a result of absolute neglect, a preference for crude oil, and other relevant reasons, most notably climate change fluctuations and post-harvest losses [2]. Empirical researches have indicated that if climate change is not handled, it would alter the direction of economic growth and exacerbate the poor status of Nigerian agricultural households [3]. This issue has prompted the incorporation of climate-smart agro-technologies and effective post-harvest management activities to mitigate the effects of harsh climatic conditions on agricultural productivity and stored products. Climate smart agriculture (CSA) refers to agricultural strategies that increase farm production and profitability, assist farmers in adapting to the negative consequences of climate change, and reduce climate change effects, such as soil carbon sequestration or greenhouse gas emissions reductions. Climate smart agriculture is clearly an integrated strategy to manage landscapes, farmland, livestock, forests, and fisheries in order to meet the interconnected concerns of food security and climate change [4]. It is used to describe agricultural systems that aim to enhance food security and rural livelihoods while also assisting with climate change adaptation and mitigation initiatives. Furthermore, it is a strategy for reforming and reorienting agricultural growth in response to the new realities of climate change [5]. By 2050, climate change is anticipated to have a detrimental influence on at least 22% of the cultivated land area for the most essential crops [6]. In addition to the need for agricultural resilience, land use accounts for more than 30 percent of global greenhouse gas emissions, 17 percent of forest conversion, and 14 percent of agriculture (soil erosion and cultivation, livestock and manure, and rice cultivation). Furthermore, land-based carbon sequestration operations, such as photosynthesis and soil carbon sequestration, are presently providing a significant possibility for large-scale removal of Greenhouse Gases (GHG) from the atmosphere. Agricultural soil carbon accounts for 89 percent of this sequestration capacity, with an estimated potential of 5.5-6 gigatonnes of CO2 each year, approximately equaling agriculture's total annual contribution to world emissions [7]. Even with superhuman mitigation efforts in land use sectors and elsewhere, climate change will have a substantial impact on agricultural productivity, necessitating an increase in agricultural adaptation activities [8]. The need of climate-smart agro- technologies and effective post-harvest management operations in meeting Nigeria's expanding demand for food, fiber, fuel, and other commodities cannot be overstated. Post-harvest management procedures protect up to 90% of food in industrialized nations and significantly contribute to agricultural growth and development [9]. According to empirical estimates, Nigeria's population will outgrow its present figures by 2050, with the majority of the rise occurring in rural regions. Taking this into account, as well as changes in climate, the composition and level of consumption associated with rising household incomes, estimates show that feeding the growing population will necessitate a 70% increase in total agricultural production [10], and in order to achieve this, climate smart agriculture and efficient post-harvest operations are non-negotiable. Climate change is having a significant impact on the food value chain, particularly the post-harvest value chain, which includes harvesting, threshing, shelling, drying, processing, storage, packing, shipping, milling, marketing, and consumption [11]. Because agricultural product is prone to physiological changes before and after harvest, variations in rainfall patterns with harsh weather conditions would inevitably result in changes in temperature and humidity over time, producing significant food losses and degradation. Changing climatic circumstances, such as significant precipitation as a result of wet weather, lead grains to absorb more moisture content than the suggested optimal moisture level for storage. Increased moisture content promotes the growth of fungus and mould, resulting in massive losses in stored grains. In the presence of high ambient humidity, the moisture content of stored produce rises, facilitating the contamination of grains with mycotoxins that are hazardous to human health [12]. Drying grains under damp weather conditions will necessitate a longer drying period, which is sometimes hard to perform. High temperatures cause agricultural residues in fields to dry quickly and bioactive chemicals in crops to deteriorate. High temperatures increase the danger of fire risks in mature crops and stimulate shorter life cycles, new breeding areas, and quicker reproduction of insects and pests, resulting in the rapid degradation and loss of stored grains [13]. Crop diseases are more common in places with higher local temperatures, according to Ndebedum [14]. In those areas, infected grains are either thrown away (wasted), leading to greenhouse gas emissions, or retreated (sorted, winnowing, drying, and fumigated), incurring costs. Again, the increased sensitivity to high temperatures and excessive amounts of carbon dioxide and ozone produces a change in the physicochemical quality of fruits and vegetables, resulting in a drop in organic acid content, flavonoids and antioxidants, and unsatisfactory hardness. Again, climate change has an impact on both quantitative and qualitative food supply losses. These losses have a direct impact on food security and food shortages [15]. As a result of the foregoing, this study is particularly pertinent in this era of agricultural post-harvest losses caused by changing weather conditions (climate change) in integrating climate agro-technologies and efficient post-harvest management operations as an alternative measure for increased food production, income, and food security.

The current impacts, implications and projected increases of climate change across the states (location), ecological and geopolitical zones of Nigeria are shown in Table 1 and 2 below. While, Table 3 revealed the climate change threats and the required climate smart agricultural practices. Figure 1 and 2 also validated the above reports.

