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Assessing the Role of Agroforestry in Mitigating Climate Change and Enhancing Food Security in Nigeria

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Abstract
Climate change poses significant challenges to agriculture in Nigeria, threatening food security and livelihoods. This research assesses the role of agroforestry in mitigating climate change impacts and enhancing food security in Nigeria. Through a systematic literature review and analysis of case studies, the study explores the diverse applications and benefits of agroforestry practices across different agroecological zones in Nigeria. Findings reveal that agroforestry systems offer sustainable solutions by sequestering carbon, reducing greenhouse gas emissions, and improving soil fertility. Case studies illustrate successful agroforestry initiatives, including alley cropping, agro-silvopastoral systems, home gardens, and agroforestry parklands, showcasing enhanced agricultural productivity, resilience, and food security. Recommendations are provided to promote the adoption of agroforestry practices, including policy support, capacity building, research, community engagement, partnerships, monitoring, and scaling up successful models. Implementing these recommendations can harness the potential of agroforestry to address climate change and food insecurity, fostering sustainable agricultural development in Nigeria.

Keywords*: Agroforestry, Climate Change, Food Security, Nigeria, Sustainable Agriculture, Mitigation, Adaptation*

Introduction

Climate change poses a significant threat to the agricultural sector of Nigeria, as it brings about a range of adverse impacts such as rising temperatures, erratic rainfall patterns, and extreme weather events. These factors have a detrimental effect on crop yields and livestock production, ultimately jeopardizing the livelihoods of millions of smallholder farmers and threatening food security for the entire population. Alao and Shuaibu (2013) describe agroforestry as a dynamic and ecologically based natural resource management approach that integrates trees within agricultural

landscapes, aiming to diversify and sustain production while generating increased social, economic, and environmental benefits for land users at various levels. They argue that agricultural practices or farming systems that prioritize environmental quality alongside ensuring food security should be promoted. Neglecting to address environmental changes and failing to create opportunities for alternative livelihoods through farming systems can lead to detrimental consequences. Therefore, urgent attention is required to mitigate the adverse effects of such environmental changes (Alao & Shuaibu, 2013). The rise in temperatures brought about by climate change leads to an increase in evaporation rates, resulting in soil moisture depletion and water scarcity for irrigation. As a consequence, crop yields are negatively impacted, leading to reduced agricultural productivity. Additionally, the unpredictable rainfall patterns associated with climate change further exacerbate these challenges, as they disrupt planting and harvesting schedules, affecting the overall crop yield and quality. Extreme weather events such as droughts and floods also contribute to crop failure, livestock mortality, and loss of agricultural infrastructure, further threatening the food supply of the nation.

Agroforestry represents a land utilization system and technology whereby perennial tree crops are intentionally intercropped with agricultural crops and/or animals, arranged spatially or temporally to ensure each component can economically sustain itself without compromising the survival chances of others. Leakey (2015) highlights that the global adoption of agroforestry by over 1.3 million people signifies its emergence as a leading approach towards achieving sustainable agriculture and food security. This trend is driven by the recognition of agroforestry as a recommended land management system due to escalating deforestation, ecological degradation, fertilizer shortages, and renewed scientific interest in farming systems, attributed to its ability to enhance species diversity within agricultural landscapes. Additionally, agroforestry serves diverse human needs while simultaneously supporting wildlife, soil microorganisms, rural communities, economic interests, watersheds, biodiversity, and other ecological functions (Elevitch & Wilkinson, 2003). Many agroforestry systems worldwide blend traditional agricultural practices with accessible, low-cost modern technologies to fulfill their objectives. Against the backdrop of diminishing soil fertility, exacerbated by factors such as soil leaching from increased annual rainfall, fertilizer unavailability and high costs, limited arable land, and deforestation due to urbanization in Nigeria, food insecurity persists as a significant challenge. This predicament has contributed to the proliferation of social vices including kidnapping, armed robbery, cyber fraud, prostitution, cultism, and militancy (Leakey, 2015).

In order to address the threats posed by climate change to the agricultural sector in Nigeria, there is a need to implement adaptation measures that focus on increasing the resilience of the agricultural systems. This may involve promoting the adoption of climate-smart agricultural practices, improving water management and irrigation systems, and diversifying livelihoods to reduce dependency on agriculture. Additionally, policies and strategies aimed at promoting sustainable agricultural practices and mitigating the impacts of climate change on the sector are essential for ensuring food security and the long-term sustainability of agriculture in Nigeria. Coupled with the effects of climate change, Nigeria's increasing population and rapid urbanization put additional pressure on the country's limited land and natural resources. With the demand for

food continuing to rise, it is imperative to implement sustainable agricultural practices that can mitigate the impact of climate change while simultaneously increasing food production.

Climate change has been identified as a significant threat to global food security, particularly for smallholder farmers in developing countries who rely on agriculture for their livelihoods (Lal, 2018). These farmers often lack the resources and technology to adapt to the changing climate, making them particularly vulnerable to its impacts (Niang et al., 2014). In addition to the direct effects on crop production, climate change can lead to increased frequency and severity of extreme weather events such as droughts, floods, and storms, which can result in crop failures, loss of livestock, and damage to infrastructure (Lobell et al., 2019). This can have devastating effects on the income and food security of smallholder farmers, pushing them further into poverty and food insecurity (Lal, 2018; Lobell et al., 2019). Furthermore, climate change can also affect the availability and quality of natural resources such as water and soil, which are essential for agricultural production (Niang et al., 2014). Changes in precipitation patterns and increased temperatures can lead to water scarcity and soil degradation, further compromising the ability of smallholder farmers to sustain their livelihoods (Lobell et al., 2019). As a result, smallholder farmers are at a higher economic risk due to their increased vulnerability to climate-related risks, as they struggle to recover from losses and maintain their livelihoods in the face of such challenges (Niang et al., 2014). Addressing the impacts of climate change on agriculture and livelihoods of smallholder farmers requires comprehensive adaptation strategies that consider not only the immediate effects on production, but also the broader socio-economic implications for the farmers and their communities (Lal, 2018).

