SUSTAINABLE FOOD SECURITY IN NORTHEAST NIGERIA: A SYSTEM SCIENCE APPROACH

PhD in Agricultural, Environmental and Food Economics

School of Agriculture, Policy and Development
Agric-Food Economics and Marketing Department

Chinweoke Uzoamaka Ike
Student Number:

September 2025

Declaration of Original Authorship

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Signed

Chinweoke Uzoamaka Ike

Student number:

Acknowledgements

Lord Jesus, I want to express my deep appreciation for the peace, solace, and motivation I found in your teachings throughout the years of my academic journey. Your calming presence, even during the challenging times of the COVID-19 pandemic and the writing of this thesis, has been my anchor.

I am immensely grateful to numerous individuals and institutions for the crucial roles they played in my academic pursuit. Their cooperation, financial assistance, emotional support, and guidance have been invaluable.

I would like to extend my heartfelt thanks to my family members: Mike Chikaodi Ike, Ebubechim Daniel Ike, and Chimeremiheoma David Ike for their unwavering love, patience, and encouragement that provided me with the strength to persevere through the most challenging moments of my studies. Ebube and Iheoma, your presence served as a constant reminder of why I could not give up. I acknowledge the sacrifices you made during my absence, especially during the COVID-19 pandemic, and I will forever be indebted to you.

I owe a tremendous debt of gratitude to my supervisors, Prof. Richard Tranter and Dr Yiorgos Gadanakis, for their continuous guidance, feedback, motivation, and effective communication. Your invaluable contributions greatly facilitated the success of this endeavour, and I hold dear the scholarly knowledge I gained under your tutelage. Thank you.

I extend my appreciation to my academic advisors and those who assisted with my research. To my academic mentors at the School of Agriculture Policy and Development, Dr. Ariane Kehlbacher, Philip Jones, Prof. Elizabeth Robinson, and Dr. Giacomo Zanello, as well as the many instructors who contributed to my education, I express my gratitude. To my lecturers back in Nigeria, Prof. S.A.N.D Chidebelu and Prof. A.A. Enete, along with my wonderful colleagues at the Department of Agricultural Economics at the University of Nigeria, Nsukka, I offer a heartfelt thank you for your unwavering support.

I would also like to acknowledge the dedicated administrative staff at SAPD University of Reading, particularly Karen Garrod and Teresa Hicks, for their efficiency and support. Special thanks go to Prof. Martin Lukac for his support in funding the essential VENSIM training needed to complete my thesis- a skill that I consider invaluable.

I am grateful for the dedication and diligence of my data collection team, including Samaila, Ebuwaseh Pearl, Pastor Never, and Yusuf. Your tireless efforts, especially amidst COVID-19 restrictions. and risks in the study area, were truly commendable. I deeply appreciate your unwavering dependability.

To my fellow members of the systems thinking model group, Dr. Okore Ikokwu, Pastor Never Jubrin Dubugari, Jessica Odoh, Ben Oni, Hon. Kuria Katrafi, Yakubu Matin, Chinonyerem, Samuel Okorafor, and Prof. Anselm Enete, I am thankful for your contributions to building the model. Your time, knowledge, and enthusiasm for this study were indispensable.

I want to express my gratitude to my beloved mother, Dr Philomena Nnennaya Okorafor, for her timely and uplifting phone calls that always seemed to arrive just when I needed them most. To my late father, Mazi Nduka Okorafor, your foundational support has paved the way for my education, and I am proud to have fulfilled your aspirations. To my beloved Aunt, Florence Okore, your financial support, prayers, and encouragement have been a constant source of strength.

I also extend my thanks to my uncles, Dr. Ikokwu Okore and Moses Kalu Okore, my siblings- Osinachi, Chinoyerem, Amarachi, Chichetam, and my cousins- Eberechi, Oluchi, Kelechi, Chizaram, and Chiziterem. I want you all to know that I deeply appreciate having you as family. Your unwavering love and support mean the world to me.