Table-1. Current Climate Change Implications, Impacts and Projections in Nigeria

Geopolitical Zone	Ecological Zone	Climate change Impacts	Projected Effects
North West	Sudan Savannah	Increased temperature, drought, desertification	Increaseintemperature,2.0-2.2°C(2046-2-65) at the end of the 21stcentury
North East	Sudan Sahel	Increased temperature, drought, desertification	Increase in temperature, 2.0 - 2.2°C(2046-2-65)and3.5-4.5°C at the end of21st century
North Central	Southern/Northern Guinea Savannah	Gully erosion, flooding	Increased rainfall of0.2-0.4 mm/day
South West	Coastal Swamp /Rain-Forest	Sea rise, erosion	Sea level rise of 0.3m by 2020 and 1m by2050
South East	Coastal Swamp	Sea rise, flooding	Sea level rise, flooding
South South	Coastal Swamp	Sea rise, flooding	Sea level rise of 0.3m by 2020 and 1m by2050

Source: Food and Agricultural Organization FAO [5].

Table-2. Current and Projected Maximum Daily Temperature by Location

Location	Current Mean Annual Maximum (°C)P	Projected Increase; 2046-2065(°C)
Maiduguri	35.5	1.5 -3.2
Owerri	32.5	1.5 -2.3
Kano	33.7	1.5 -3.2
Abuja	33.1	1.4 -2.7
Ikeja	31.6	1.4 -2.3
Ilorin	32.6	1.4 -2.6
Makurdi	33.6	1.5 -2.6
Zaria	32.0	1.4 -3.0
Ibadan	32.0	1.4 -2.5
Warri	32.0	1.4 -2.3
Sokoto	35.5	1.5 -3.2

Source: Food and Agricultural Organization FAO [5].

Table-3. Climate Change Threats and Required CSA Practices

Climate change index	Impact of Agriculture	CSA practices required
Extreme weather events	Loss of crops & food grains	Improved techniques to increase resilience of crops to extreme weather events. Improved extreme weather events & early harvesting of matured crops infield. Prediction and early warning systems
Increased incidence of pests, diseases, fungi, mould, and Aflatoxin contamination.	Reduced crop yield and quality	New crop varieties with improved pest and disease resistance. Improved pests and disease management techniques
Increased flooding or water logging	Reduced crop yields or loss of crops. Causes difficulty in drying of grains infield & increases ability to absorb moisture beyond the optimum condition for storage	New crop varieties with higher moisture tolerance. Improved drainage or flood control techniques. Using climate smart solar drying techniques to conserve and renew energy.
Salt water intrusion	Reduced irrigation water	Barrier to salt water intrusion. New crop varieties with greater salinity tolerance. Improved water collection, storage and distribution techniques.
Reduced availability of irrigation water,	Reduced crop yields in irrigated agriculture	Improved irrigation efficiency. New crop varieties with lower water requirements.
Less precipitation	Reduced crop yields in rain-fed agriculture	New crop varieties with lower water requirements. Improved irrigation techniques. Improved water collection, storage and distribution techniques.
Higher temperatures	Reduced crop yield. Increase risks of	New crop varieties with greater heat tolerance. Early

	fire hazards in matured crops & causes new breeding ground for pests & diseases	harvesting of matured crops. Sanitation & fumigation of stored food warehouses

Source: Esper and Muhibauer [16].

2. Climate Smart Agriculture Goals and Aims

By 2050, climate change is anticipated to have a detrimental influence on at least 22% of the cultivated land area for the most essential crops [17]. As a result, the fundamental objectives and/or purposes of climate smart agriculture are as follows:

2.1. Mitigation

Wherever practicable, CSA helps to reduce and/or eliminate greenhouse gas (GHG) emissions. This implies that it has the potential to reduce emissions for every calorie or kg of fruit, fiber, and fuel produced. Essentially, agricultural deforestation should be prevented, and soils and trees should be handled in ways that maximize their ability to function as carbon sinks and absorb CO2 from the atmosphere [18].