Agroforestry provides a holistic approach to sustainable land management, offering smallholder farmers the opportunity to diversify and intensify their agricultural production while also enhancing ecological resilience and climate change adaptation. By integrating trees into farming systems, agroforestry can provide numerous benefits to farmers, including improved soil fertility, increased crop yields, and enhanced carbon sequestration, contributing to climate change mitigation. Moreover, the diversification of crops and incorporation of tree products in agroforestry systems can create new market opportunities for smallholder farmers, leading to increased economic stability and improved livelihoods. Agroforestry also has the potential to alleviate poverty and food insecurity among smallholder farmers by enhancing food production and income diversification. The integration of diverse tree and crop species in agroforestry systems can provide a more reliable and sustainable source of food and income, particularly in the face of climate variability and extreme weather events. Thus, agroforestry represents a promising strategy for promoting sustainable agriculture and improving the resilience of smallholder farming communities in the context of climate change.

The economic situation in Nigeria has faced challenges despite efforts from various levels of government. The country's heavy reliance on oil and gas as its main sources of revenue has made its economy vulnerable to fluctuations in international market prices. Factors such as debt servicing and inflation have further strained the Nigerian economy and weakened the value of its currency on the global stage. Consequently, Nigeria has experienced a significant increase in food insecurity, exacerbated by a rapidly growing population. Climate change, particularly heavy

rainfall, has led to severe soil leaching, depleting soil nutrients and resulting in low agricultural yields and income. Additionally, rapid urbanization and land development have encroached upon arable lands, exacerbating hunger in the country.

Moreover, multinational oil and gas operations have contributed to environmental degradation through increased emissions and depletion of the ozone layer. Daily occurrences of air pollution from gas flaring further exacerbate the situation, leading to pollution that persists even after land remediation efforts. Concerns arise regarding the duration required for remediated land to regain its fertility for sustained agricultural production. Despite various agricultural development initiatives by past and present governments, food security remains elusive in the face of escalating climate change challenges. Given these circumstances, there is a pressing need to explore farming systems that can address food security concerns while effectively utilizing limited arable land to ensure sustainable food production. To bridge this gap and mitigate the potential escalation of insecurity, particularly in the oil-rich Niger Delta region and Nigeria as a whole, conducting research on agroforestry as a climate change mitigation measure for sustainable food security is imperative. Given the potential benefits of agroforestry, this research aims to explore the role of agroforestry as a sustainable land management practice for enhancing agricultural productivity and food security in Nigeria. By investigating the environmental, social, and economic impacts of agroforestry systems, this study seeks to provide valuable insights that can inform policy decisions and support the widespread adoption of agroforestry practices in Nigeria. Ultimately, the integration of agroforestry into agricultural systems has the potential to not only mitigate the effects of climate change but also contribute to the sustainable development of the agricultural sector and the broader economy in Nigeria.

Methodology

The literature search and review process was conducted using a systematic approach to ensure that all relevant and current information on Agroforestry, climate change, and food security in Nigeria was gathered. This involved using various databases such as Google Scholar, JSTOR, and Pub Med to search for peer-reviewed articles, as well as accessing reputable websites and organizations working in the field. The gathered data was then carefully analyzed using qualitative methods, including thematic analysis and content analysis, to extract key insights and findings. This involved identifying recurring themes and patterns within the literature, as well as critically evaluating the quality and reliability of the information. The analysis process also involved comparing and contrasting different viewpoints and perspectives to gain a comprehensive understanding of the research topics. By utilizing a systematic literature review approach, this study was able to provide a robust and comprehensive overview of the current state of knowledge on Agroforestry, climate change, and food security in Nigeria. This allowed for the identification of gaps in the existing literature and the generation of new insights that could contribute to the advancement of research in this area. The findings from the literature review were used to inform the development of the research methodology, as well as to provide a solid theoretical foundation for the study's conceptual framework.

Agroforestry in Nigeria

Agroforestry, an age-old practice deeply rooted in Nigeria's agricultural heritage, has seen farmers integrating trees and shrubs into their farming systems for generations (Ogbonna, 2017). These traditional agroforestry systems were characterized by their multifunctional nature, contributing to soil fertility enhancement, fodder production, and environmental conservation efforts. However, the advent of modern agricultural practices and the rising demand for food and other agricultural commodities have precipitated transformations in land use dynamics across Nigeria. The transition towards more intensive and specialized farming systems has become increasingly prevalent, often at the expense of agroforestry practices. In these modernized agricultural landscapes, there is a discernible trend towards monoculture cropping and livestock production, which tend to exclude trees and other woody vegetation. This shift reflects a departure from the holistic and integrated approach of traditional agroforestry towards more streamlined and specialized production methods.