I cannot forget to thank my friends in Reading, UK, including Ogbonne, Joy, and many others whose friendships have been invaluable.

Lastly, I would like to express my profound gratitude to my sponsor, the Commonwealth Scholarship Commission, for providing me with the opportunity to pursue my long-held dream of obtaining a Ph.D. degree. Your timely monthly stipend helped me meet my financial obligations, including rent, and I am sincerely thankful for the Commonwealth team's commitment to supporting students like me in achieving their educational goals.

List of Abbreviations

APP - Agriculture Promotion Policy
ATA - Nigerian Agricultural Transformation Agenda
CAP - Common Agricultural Policy
CLD - Causal Loop Diagram
CSI - Food Insecurity Coping Strategies Index
DDS - Dietary Diversity Score
DMNL – Dimensionless
FANTA - Food and Nutrition Technical Assistance
FAO- Food and Agriculture Organization
FEE - Failure of Exchange Entitlements
FGD - Focus Group Discussion
FSIN - Food Security Information Network
HDDS - Household Dietary Diversity Score
HFIAS - Household Food Insecurity Access Score
HFSSM - Household Food Security Survey Module
HH - Household
IDDS - Individual Dietary Diversity Score
IFST - The Institute of Food Science and Technology
IRD – Interrelationship Digraph
LCA - Life Cycle Assessment
NCE - Nigerian Certificate of Education
OND - Ordinary National Diploma
SDG - Sustainable Development Goal
SDM - System Dynamic Modelling
UN- United Nations
USDA- U.S Department of Agriculture
WDDS - Women Dietary Diversity Score
FSP - Farm Settlement and Plantation Programme
OFN - Operation Feed the Nation
ADP - Agricultural Development Project
ACGS - Agricultural Credit Guarantee Scheme
RBDA - River Basin Development Programme
RBS - Rural Banking System
GR - Green Revolution
DFRRI - Directorate for Food, Roads and Rural Infrastructure
CBP - Better Life for Rural Women Programme (Now women Commission,
Community Banking Programme
NADLA - National Agricultural Development Land Authority
FSP - Family Support Programme
FEAP - Family Economic Advancement Programme
NSPFS - National Special Programme for Food Security
NATIP - National Agricultural Technology and Innovation Policy

Abstract

This study explored the complex challenges of achieving food security in Northeast Nigeria. The study employed a system thinking approach to identify interventions to achieving sustainable food security, biodiversity, and income and employment opportunities. To achieve its objectives, the research gathered primary data from 375 randomly selected households using questionnaires, organized six focus group discussions on the effectiveness of agricultural policies, and conducted stakeholder consultations to comprehend the intricate interactions and feedback within the food system. The data analysis employed both qualitative and quantitative methodologies. The Dietary Diversity Score (DDS) was employed to capture the food security of households. The study harnessed system thinking analysis, and causal loop diagrams to explore and unearth potential pathways towards sustainable food security. It also identified effective policies, such as promoting organic farming, mixed cropping, and providing credit and labour subsidies to small-scale farmers, which enhanced food access, biodiversity, income, and environmental benefits. The study identified that Cereal (98.4%), white roots and tubers (96.3%), and oil and fat (91.5%) constituted the most consumed food groups. In contrast, eggs (15.2%), organ meat (23.5%), milk and dairy products (21.9%), and flesh meat (34.1%) were consumed less, highlighting the issue of hidden hunger in the region. Causal loop diagram unveiled agrochemicals, food harvest, monocropping, and mixed cropping as root drivers of the food system, with key outcomes being biodiversity, food security, income, farm labour, and soil quality. Traditional and indigenous knowledge emerged as crucial in preserving biodiversity and a sustainable food system. Recommendations include addressing protein and micronutrient gaps, re-evaluating monocropping and food industrialization policies, supporting mixed cropping through labour subsidies, and promoting forest growth.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Background to the Study