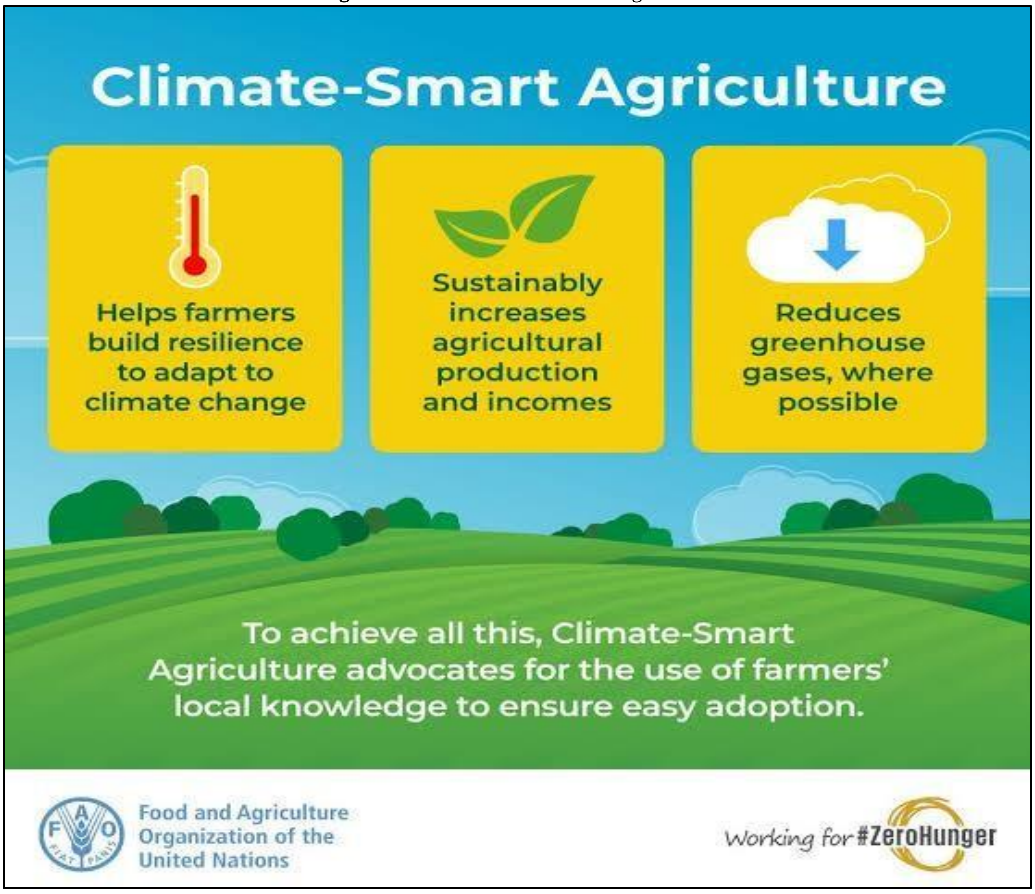
2.2. Adaptation

CSA strives to reduce farmers' exposure to short-term hazards while also enhancing their resilience by developing their adaptive ability. The conservation of ecological resources receives special emphasis. These methods are critical for preserving efficiency and farmers' capacity to adjust to fluctuations in climate change.

2.3. Production

The CSA's purpose is to boost agricultural productivity and revenue from crops, livestock, and fishes in a sustainable way that does not harm the environment. As a result, food and nutritional protection will be improved. Sustainable CSA intensification is a major factor associated to rising productivity of household farmers [19].

Figure-1. Goals of Climate Smart Agriculture



Source: [10]

3. Phenomenal Features of Climate Smart Agriculture

3.1. CSA is Context-Specific and Long-Term

CSA, in contrast to conventional agricultural development, is focused on addressing the effects of climate change and systematically incorporates climate change into the design and development of sustainable agricultural systems.

3.2. CSA Combines many Objectives and Manages Trade-Offs

CSA is designed to generate triple- win benefits such as higher output, increased resilience, and lower emissions. However, it is not always possible to fulfill all three objectives at the same time. As a result, trade-offs must be made during CSA installations. This necessitates identifying synergies and analyzing the costs and advantages of various solutions in light of stakeholder objectives expressed through participative methodologies [20].

3.3. CSA is Feasible and Preserves Ecological Services

Farmers rely on ecosystems for important services such as clean air, water, food, and materials. It is critical that CSA interventions do not add to their deterioration, but rather take a landscape approach that preserves ecosystems, builds on the principles of sustainable agriculture, and guarantees that its goals are attained without compromise at all times.

3.4. CSA is Quantifiable and has Several Access Points

CSA is quite measurable; its objectives can be measured both in the short and long run, and it has multiple entry points, ranging from the development of technologies and practices to the development of climate change models and scenarios, information technologies, insurance schemes, value chains, and the strengthening of institutional and political enabling environments. As such, it extends beyond single farm-level technology to cover the integration of numerous interventions at the food system, landscape, and value chain levels [21].

3.5. CSA is Time Bound and Relevant

The context of CSA is relevant and time limited, and it is frequently focused in attaining its numerous aims and objectives in connection to climate change exigencies and/or results. What is climate-smart in one location may not be climate-smart in another, and no action is climate-smart everywhere or all of the time. Interventions must be appropriate and timely, taking into consideration how various factors interact at the landscape level, within or across ecosystems, and as part of various institutional setups and political realities.