The abandonment or marginalization of traditional agroforestry systems in favor of intensified agricultural practices raises concerns about the loss of ecosystem services and biodiversity, as well as the degradation of soil health and resilience. Moreover, the exclusion of trees from farming landscapes may exacerbate vulnerability to climate change impacts, such as soil erosion, water scarcity, and reduced resilience to extreme weather events (Montagnini & Nair, 2004). As Nigeria grapples with the dual challenges of ensuring food security and mitigating climate change, there is a growing recognition of the potential of agroforestry to address these pressing issues. Revisiting and revitalizing traditional agroforestry practices, while also integrating innovative approaches and technologies, could offer a pathway towards sustainable agricultural development in Nigeria. By promoting the adoption of agroforestry systems, policymakers, researchers, and agricultural practitioners can harness the multiple benefits of trees within farming landscapes, ranging from enhanced soil fertility and biodiversity conservation to climate change mitigation and adaptation (Franzel et al., 2004).

Despite the rich historical legacy of agroforestry in Nigeria, the uptake of modern agroforestry practices and technologies remains constrained. Several factors contribute to this limited adoption, reflecting systemic challenges within Nigeria's agricultural landscape. One key barrier is the prevailing land tenure systems, which often discourage long-term investments in tree planting due to uncertainties regarding land ownership and tenure security (Ogbonna, 2017). Moreover, the inadequate access to essential inputs and resources necessary for implementing agroforestry practices presents a significant hurdle for farmers. This includes challenges related to acquiring suitable tree species, seeds, and planting materials, as well as accessing credit and financial support for agroforestry establishment and maintenance. Additionally, the lack of technical knowledge and awareness about agroforestry among farmers further impedes its widespread adoption. Insufficient extension services and outreach programs focused on agroforestry education and training exacerbate this knowledge gap, limiting farmers' ability to effectively implement agroforestry practices on their lands.

Furthermore, the absence of supportive policies and incentives for agroforestry within the broader agricultural policy framework undermines efforts to promote its adoption. The prevailing

perception among some stakeholders that trees compete with crops for resources also acts as a deterrent to agroforestry adoption. This misconception perpetuates the belief that agroforestry may compromise crop yields and profitability, thereby discouraging farmers from embracing agroforestry as a viable land use option (Ogbonna, 2017). Addressing these multifaceted barriers to agroforestry adoption requires coordinated efforts from government agencies, agricultural extension services, non-governmental organizations, and other relevant stakeholders. Policy interventions aimed at providing secure land tenure arrangements, improving access to inputs and resources, and offering targeted incentives for agroforestry could help overcome some of the existing challenges. Additionally, investing in farmer education and extension services to build technical capacity and raise awareness about the benefits of agroforestry is essential for fostering its widespread adoption and integration into sustainable agricultural practices in Nigeria.

In Nigeria, a diverse range of agroforestry systems are practiced, each tailored to suit the unique agroecological conditions and farming traditions prevalent in different regions of the country (Ogbonna, 2017). These agroforestry systems encompass various combinations of trees, crops, and livestock, integrated in ways that maximize synergies and mutual benefits. Among the most prominent agroforestry systems in Nigeria are alley cropping, silvopastoral systems, and agroforestry parklands. Alley cropping, also known as alley farming, is widely practiced in the southern regions of Nigeria. This system involves planting rows of trees or shrubs alongside rows of annual crops, creating alleys where crops are cultivated. The trees provide multiple benefits such as nitrogen fixation, nutrient recycling, and soil conservation, while the alley spaces allow for crop production. Alley cropping systems are particularly effective in improving soil fertility, reducing erosion, and enhancing biodiversity in agroecosystems.

Silvopastoral systems integrate trees, forages, and livestock within the same land area, providing multiple outputs including timber, fodder, and livestock products. These systems are prevalent in both the northern and southern regions of Nigeria, where livestock rearing is an integral component of agricultural livelihoods. Silvopastoral systems contribute to soil conservation, climate change mitigation, and improved livestock productivity through the provision of shade, forage, and shelter. Agroforestry parklands, commonly found in the arid and semi-arid regions of northern Nigeria, consist of scattered trees or shrubs within agricultural landscapes. These parklands serve as important repositories of biodiversity, providing valuable resources such as fuelwood, fodder, and medicinal plants for local communities. Agroforestry parklands contribute to soil moisture retention, microclimate regulation, and resilience to climate variability in regions prone to drought and desertification.

The prevalence of specific agroforestry systems in different parts of Nigeria reflects the diverse environmental conditions, socio-economic contexts, and cultural practices across the country. Farmers adapt and innovate agroforestry practices to suit local needs and constraints, harnessing the potential of trees to enhance agricultural productivity, conserve natural resources, and improve livelihoods in diverse landscapes. In order to fully realize the potential benefits of agroforestry at the national scale, it is crucial to understand the factors influencing the adoption and performance of agroforestry systems in Nigeria. This includes addressing socio-economic, cultural, and institutional barriers to agroforestry adoption, as well as promoting policies and interventions that

support the integration of trees into farming systems (Ogbonna, 2017). By studying the current state of agroforestry in Nigeria and identifying the challenges and opportunities for its expansion, we can develop strategies to promote sustainable agricultural development and environmental conservation in the country.

Climate Change Impacts on Agriculture in Nigeria

Climate change poses significant challenges to agriculture in Nigeria, potentially exacerbating food insecurity and poverty levels across the country. Numerous studies have highlighted the profound impacts of climate change on agricultural productivity, projecting substantial reductions in crop yields attributable to shifts in temperature and precipitation patterns (Udoh, Etim, & Etim, 2020). These changes have significant implications for Nigeria's predominantly agrarian economy, where agriculture remains a primary source of livelihood for a majority of the population. Smallholder farmers, who constitute the backbone of Nigeria's agricultural sector, are particularly vulnerable to the adverse effects of climate change. Limited access to resources, including land, water, and inputs, as well as a lack of credit and financial support, exacerbate their susceptibility to climate-related risks (Adefolalu, Yusuf, & Adeniran, 2018). Moreover, the heavy reliance on rain-fed agriculture leaves smallholder farmers highly exposed to the variability of seasonal rainfall patterns, further compounding their vulnerability to climate change impacts.