At the global level, agricultural productivity has increased greatly in recent years (FAO, 2018a). However, the need for sustainable agriculture came as the productivity increase came with high social and environmental costs, including soil degradation, water scarcity, biodiversity loss, ecosystem stress, decreasing forest cover, and increased greenhouse gas emissions (FAO, 2018a). To achieve the sustainable development goal of food and nutritional security, there is need for the food system to be socially just, and the environment managed sustainably (Capone et al., 2014; El Bilali et al., 2022). Hence, agricultural programmes should aim not only to ensure food security, but doing so in a sustainable manner as emphasised in the second United Nations Sustainable Development Goal (SDG2). Specifically, SDG2 recognizes the interdependency and linkages among food security, sustainable agriculture, empowering smallholder farmers, ending poverty and promoting healthy lifestyles. Achieving the SDG2 of food security will be a great challenge to Nigeria given the enormous economic difficulties the country is facing (Food Security Information Network, 2018). Nigeria has been experiencing prolonged economic challenges as a result of insurgency, climate extreme events, and heavy reliance on delicate and diminishing natural resources e.g., crude oil. Nigeria is a net food importer and an exporter of natural resources, making the country vulnerable to international food prices instability (Eboh, 2018; Thibiebi, 2018).

One in three people worldwide are malnourished, and the FAO (2018e) estimates that 815 million people are undernourished, which is as a result of a failing food system. From 2019 to 2020, there was a rise in the undernourishment prevalence, from 8.0 to 9.3% of the total population, and in 2021, it grew to 9.8%. In 2021, hunger impacted about 702 to 828 million people (AFAO 2022b). Since the COVID-19 pandemic outbreak, the number of people affected by hunger in the world has increased; between 2019 and 2020, it increased by 103 million, and in 2021, it increased further by 46 million (FAO, 2022b). According to Care (2023), 4 in 5 Nigerian homes are food insecure, accounting for 80% of Nigerian households, and 20% of the food insecure households are severely food insecure, going an entire day without food. Care (2023) puts the number of people in Nigeria that are expected to suffer from acute food insecurity in 2023 at over 25 million.

In Northeast Nigeria, in Borno State alone, live about 400,000 severely malnourished children, and Yobe State has 4.3 million children (under the age of 18) in need of urgent humanitarian assistance (UNICEF, 2018). UNICEF, in January 2017, announced that about 240 children were expected to starve to death daily in Nigeria (FSIN, 2017). This amounts to 90,000 children dying in a year due to hunger. In the same year (2017), the UN warned that at least 1.5 million people were expected to die in Nigeria due to starvation, also that 5.1 million people will face serious food shortages. Care (2023) estimated the number of acutely malnourished children to be 2 million children in the Northeast states during the lean period of 2023. This represents about 15% increase from the 1.74 million acutely malnourished children in December 2022. The widespread poverty and unemployment, especially among the youths, call for a practical means of combating food insecurity in Nigeria. Poverty limits the ability of households to purchase the necessary balanced diet. Consumption of few varieties of food is also a problem to achieving nutrition security.

In response to critical issue of food insecurity in Nigeria, which prompted the declaration of a state of emergency on the 14th of July 2023. On this matter, the government has introduced a comprehensive intervention plan aimed at achieving food security, sustainability, and affordability (Care, 2023). This action plan is derived and aligned to the Agricultural Promotion Policy (APP) and National Agricultural Technology and Innovation Policy (NATIP) for the achievement of food security. This plan consists of 12 specific action points, two of which are directly directed towards farmers, and they are: distribution of fertilizers and grains, and the enhancement of security measures for farmers. The remaining action plans include the following:

1. Promoting year-round farming and irrigation through collaboration between the Ministry of Agriculture and water resources,
2. Establishing a national commodity board for assessing prices and managing strategic food reserves,
3. Expanding the Central Bank's role in financing the agricultural value chain,
4. Initiating the cultivation of 500,000 hectares of land and river basins for continuous farming,
5. Providing concessional funding to support the agricultural sector,
6. Improving transportation and storage facilities for agricultural products,
7. Increasing agricultural export earnings,
8. Collaborating with customs authorities to facilitate trade,
9. Reducing unemployment and generating employment opportunities in the agricultural sector, and
10. Ensuring that every Nigerian has access to affordable food (Care, 2023).