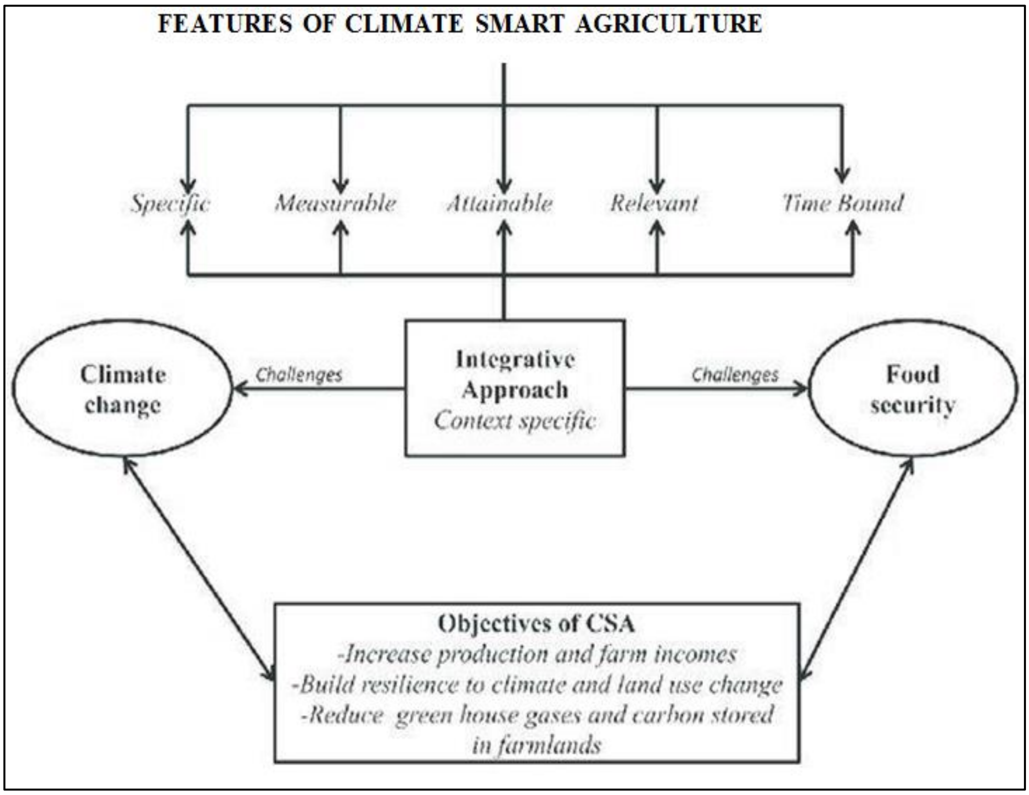
3.6. CSA is Social and Gender Inclusive

CSA is sociable and gender inclusive. CSA initiatives must include the poorest and most vulnerable populations in order to accomplish food security goals and boost resilience. These communities are frequently found on marginal areas, which are particularly vulnerable to climatic catastrophes such as drought and flooding. As a result, they are most likely to be affected by climate change. CSA accommodates gender, including women, and exposes them to climate-smart technology and validated post-harvest management practices that improve agricultural output and food security [22].

3.7. CSA is All-Inclusive and All-Encompassing

CSA is all-inclusive and all-encompassing in nature. It makes every effort to include all local, regional, and national stakeholders in decision-making. This assures overall success as well as national growth and development in the agriculture industry.

Figure-2. Features of Climate Smart Agriculture



Source: Merem [13].

4. Efficient and Proper Post-Harvest Management Operations

Improper post-harvest management, such as insufficient knowledge of handling and processing, as well as a lack of adequate storage and transportation facilities, equipment, and smooth marketing systems, can exacerbate food losses with reduced grain quality, particularly in the face of changing weather conditions [23]. Significant levels of moisture content, damaged grains, fractured grains, and high levels of aflatoxin contamination can all indicate poor grain quality. As a result, effective and proper post-harvest management procedures are required to minimize these losses. Adaptive post-harvest management procedures that will alleviate the effects of climate change include efforts to prevent pests from spreading from the field to grain storage. This may be accomplished by early harvesting and effective storage strategies. Drying grains in the shade can also protect them from unexpected rainfall and allow for re-drying if the crop becomes damp or insect-damaged, to prevent mycotoxins contaminations [16]. Improved storage management procedures, such as good sanitation and fumigation of food storage warehouses, as well as monitoring, should be used in addition to the storage of grains in roofed dry buildings packaged in airtight containers to extend storage periods and boost shelf life. The usage of climate smart food storage facilities is also advantageous in dealing with climate change-related adverse weather events [24]. Furthermore, crop storage devices that is less sensitive to post-harvest pest attack, as well as analyzing pre-harvest and post-harvest crop attributes, should be promoted. These management strategies will assist create resilience in the face of climate change. Table 4 shows the traditional and correct post-harvest management activities identified for grains during the study, which are divided into handling, conventional / traditional practices, and proper post-harvest management operations.