The changing climate has also led to an increase in the frequency and severity of extreme weather events, such as droughts, floods, and storms, which pose significant risks to agricultural production and food security (Nzeadibe & Egbule, 2019). These extreme events can result in crop failure, livestock losses, and damage to infrastructure, disrupting livelihoods and exacerbating food shortages in affected communities. Additionally, the compounding effects of climate change on natural resource degradation, including soil erosion, deforestation, and loss of biodiversity, further exacerbate the challenges faced by Nigerian farmers. Addressing the complex interplay between climate change, agriculture, and food security requires coordinated efforts from policymakers, researchers, and agricultural practitioners. Adaptation strategies such as promoting climate-resilient crop varieties, implementing water conservation measures, and diversifying livelihood options can help build resilience among smallholder farmers. Furthermore, investments in climate-smart agriculture practices, including agroforestry, conservation agriculture, and integrated water management, are crucial for enhancing the adaptive capacity of agricultural systems and ensuring sustainable food production in Nigeria.

Climate change poses a significant threat to agriculture in Nigeria, as rising temperatures, changing precipitation patterns, and extreme weather events are likely to impact crop yields, livestock productivity, and food security in the country (Abaje, 2019). According to the Intergovernmental Panel on Climate Change (IPCC), Nigeria is projected to experience higher temperatures and more erratic rainfall, which will lead to reduced agricultural productivity and increased vulnerability for smallholder farmers (IPCC, 2014). The impacts of climate change on agriculture in Nigeria are already being felt, with changes in crop phenology, increased incidence of pests and diseases, and reduced availability of water for irrigation posing significant challenges for farmers (Oluwaseun,

2018). These impacts not only threaten food production and livelihoods but also exacerbate poverty and food insecurity in the country.

In response to these challenges, there is an urgent need for adaptation and mitigation strategies to safeguard food production and livelihoods in Nigeria. Effective policies and interventions are required to build the resilience of smallholder farmers and enhance the overall adaptive capacity of the agricultural sector. This may include promoting climate-smart agriculture practices, investing in sustainable water management, improving access to weather information and early warning systems, and supporting the development and adoption of resilient crop varieties and breeds (Yusuf, 2017). Furthermore, efforts to enhance the adaptive capacity of the agricultural sector should also address the socio-economic, institutional, and governance aspects of climate change adaptation. This may involve strengthening the capacity of agricultural extension services, promoting inclusive and participatory decision-making processes, and providing financial and technical support to smallholder farmers to implement adaptation measures (Nkonya, 2015).

Agroforestry Practices and Principles

Agroforestry, recognized as a sustainable land use system, integrates trees, crops, and/or livestock in a synergistic and mutually beneficial manner (Leakey et al., 2019). This approach encompasses a variety of practices implemented across different regions worldwide. Among these practices are alley cropping, agro-silvopastoral systems, and home gardens, each offering unique benefits and contributions to agricultural sustainability. Alley cropping, a widely adopted agroforestry practice, involves planting rows of trees or shrubs between rows of crops. This arrangement not only provides shade and shelter for crops but also enhances nutrient cycling and soil fertility, thereby improving overall agricultural productivity. Additionally, the presence of trees helps to mitigate soil erosion and reduce the impacts of wind and water runoff (Franzel et al., 2004).

Agro-silvopastoral systems represent another form of agroforestry that integrates trees, crops, and livestock grazing within the same land area. By combining these components, farmers can diversify their income streams and optimize land use efficiency. Trees in agro-silvopastoral systems provide forage, shade, and fodder for livestock while also contributing to soil improvement and carbon sequestration (Nair, 2018). Home gardens, characterized by their small-scale and diverse composition, are prevalent in many tropical regions. These agroforestry systems incorporate a wide array of tree species, shrubs, herbs, and other perennial plants for food, medicine, and other non-timber forest products. Home gardens contribute to household food security, nutrition, and resilience by providing a continuous supply of diverse and nutritious foods throughout the year (Franzel et al., 2004). The adoption of agroforestry practices offers numerous benefits, including enhanced biodiversity, improved soil health, increased resilience to climate change, and diversified income sources for farmers. As such, agroforestry plays a crucial role in promoting sustainable land management, mitigating environmental degradation, and supporting the livelihoods of millions of people worldwide.

Agroforestry, as a multifunctional land use system, offers a plethora of ecological and socioeconomic benefits that contribute to sustainable agriculture, environmental conservation, and

livelihood improvement. Extensive research has highlighted the diverse advantages associated with agroforestry practices, underscoring its potential as a transformative approach to land management and rural development. One of the primary ecological benefits of agroforestry lies in its capacity to improve soil fertility and health. By integrating trees with agricultural crops and/or livestock, agroforestry systems enhance nutrient cycling, increase organic matter content, and promote soil structure development (Jose, 2009). These processes result in improved soil fertility, higher water retention capacity, and enhanced soil biodiversity, ultimately leading to increased crop productivity and resilience to climate change-induced stresses such as droughts and floods.