It is important to note that these key actions, as well as previous agricultural policies, have primarily focused on addressing obstacles related to physical and economic access to food, including lack of storage facilities, access roads, low income and flood control. However, little or no attention has been given to the nutritional aspects of food production, and food security, which are crucial in combating malnutrition. These policies have concentrated on increasing the quantity of food available without considering the nutritional quality and adequacy of the food accessible to the population. Even less attention is given to the importance of biodiversity and inclusion in the intervention processes. To achieve food security, the policies have paid little attention to traditional food crops like cocoyam, cassava, fruits, and vegetables, especially those from the wild. Hence, the policy strategies for achieving the food security objectives were not focused on producing food crops and animals that could increase access and availability to diversity of food for households.

Biodiversity is important for continuing provision of food varieties, and biodiversity and food security are linked in many ways. It is well documented that biodiversity provides the pool for sourcing diverse food production (Child, 1996; Cramer et al., 2017; 2011a; Tscharntke et al., 2012). Agrobiodiversity constitutes the biodiversity of the agroecology, from the different species to the different breeds and varieties within species (Frison, Cherfas, Hodgkin, et al., 2011). Because there are strong linkages between food systems and food security (Frison, Cherfas, Hodgkin, et al., 2011), sustainable food system policies and interventions should be based on thorough and holistic analyses. A sustainable food system is a system that will not only ensure long-term food security, but sustainable development through inclusive employment and income for the vulnerable, reduced food miles, a resilient food system and balanced food trade in Nigeria. Hence, crop and animal diversity need to be the emphasis for sustainable agriculture policies.

Table 1.1 Government funded agricultural policy projects and programmes in Nigeria since 1960

Agricultural projects and programmes	**Date**	**Focus**
Farm settlement and plantation programme- FSP	1960	Establishment of agricultural communities to boost food production and provide employment. It focused on settling young farmers on farmlands where they could live and farm, thus promoting agricultural development and community living.
Operation Feed the Nation - OFN	1976	Encouraging self-sufficiency in food production through mobilization of resources, provision of inputs, and technical support to farmers. OFN's goal was to increase food production across the country by encouraging, not just farmers, but everyone, including students, civil servants, and military personnel, to engage in farming activities.
Agricultural Development Project -ADP	1976	Implementing integrated agricultural development programs at the state level to enhance productivity, income generation, and rural development. Implemented to support small-scale farmers through the provision of inputs, extension services, and infrastructure to increase agricultural productivity and improve rural livelihoods.
Agricultural Credit Guarantee Scheme - ACGS	1977	Facilitating access to credit for farmers and agribusinesses by providing guarantees to financial institutions against risks associated with lending to the agricultural sector. Aiming to encourage banks to lend to farmers by reducing the risk associated with agricultural financing.
River Basin Development Programme- RBDA	1978	Development of water resources for irrigation, flood control, and agricultural expansion in river basins to improve agricultural productivity and livelihoods.
Rural Banking System-RBS	1978	Establishing banking services in rural areas to enhance financial inclusion, access to credit, and promoting economic activities in rural communities.
Green Revolution - GR	1980	Introducing modern agricultural techniques, improved seeds, and technologies to increase agricultural productivity and food security
Directorate for Food, Roads and Rural Infrastructure - DFRRI	1986	Infrastructure development in rural areas, including roads, bridges, and storage facilities, to support agricultural production and rural livelihoods.
Better Life for Rural Women Programme (Now women Commission,	1987	Empowering rural women through skill development, access to resources, and support for income-generating activities to improve their livelihoods.