Table-4. Conventional Practices and Proper Post Harvest Management Operations

Handling	Conventional/traditional operations	Proper post-harvest management Operations
Harvesting	Harvesting and left on the farm for days.	Harvesting and transported by car to outside the farm and thenstored in room temperature.
Drying	Sun drying by putting the grains directly on the sun.	Sun drying under shade and re-drying of grains in case the produce gets damper insect damaged to reduce contamination. Drying done mechanically until the moisture content is reduced to10% and then ready for storage
Threshing	Threshing done manually	Threshing done mechanically
Packaging	Package in plastic bags used previously for non-grain products.	Package in new plastic bags that are airtight to avoid re-absorption of moisture.
Storage	Stored on farm or farmers house	Stored on sanitized storage rooms with roofed dried structures and in a good storage conditions.

Source: Ajadike [21]

5. Agro-Climate Smart Technologies

Climate change is expected to have a severe effect in the future, according to projection estimates. Stored agricultural output should be properly protected in order to ensure adequate food security and appropriate feeding of Nigeria's rising population. Agro-climate smart solutions in post-harvest food storage will help alleviate the negative effects of climate change while also providing a rapid reaction and environmental responsible approach. Among these cutting-edge agro-climates smart approaches are:

6. Solar Energy Techniques

A solar-based technology is a thermal process used in the food industry to dry meals. Drying is a key food preservation manufacturing activity. Electricity and fossil fuels are used in traditional food drying methods. It is estimated that around 40% of world emissions are generated by power generation via the combustion of fossil fuels, resulting in a 0.74oC increase in global average temperature [25]. As a result, switching from a traditional drying system to an alternate energy-driven system will assist minimize energy usage and emissions? Carbon dioxide, a greenhouse gas responsible for global warming, is produced by the combustion of coal, natural gas, and fossil fuels; whereas solar and other hydropower systems generate no greenhouse gases since their fuel sources are carbon-free. It is considered that the amount of greenhouse gases can be lowered exclusively by avoiding or replacing fossil fuel generation with renewable energy sources. Solar and other solar sources, such as wind, hydroelectric energy, wood, landfill gases, and energy crops, are critical sources of renewable energy for electricity and heat generation. The heat generated by sun drying systems is helpful in reducing moisture content in food for storage, as well as in energy efficiency and maintaining product quality such as flavor, appearance, and marketability. It is also employed in large-scale production [26]. It is non-polluting, environmentally beneficial, and saves energy by storing energy during peak times and utilizing it when it is insufficient. Solar energy is free; however, harnessing it may be costly, although it is not comparable to rising fuel prices and the cost of electricity for drying. Solar drying systems can reduce carbon dioxide emissions by a significant proportion. The solar system operates by capturing solar energy and converting it to electrical energy using photovoltaic cells [27]. Traditionally, grains are sun dried to minimize moisture content and allow for longer storage; here, grains are dried straight from the sun. This approach is directly dependent on favorable conditions, since unfavorable conditions will result in inefficient and non-uniform drying, which is capable of incurring significant losses, contaminations, dirt's, dusts, bird attack, and foreign materials. Solar dryers with an enclosed inlet energy collector for heating the air, a drying system for energy collecting, and drying goods address these challenges. Conventional or forced circulation transports heat from the air heater to the drying chamber [28]. Solar collectors dry agricultural products efficiently and affordably in both bright and cloudy circumstances. Animal, bird, and rodent damages to crops, as well as quality degradation due to direct exposure to sun, dew, rain, dirt, dust, and debris, are all eliminated. Solar inverters capture electricity and minimize reliance on fossil fuels, lowering greenhouse gas emissions and the impact of climate change.

7. Green House Technology

Green house technology is used to grow plants in an enclosed transparent structure using solar radiation to generate customized agro-climatic conditions within it. Green houses are normally transparent, with a glass wall or polyethylene film on the outside, and contain all of the required conditions for crop development and drying. The benefits of greenhouse technology include the ability to cultivate plants during the off-season and to protect them from unfavorable environmental and agro-climatic conditions such as extreme temperature, precipitation, disease, and pest, while other climatic factors such as temperature, humidity, carbon dioxide, light, pH of soil, and dissolved oxygen are controlled [29]. With the world's population growing, food supply must expand to keep up with demand. As the population grows, an imbalance between supply and demand develops. This mismatch is exacerbated by harvest losses, post-harvest losses, and climate change. To prevent climate change, it is critical to enhance output as well as create effective post- harvest technology. Greenhouse culture is currently a feasible method for increasing output, facilitating off-season cultivation, and protecting crops from poor external circumstances. Most green homes are built with sensors to read wealthier conditions, regulate carbon dioxide concentrations, and limit bug, pest, and energy losses to the outside. Green houses may also be utilized for nursery and cultivation in areas prone to soil difficulties, erosion, and harsh weather conditions [30].