The presence of trees in agroforestry landscapes facilitates carbon sequestration, thereby mitigating greenhouse gas emissions and contributing to climate change mitigation efforts (Jose, 2009). Trees act as carbon sinks, absorbing and storing atmospheric carbon dioxide through photosynthesis, while also providing additional environmental benefits such as shade, windbreaks, and microclimate regulation. In addition to its ecological benefits, agroforestry plays a crucial role in biodiversity conservation and habitat restoration. Agroforestry systems provide diverse habitats for a wide range of plant and animal species, promoting biodiversity within agricultural landscapes (Schroth et al., 2015). The presence of trees in agroforestry systems creates ecological corridors and connectivity, facilitating the movement of wildlife and promoting genetic diversity, resilience, and ecosystem stability.

From a socioeconomic perspective, agroforestry offers numerous advantages for rural communities and smallholder farmers. By diversifying income sources through the production of multiple crops, timber, fruits, nuts, and other non-timber forest products, agroforestry reduces farmers' dependency on single commodities and markets (Dawoe et al., 2019). This diversification helps buffer farmers against market fluctuations, price volatility, and environmental risks, thereby enhancing their resilience and livelihood security. Overall, the ecological and socioeconomic benefits of agroforestry underscore its potential as a sustainable land use strategy for addressing pressing global challenges such as food insecurity, climate change, biodiversity loss, and rural poverty. By promoting the adoption and scaling up of agroforestry practices, policymakers, researchers, and development practitioners can contribute to the achievement of multiple sustainable development goals, including those related to environmental sustainability, poverty reduction, and food security.

Case Studies of Agroforestry in Nigeria

This section provides a comprehensive overview of case studies and empirical evidence showcasing successful agroforestry initiatives implemented in various regions of Nigeria. These case studies highlight the diverse agroecological zones where agroforestry practices have been adopted, the specific tree-crop combinations utilized, and the resulting outcomes, including enhanced agricultural productivity, resilience to climate change, and improved food security.

- **Alley Cropping in Southern Nigeria**

In the southern regions of Nigeria, particularly in Oyo State, alley cropping has emerged as a widely adopted agroforestry practice among smallholder farmers. This innovative approach involves intercropping rows of nitrogen-fixing trees, such as Leucaena leucocephala or Gliricidia sepium, with annual food crops like maize, cassava, and vegetables. A study conducted by Akinpelu et al. (2020) assessed the impact of alley cropping on soil fertility, crop yields, and farm income, comparing it to conventional monoculture systems. The research findings revealed significant improvements in soil quality and crop performance in alley cropping systems compared to monoculture practices. The presence of nitrogen-fixing trees in alley cropping plots contributed to enhanced soil nitrogen levels, reduced the need for synthetic fertilizers, and improved soil structure and fertility. As a result, maize and cassava yields in alley cropping systems were observed to increase by up to 30% compared to monoculture systems.

The integration of trees into agricultural fields provided additional benefits beyond soil fertility improvement. The tree canopy created by Leucaena or Gliricidia species offered shade and shelter to crops, reducing water evaporation and soil erosion while promoting microclimate regulation. Furthermore, the leaves and pruning of nitrogen-fixing trees served as valuable sources of organic matter, contributing to soil organic carbon accumulation and long-term soil health. Economically, alley cropping proved to be financially rewarding for farmers, as evidenced by the increase in farm income associated with higher crop yields. By diversifying their cropping systems and reducing input costs, farmers practicing alley cropping were able to improve their resilience to market fluctuations and environmental risks, ultimately enhancing their livelihoods and food security. Overall, the case study highlights the potential of alley cropping as a sustainable agroforestry practice for enhancing agricultural productivity, soil fertility, and farm income in southern Nigeria. By promoting the adoption of alley cropping and other agroforestry techniques, policymakers and extension agents can support smallholder farmers in improving their livelihoods and contributing to sustainable agricultural development**.**

- **Agro-silvopastoral Systems in Northern Nigeria**

In the arid and semi-arid regions of northern Nigeria, agro-silvopastoral systems have emerged as a promising approach to sustainable land management. These integrated systems combine trees, forage crops, and livestock grazing, offering multiple benefits to farmers and the environment. A study conducted by Ibrahim et al. (2018) in Kano State exemplifies the success of agro-silvopastoral systems, particularly through the integration of Faidherbia albida trees with improved forage grasses and small ruminants. The research findings demonstrated that integrating Faidherbia albida trees into grazing lands improved livestock productivity, soil fertility, and carbon sequestration rates. By strategically planting Faidherbia albida trees alongside improved forage grasses, farmers were able to provide nutritious fodder for their livestock while simultaneously enhancing soil health and fertility. The deep-rooted nature of Faidherbia albida facilitated nutrient cycling and improved water infiltration, resulting in increased soil moisture retention and reduced soil erosion.

Furthermore, the integration of small ruminants such as sheep and goats into agro-silvopastoral systems proved beneficial for farmers in Kano State. Farmers reported higher milk yields,

improved animal health, and reduced feed costs as a result of the diverse forage resources provided by the Faidherbia albida trees and improved grass species. Additionally, the shade provided by the trees offered relief to livestock during periods of intense heat, thereby reducing heat stress and improving animal welfare. Importantly, agro-silvopastoral systems enhanced the resilience of farmers to climate variability and extreme weather events, such as droughts. The presence of Faidherbia albida trees contributed to improved soil moisture retention, enabling vegetation to thrive even during dry periods. This resilience to droughts ensured a continuous supply of forage for livestock, reducing the vulnerability of farmers to feed shortages and livestock losses. The case study underscores the importance of agro-silvopastoral systems as a sustainable land management strategy in arid and semi-arid regions of northern Nigeria. By integrating trees, forage crops, and livestock grazing, these systems offer a holistic approach to agricultural production, soil conservation, and livelihood improvement, ultimately enhancing food security and resilience to climate change.