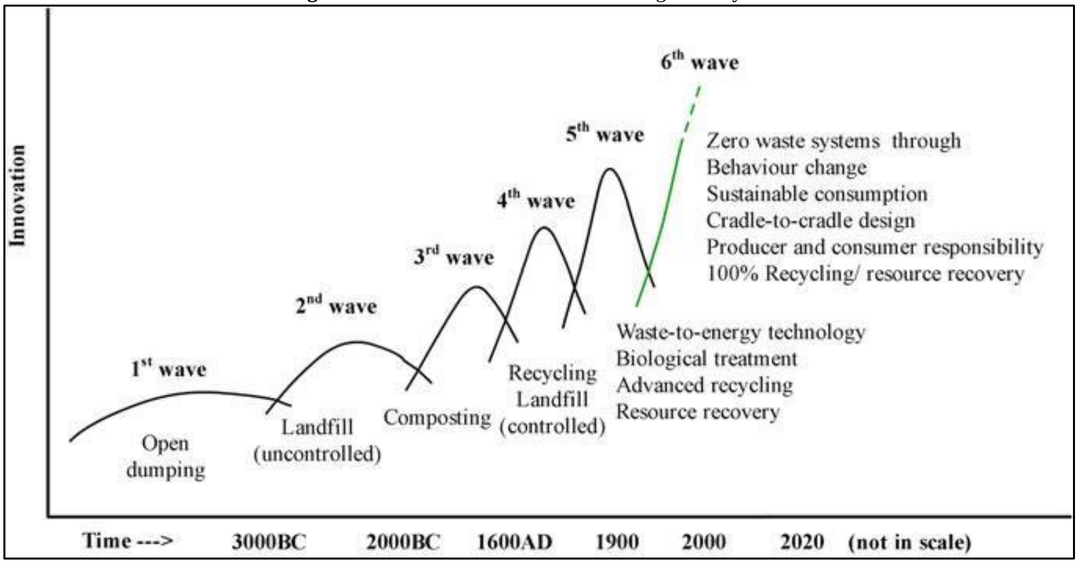
8. Climate Smart Storage Structures

After harvest, food still undergoes physiological changes that might cause rotting. Spoilage factors in food can include chemical/biochemical, microbiological, enzymatic, birds, and pests, among other things, thus agricultural goods must be stored properly. The use of chemical preservatives in food to enhance shelf life has recently been a major source of worry due to the health risks linked with it Singh, *et al.* [31]. People are increasingly seeking natural foods with few or no artificial preservatives. Because of the refrigerants chlorofluorocarbons, the use of a refrigerator for storing fresh fruit and vegetables causes an excessive concentration of green- house gases. Climate smart storage structures such as controlled atmosphere storage (CAS) and modified atmosphere storage (MAS) will aid in mitigating the effects of climate change [32]. The activities of spoiling agents, as well as the respiration of produce, will be minimized by changing the ambient conditions, such as lowering the quantity of oxygen, as well as ethylene, temperature, and relative humidity levels. Insecticides are discouraged in climate smart constructions since they are known to create carcinogenic residues. Climate-smart buildings are useful for storing fresh fruits and vegetables. With minimal weight losses, the textures and freshness of fresh harvested perishable items are preserved. CAS and MAS are both eco-friendly and cost-effective.

9. Climate Smart Technologies for Waste Management and Utilization

Agricultural waste is thought of as a byproduct of agricultural output. Because of the expanding population, agricultural output has increased to fulfill the growing population's food needs. Agricultural operations generate and accumulate trash on a daily basis, and in most situations, there are no acceptable waste treatment methods [33]. Improper agricultural waste management and use, such as burning and improper disposal, can result in health and environmental harm, pollution, and the production of greenhouse gases, which will contribute to global warming. For example, improper agricultural waste burning has been observed to create carbon dioxide, nitric oxide, and hydrocarbons, all of which have a warming effect on the climate [34]. Agricultural waste is expanding on a daily basis, and improper trash disposal will harm the land and air. Waste from animal droppings and manure released into bodies of water can contaminate the aquatic ecosystem. As a result, waste management must be eco-friendly and sustainable in order to minimize greenhouse gas emissions and assist ameliorate the effects of climate change [35]. Agricultural waste may be changed and reused in different ways with good management. Other kinds of agricultural byproducts can be reduced, recycled, and reused (3Rs), minimizing environmental pollution. Proper agricultural waste technology and automation, waste policies, and trash collection are all approaches to manage agricultural waste. To limit the effects of climate change and global warming, good waste management solutions must be implemented. Looking back in time, waste management and usage have evolved with innovation and civilization [36]. Open dumping landfill (uncontrolled), composting, and recycling landfill (controlled) are some of the older waste management strategies; nevertheless, these practices have drawbacks and limitations. Modern waste management and utilization technologies, such as waste to energy technologies, including the conversion of value-added goods by hydrolysis, food waste to animal feed, and zero waste management systems, should be implemented. These new technologies provide a more sustainable approach to waste management, particularly in the twentieth and twenty-first centuries, and should be applied at all levels of production to reduce waste and mitigate the effects of climate change. It is important to note that for proper and effective agricultural waste management and utilization, developing economies must consider the 3Rs, which include reducing materials that are not originally needed in production, reusing and considering materials as multipurpose and recycling waste raw materials. Figure 3 depicts the waves of innovation in waste management systems.

Figure-3. Innovation waves in waste management systems



Source: Zaman and Lehmann [35].

10. Waste to Energy Management and Utilization Technologies

The under-following discussion centered on the conversion of agricultural wastes into useful by- products using improved technologies;

11. Conversion of Value Added Products by Hydrolysis

Agricultural wastes have complicated structures that must be broken down into smaller forms before they can be used industrially. This can be accomplished by the activity of microbes or through pre-treatment with chemicals or enzymes that hydrolyze or break down complicated materials. These processes transform monomers (sugar) from waste biomass (lingnocellulosic, cellulose, and starch) into value-added goods such as bio-plastics and other bioavailable products (bio ethanol and bio fuels).

12. Food Waste to Animal Feed

The conversion of agricultural waste into animal feed will aid in the prevention of environmental pollution. Dehydration, silage preparation, and liquid feeding are all methods for converting waste to feed. According to Singh, *et al.* [31], these strategies for managing agricultural waste are both financially effective and environmentally beneficial, and will help to mitigate the effects of climate change.

13. Zero Waste Management System

A zero waste management system is viewed as a comprehensive approach to sustainable waste management. Zainal and Bilang [37], divided zero waste into five categories: zero waste in administration and manufacturing, zero waste in resources, zero emission, zero waste in product, and zero harmful usage. As a result, a zero waste management system is a wide term that encompasses all levels of management that attempt to eliminate waste at all stages of agricultural production. To do this, the three R's (reduce, reuse, and recycle) must be integrated into the manufacturing process.

14. Assessment of Climate Smart Agricultural Change Response

The ability of individuals and communities to adapt to climate change, to limit possible changes, to capitalize on opportunities, or to cope with the consequences is referred to as adaptive capacity. It is contingent on enough education, possessions, information, and income. Climate change ability may be evaluated at three levels: individual, organizational or institutional, and systemic.

The individual level, concerns all relevant actual and potential actors (for example, policymakers, the private sector, and local population) who perform activities or functions connected to climate change management. Individual climate capacity is heavily influenced by the level of knowledge and skills, as well as the quality of information, accessible to individuals and groups, as well as the ease with which they can acquire the information [38]. Individuals' or social groupings' adaptation ability varies and is determined by their access to and control over resources. The poor have notably limited access to such resources, making them more vulnerable to climate change and least capable of developing meaningful adaption methods.

The organizational/institutional level is concerned with overall organizational performance and managerial capabilities (for example, the existence of an organization with a specific mandate on climate change or a specific climate unit). The National Emergency Management Agency (NEMA) is one of the national government bodies in Nigeria tasked with handling environmental challenges such as climate change. Effective adaptation response plans necessitate the strengthening of the Special Climate Change Unit under the Federal Ministry of Environment. The systemic level is concerned with creating an environment conducive to climate action (for example, policy, economic, regulatory, and accountability frameworks within which organizations and individuals operate). It is concerned with the long-term framework conditions for climate action, as well as the opportunity structure of climate players [39]. Nigeria has several frameworks in place, but as previously said a lack of suitable legislative support, as well as insufficient resources and expertise, has resulted in little progress toward the adoption and use of renewable energy.

15. Climate Smart Agriculture Problems in Nigeria

CSA confronts a variety of obstacles linked to the approach's conceptual understanding, practice, policy context, and finance. The following are specific difficulties that are deemed to require immediate attention and intervention(s):

15.1. Lack of Practical Understanding of the Approach

The majority of smallholder farmers in Nigeria lack expertise and comprehension of CSA techniques making its use in the Nigerian setting problematic.

15.2. Lack of Data and Information and Appropriate Analytical Tools at Local and National Levels

Many African countries, including Nigeria, lack long-term climate and landscape-level data. Where such data exists, it is difficult to obtain. Global climate change models are too large in scale and resolution for local, national, or regional managers to operate with. There is a lack of capacity and analytical tools to downscale the results of global models to regional, national, and watershed sizes. As a result, decision-makers are unaware about the existing and expected future effects of climate change, as well as the implications for agricultural practices, food security, and natural resource management. Lack of knowledge, inadequate human and institutional capacity, and a lack of research-based evidence hamper decision-makers' ability to direct CSA implementation to the most vulnerable areas and execute suitable finance strategies.