- **Home Gardens in Southwest Nigeria**

Another compelling case study comes from the southwest regions of Nigeria, where home gardens are prevalent among rural households. Home gardens are small-scale agroforestry systems that incorporate a diverse array of tree species, shrubs, and herbs for food, medicine, and other non-timber forest products. Oyinlola et al. (2019) conducted a study in Ogun State, Nigeria, documenting the contributions of home gardens to household food security and nutrition. They found that home gardens provided year-round access to fresh fruits, vegetables, and medicinal plants, significantly improving dietary diversity and nutritional intake among households. Furthermore, the surplus produce from home gardens was sold or exchanged, generating additional income for rural families.

- **Agroforestry Parklands in Northern Nigeria**

In the northern regions of Nigeria, particularly in Sokoto State, agroforestry parklands have emerged as essential components of agricultural landscapes, playing a pivotal role in sustaining agricultural production and livelihoods in semi-arid environments. These parklands are characterized by the integration of scattered trees or shrubs within agricultural fields, offering a range of benefits to farmers and the environment. Research conducted by Abubakar et al. (2017) provides valuable insights into the contributions of agroforestry parklands to soil fertility improvement, water conservation, and crop diversification in Sokoto State. The study documented the positive impacts of integrating multipurpose tree species such as Acacia senegal and Ziziphus mauritiana into cropping systems, highlighting the multifaceted benefits derived by farmers.

One of the key contributions of agroforestry parklands is their role in enhancing soil fertility and organic matter content. The presence of trees in agroforestry parklands promotes nutrient cycling and soil aggregation, leading to improved soil structure and fertility. The roots of multipurpose tree species penetrate deep into the soil, facilitating the uptake of nutrients and water, while their leaf litter and organic residues contribute to the enrichment of soil organic matter. Furthermore, agroforestry parklands play a crucial role in water conservation and management, particularly in

semi-arid environments characterized by limited rainfall and high evaporation rates. The canopy cover provided by trees helps to reduce soil moisture evaporation, while their root systems enhance water infiltration rates and groundwater recharge. As a result, farmers practicing agroforestry parklands are better able to cope with droughts and water scarcity, ensuring sustained agricultural productivity even under challenging climatic conditions.

In addition to soil fertility and water conservation benefits, agroforestry parklands contribute to crop diversification and income generation for farmers. By incorporating multipurpose tree species such as Acacia senegal, farmers can tap into additional income streams through the sale of tree products such as gum arabic and fruits. This diversification of income sources enhances the resilience of farming households to market fluctuations and economic uncertainties, thereby improving their livelihoods and food security. Overall, the case study underscores the importance of agroforestry parklands as sustainable land management systems in northern Nigeria. By harnessing the ecological and economic benefits of multipurpose tree species, farmers can enhance soil fertility, conserve water resources, and diversify their income sources, ultimately contributing to agricultural sustainability and rural development in semi-arid environments.

- **Integration of Agroforestry with Cash Crops in Southwest Nigeria**

In the southwest regions of Nigeria, particularly in Ondo State, the integration of agroforestry practices with cash crops such as cocoa and oil palm has emerged as a sustainable land use strategy with multifaceted benefits. Agroforestry systems, including shade-grown cocoa and oil palm plantations, offer a holistic approach to agricultural production that promotes biodiversity conservation, enhances soil fertility, mitigates climate change, and maintains economic productivity. A study conducted by Ogunsumi et al. (2020) sheds light on the positive impacts of shade-grown cocoa agroforestry systems on cocoa yield stability, pest and disease control, and farmer livelihoods in Ondo State, Nigeria. The research findings underscore the importance of maintaining a diverse tree canopy within cocoa plantations to maximize ecological and economic benefits. One of the key benefits of shade-grown cocoa agroforestry systems is their role in enhancing cocoa yield stability and resilience to climate variability. By providing shade and microclimate regulation, the tree canopy buffers cocoa plants from extreme temperatures and moisture fluctuations, reducing stress and promoting healthy growth. As a result, farmers practicing shade-grown cocoa agroforestry systems are better able to maintain consistent cocoa yields, even during periods of adverse weather conditions.

The integration of diverse tree species into cocoa plantations enhances pest and disease control through natural ecological mechanisms. Certain tree species serve as habitat and food sources for natural enemies of cocoa pests, such as predatory insects and birds, thereby reducing pest populations and the need for chemical pesticides. Additionally, the leaf litter and organic matter from trees contribute to soil health and microbial diversity, further supporting the resilience of cocoa plants to diseases. Economically, shade-grown cocoa agroforestry systems contribute to farmer livelihoods by reducing reliance on agrochemical inputs and enhancing resilience to market fluctuations. By diversifying income sources through the sale of tree products such as timber, fruits,

and medicinal plants, farmers can mitigate risks associated with mono-cropping and fluctuating commodity prices, thus improving their economic stability and food security.