15.3. Lack of Adequate Investment at the National/Regional Level and High Up-Front Cost of Investment in CSA at the Farm Level

Increasing agricultural climate adaptation and resilience need infrastructure investments at several sizes, from regional to national to river basin and farm. In Nigeria, infrastructure investment (roads, transportation, communication, power, agricultural water infrastructure, and development and management of water resources relevant to CSA) is lacking. Farmers have few assets that they can invest in on their own and lack access to financial services that would allow them to participate in CSA. Furthermore, few investors are available to provide loans, leaving government agencies, donors, and non-governmental organizations (NGOs) to support farmers' investment in CSA. It has been claimed that there is a lack of a clear business case for CSA procedures in order to entice investors and the credit market sector to participate in CSA. There are few known examples of CSA practices in Africa, with the majority focusing on conservation agriculture (CA) [40].

15.4. Inadequate Coordinated, Supportive and Enabling Policy Frameworks

To avoid inconsistencies and promote harmonization of efforts, CSA implementation in Nigeria necessitates the development of supportive policies and frameworks, as well as coordination across programs and institutions responsible for agriculture, climate change, food security, land use, water management, and energy generation. Existing policy frameworks that were developed without considering the need or need for CSA are likely to provide compatibility issues. The rising evidence of climate change's influence also points to the necessity to clearly define and educate CSA practices and innovations by enumerating the primary parts and consequences of climate change. Climate change will primarily impact agriculture through three primary drivers: I temperature changes; (ii) changes in GHG concentrations in the atmosphere; and (iii) changes in rainy season regime in terms of length, total rainfall amount, and distribution [41]. Farmers have always adapted and coped with climate variability manifested, for example, in delayed onset of rains, seasonal water deficit, and increasing seasonal maximum temperature, but they frequently lack knowledge about potentially feasible options for adapting their production systems to increasing frequency and severity of extreme weather events (droughts and floods) and other climate changes. Another barrier is access to land and water resources, as well as land tenure [42]. In many regions of SSA, millions of impoverished farmers, including women, have shaky and unstable water and land rights. Existing customary and institutional reasons, as well as new drivers, such as large-scale foreign investment in agricultural land, which causes displacement of present impoverished land users, have aggravated the situation [43]. At another level, a lack of accurate and timely information and technical advisory services, as well as a lack of availability and access to inputs such as suitable crop types, limit their capacity to analyze the risks and advantages of CSA and make educated investment decisions. At the agricultural size, competing resource utilization (e.g., labor, cash, biomass) has been a primary constraint. Furthermore, smallholders confront specific challenges in accessing domestic, regional, and worldwide markets.

15.5. Inadequate Empowerment of Women and Youth

Women and adolescents are underserved in CSA programs. Women contribute considerably to food production in Nigeria, yet they are disenfranchised and have limited access to production elements. Gender stereotypes in areas such as land and water rights, education, access to technology, labor, money, support services, and credit are some of the barriers to women's successful participation in agriculture [44]. Youths and women should be empowered via education, access to inexpensive financing, and suitable mentorship programs so that they can play their roles in agriculture [45].

15.6. Lack of Adequate and Innovative Financing Mechanisms and Effective Risk-Sharing Schemes

In Nigeria, there are no finance plans in place to encourage the use of CSA, despite the fact that the shift to climate-smart agricultural growth paths necessitates additional investments. Farmers in Nigeria face significant risks as a result of the effects of climatic hazards, but they also face the challenge of managing risks associated with the high costs (at least initial costs) of adopting new technologies (e.g., conservation agriculture and agro-forestry), the benefits of which often do not become apparent for several years/seasons) of production [46]. The majority of farmers have limited or no access to credit, microfinance, and/or insurance.

15.7. Difficulty in Managing Trade-Offs from the Farmers' and Policy Makers' perspectives

When it comes to resource management goals, there is frequently a schism between farmers and agricultural policymakers. The disparity in aims between the two groups is one of the fundamental reasons of this dilemma [47]. Prioritization of the three CSA objectives (improved productivity, adaptation, and, when practicable, reduction of greenhouse gas emissions) is likely to differ among key players such as farmers, government officers, and policymakers [48]. This has ramifications for how CSA methods are eventually judged, as well as whether policymakers and practitioners at various levels will be drawn to the supported CSA solutions for financial reasons.

16. Conclusions and Recommendation

Conclusively, for Nigeria to provide adequate food needs for her increasing population requires the integration of climate-smart agro-technologies and efficient and proper post-harvest management operations. These technologies are catalyst for improving domestic agricultural production, food sustainability, farm income and extension of shelf-life of agricultural produce. The study is quite relevant in this era of changing climate conditions and/ or variations as it provided solutions to the adverse effects of climate change and post-harvest crop losses in Nigeria. Hence farmers were recommended to embrace early warning climate signals in planning their agricultural activities and efficient post-harvest operations in reducing crop losses.

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