- **Scaling Up Agroforestry Adoption through Farmer Field Schools**

To promote the adoption of agroforestry practices among smallholder farmers, initiatives such as farmer field schools (FFS) have been implemented in various regions of Nigeria. Farmer field schools provide participatory, hands-on training to farmers on agroforestry techniques, tree species selection, and management practices. A study by Olufemi et al. (2018) evaluated the impact of FFS on agroforestry adoption in Osun State, Nigeria, and found that participating farmers significantly increased their knowledge and adoption of agroforestry practices. By empowering farmers with the skills and knowledge needed to implement agroforestry, FFS contribute to sustainable agricultural development, environmental conservation, and poverty alleviation in rural communities.

These case studies underscore the diverse applications and benefits of agroforestry across different agroecological zones in Nigeria. By showcasing successful agroforestry initiatives, policymakers, researchers, and development practitioners can promote the widespread adoption of agroforestry as a sustainable land use strategy for enhancing agricultural productivity, resilience, and food security in Nigeria.

Contributions of Agroforestry to Climate Change Mitigation

Agroforestry, as a sustainable land use practice, has been increasingly recognized for its potential contributions to climate change mitigation. This is due to the inherent ability of agroforestry systems to sequester carbon, reduce greenhouse gas emissions, and enhance carbon storage in biomass and soil. The integration of trees with food crops in agroforestry systems can play a significant role in capturing and storing carbon, thereby helping to alleviate the impacts of climate change. In this section, we will explore the various ways in which agroforestry contributes to climate change mitigation and examine the potential benefits of scaling up agroforestry practices in Nigeria.

Carbon Sequestration in Agroforestry Systems

Agroforestry systems have been recognized as an effective strategy for climate change mitigation due to their ability to sequester carbon from the atmosphere (Montagnini & Nair, 2004). Trees in agroforestry systems play a crucial role in capturing carbon dioxide and storing it in their biomass and soil, thereby reducing the concentration of greenhouse gases in the atmosphere and helping to mitigate climate change (Montagnini & Nair, 2004). Several studies have shown that agroforestry systems can sequester significant amounts of carbon, making them a valuable tool for climate change mitigation (Montagnini & Nair, 2004). comparison to conventional monoculture systems, agroforestry systems have been found to have higher levels of carbon sequestration, primarily due to the presence of trees which enhance overall biomass and soil carbon stocks (Montagnini & Nair, 2004). The diverse vegetation in agroforestry systems contributes to increased carbon

sequestration and long-term storage of carbon, making them a promising approach for addressing climate change (Montagnini & Nair, 2004).

In addition to carbon sequestration, agroforestry systems offer a range of environmental and socio-economic benefits, including soil conservation, improved biodiversity, and enhanced livelihoods for smallholder farmers (Montagnini & Nair, 2004). As a result, agroforestry has gained attention as a sustainable land use practice that can contribute to climate change adaptation and mitigation efforts.

Reduced Greenhouse Gas Emissions

Agroforestry practices have shown to have a positive impact on reducing greenhouse gas emissions. The integration of trees in agricultural land helps in mitigating the release of greenhouse gases such as methane and nitrous oxide, which are major contributors to climate change. One way in which agroforestry helps in reducing emissions is through the use of nitrogen-fixing trees. These trees can supplement the nitrogen needs of the soil, reducing the reliance on synthetic fertilizers that result in nitrous oxide emissions (van Noordwijk et al., 2014). Furthermore, the agroforestry method of alley cropping contributes to reducing greenhouse gas emissions by improving soil fertility and reducing the need for chemical inputs. By managing soil health and utilizing organic matter from tree leaves and other organic material, alley cropping minimizes the emissions associated with the production and application of agrochemicals.

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Enhancing Food Security through Agroforestry

According to Kiptot and Franzel (2012), agroforestry systems not only contribute to increased food production and improved crop yields but also play a critical role in enhancing food security by providing diversified diets and improving the nutritional status of communities. By integrating trees with food crops, agroforestry systems can increase the availability of fruits, nuts, and other nutritious food products, thereby addressing malnutrition and food insecurity. In addition, the use of agroforestry practices such as intercropping and alley cropping can help improve soil fertility, leading to sustainable and resilient food production systems (Garrity et al., 2010).

Agroforestry systems offer not only ecological benefits but also significant economic advantages, particularly in regions where conventional agriculture faces limitations due to climatic and environmental constraints. As highlighted by Roshetko (1999), agroforestry has the potential to provide supplementary income for farmers, thereby contributing to their overall household food security. This supplementary income becomes crucial, especially in areas where conventional agricultural practices may not be economically viable or sustainable in the long term. The additional income generated from agroforestry activities can serve as a vital buffer against the impacts of food price fluctuations and market volatilities. In regions where farmers rely solely on conventional agriculture, they are often vulnerable to external factors such as changes in commodity prices, weather extremes, and market uncertainties. By diversifying their income sources through agroforestry, farmers can reduce their dependence on a single agricultural commodity and mitigate the risks associated with market fluctuations.

Furthermore, agroforestry systems provide opportunities for value addition and income generation beyond primary agricultural production. For example, tree products such as timber, fruits, nuts, and medicinal plants can be harvested and sold for additional income. Agroforestry also creates employment opportunities in activities such as tree planting, pruning, and harvesting, thereby contributing to rural livelihoods and economic development. The economic benefits of agroforestry extend beyond individual farmers to encompass broader community development and poverty alleviation efforts. As highlighted by Franzel and Coe (2001), agroforestry research has shown that well-designed agroforestry systems can enhance the resilience of rural communities by diversifying income sources and improving access to resources. By promoting sustainable land management practices and fostering entrepreneurship, agroforestry contributes to poverty reduction and food security at the household and community levels. In the context of Nigeria, where malnutrition and food insecurity remain significant challenges, the adoption of agroforestry practices can be instrumental in enhancing food security and improving the nutritional status of communities. By promoting the cultivation of a diverse range of food products, including fruits, vegetables, and tree crops, agroforestry can help address the underlying causes of malnutrition and food insecurity in the country, ultimately contributing to improved livelihoods and well-being for rural households.

Discussion of Findings

The findings of this research underscore the significant role that agroforestry plays in mitigating climate change and enhancing food security in Nigeria. Through a comprehensive review of existing literature and case studies, several key insights have emerged, which warrant further discussion.

Firstly, the adoption of agroforestry practices offers a sustainable solution to the challenges posed by climate change in Nigeria. Agroforestry systems have been shown to sequester carbon, reduce greenhouse gas emissions, and enhance carbon storage in biomass and soil (Montagnini & Nair, 2004). By integrating trees with food crops, agroforestry systems contribute to climate change mitigation efforts by capturing and storing carbon dioxide from the atmosphere. This not only

helps to mitigate the impacts of climate change but also promotes environmental sustainability and resilience.

Secondly, agroforestry has the potential to enhance food security by diversifying diets, improving soil fertility, and providing supplementary income for farmers (Kiptot & Franzel, 2012). The integration of trees with food crops increases the availability of nutritious food products, addressing malnutrition and food insecurity. Additionally, agroforestry practices such as intercropping and alley cropping improve soil fertility, leading to sustainable and resilient food production systems (Garrity et al., 2010). This multifunctional approach to agriculture ensures that communities have access to a wide range of food sources, contributing to improved health outcomes and resilience to food shortages.

Furthermore, the case studies presented in this research highlight the diverse applications and benefits of agroforestry across different agroecological zones in Nigeria. From alley cropping in southern Nigeria to agro-silvopastoral systems in northern Nigeria, each agroforestry practice offers unique advantages and contributions to agricultural sustainability. These case studies demonstrate the potential for scaling up agroforestry practices to enhance agricultural productivity, resilience, and food security in Nigeria. However, despite the numerous benefits of agroforestry, there are challenges and barriers to its widespread adoption in Nigeria. These include limited access to resources and technical knowledge, inadequate policy support, and competing land use priorities (Ogbonna, 2017). Addressing these challenges will require coordinated efforts from policymakers, researchers, and development practitioners to promote the adoption of agroforestry and realize its full potential in mitigating climate change and enhancing food security.

Recommendation

Based on the findings of this research, several recommendations can be made to promote the adoption of agroforestry practices and enhance their contributions to climate change mitigation and food security in Nigeria:

- ★ **Policy Support and Institutional Framework**: There is a need for the development and implementation of supportive policies and institutional frameworks that prioritize agroforestry as a sustainable land use practice. Policymakers should integrate agroforestry into national agricultural development plans and provide incentives, subsidies, and technical support to farmers willing to adopt agroforestry practices.
- ★ **Capacity Building and Awareness**: Efforts should be made to increase awareness and build the capacity of farmers, extension workers, and other stakeholders on the benefits and best practices of agroforestry. Training programs, farmer field schools, and extension services can play a crucial role in disseminating knowledge and empowering farmers to adopt agroforestry practices effectively.
- ★ **Research and Innovation:** Continued research and innovation are essential to develop and adapt agroforestry practices that are suitable for diverse agroecological zones and farming systems in Nigeria. Research institutions, universities, and agricultural extension agencies

should collaborate to conduct research, pilot projects, and demonstrations to promote the adoption of agroforestry.

- ★ **Community Engagement and Participation**: Community engagement and participation are crucial for the successful implementation of agroforestry initiatives. Local communities should be involved in the planning, decision-making, and implementation processes to ensure that agroforestry practices meet their needs and priorities.
- ★ **Partnerships and Collaboration**: Collaboration among government agencies, non-governmental organizations, research institutions, and development partners is essential to leverage resources, share knowledge, and scale up successful agroforestry interventions. Public-private partnerships can facilitate investment in agroforestry projects and promote sustainable value chains for agroforestry products.
- ★ **Monitoring and Evaluation**: Robust monitoring and evaluation mechanisms should be established to assess the impacts of agroforestry interventions on climate change mitigation, food security, and livelihoods. Monitoring indicators should include carbon sequestration rates, crop yields, soil fertility, biodiversity, and household income.
- ★ **Scaling Up Successful Models**: Successful agroforestry models and case studies identified in this research should be scaled up and replicated across different agroecological zones in Nigeria. Lessons learned from these models can inform the design and implementation of future agroforestry initiatives.

By implementing these recommendations, policymakers, researchers, and development practitioners can harness the potential of agroforestry to mitigate climate change, enhance food security, and improve livelihoods for smallholder farmers in Nigeria.

Conclusion

This research has underscored the critical role of agroforestry in mitigating climate change and enhancing food security in Nigeria. Agroforestry practices offer multifaceted benefits, including carbon sequestration, soil fertility enhancement, biodiversity conservation, and supplementary income generation for farmers. Through case studies and empirical evidence, we have highlighted the diverse applications of agroforestry across different agroecological zones in Nigeria and demonstrated its potential to improve agricultural productivity, resilience, and livelihoods. However, realizing the full potential of agroforestry requires concerted efforts from policymakers, researchers, and development practitioners to promote its adoption, build capacity, and create enabling environments. By implementing the recommendations outlined in this research, Nigeria can harness the power of agroforestry to address the challenges of climate change and food insecurity while fostering sustainable agricultural development and rural prosperity.

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