Community Banking Programme-CBP	1990	Establishing community-based banking institutions to provide financial services tailored to the needs of rural communities, including farmers and small businesses.
National Agricultural Development Land Authority- NADLA	1991	Facilitating land acquisition, allocation, and management for agricultural purposes to promote sustainable land use and agricultural development.
Family Support Programme - FSP	1992	Providing social welfare support to vulnerable rural households to improve their living standards and resilience to economic shocks.
Family Economic Advancement Programme-FEAP	1994	Promoting economic empowerment and poverty reduction among rural families through skills training, access to credit, and income-generating activities.
National Special Programme for Food Security-NSPFS	2001	Enhancing food security through targeted interventions in areas such as crop production, livestock development, and food processing.
Agricultural Transformation Agenda (ATA)	2010	Implementing strategic reforms and initiatives to transform the agricultural sector, increase productivity, and promote agribusiness development.
Agriculture Promotion Policy (APP)	2016	Providing a comprehensive framework for promoting agricultural development, investment, and competitiveness in Nigeria's agricultural sector.
National Agricultural Technology and Innovation Policy (NATIP)	2022	Promoting the adoption of modern technologies, innovation, and research in agriculture to improve productivity, sustainability, and competitiveness.

(D’Silva & Raza, 1980; Ecker et al., 2018; Jerome, 2015)

Despite various interventions and programmes by the Nigerian government (see Table 1) to ensure food security, large segments of the population of the country still live in hunger and below the poverty line, especially those in the North East region (Ambali & Murana, 2017; Nwozor & Olanrewaju, 2020). Studies have shown that changes in policies have always only reflected a change in the framework design and characterisation and not changes in the structure or implementation of the strategies (Ambali & Murana, 2017; Iwuchukwu & Igbokwe, 2012). These studies noted that these policies had a similar objective - to achieve food security and increasing agriculture earnings through exports. D'Silva and Raza (1980) noted that while the Agricultural Development Project (ADP) aimed at generating income for local farming households, particularly targeting small-scale farmers, it predominantly focused on large-scale agriculture. This emphasis was evident in the distribution of extension service visits, where large-scale farmers received 60% of the attention from extension agents. As with the NATIP, Ecker et al., (2018), also noted that the immediate past, Nigerian Agricultural Transformation Agenda (ATA) and the Agriculture Promotion Policy (APP) were still geared toward commercialising agriculture to improve export through crop and animal production specialization. These studies evaluated the achievements of the various agricultural policies in achieving more food production for food security and income earning. Available studies have done very little in exploring how these policies and programmes aligned with the different aspects of food security and the distribution of income in view of the sustainable development goals. More importantly, the studies have very little focus on the relationships and effects of these policies and programmes on the complex and dynamic food system that produce the food security in the face of sustainability problems.

Nigeria agricultural policies have been promoting the production of fewer crops, while the need for a more diverse mix of crop production systems may be required to address the food and nutrition security objectives. Against the culture of mixed cropping in Nigeria, studies have shown that the use of agrochemicals and monocropping encouraged by past policies have resulted in increased use of hired labour and purchase of costly inputs, which may have led to high input cost and less profitable farming for the smallholder farmers (Braun, 1991; Jacques & Jacques, 2012; Majeed, 2018; Pingali, 2012; Von Braun, 1995). The impacts of monocropping and its commercialization processes on soil nutrient and water have not been well documented. Monocropping and the use of Agrochemicals and tractors have always presented a system of cropping that gives farmers the greater gains in terms of maximum output with least input cost that comes from economies of scale. It is expected that the food need and good landscape aesthetic effect of increasing population will be catered for through this kind of production system. This may be true if resource limits are considered an externality in the food system. It may also be relevant, if farmers in Nigeria owned or cultivated large expanse of land. The fact that Nigerian farmers cultivate an average of 0.5 hectare of land makes it less feasible to make profit through economies of scale.

However, Jacques and Jacques (2012) noted that loss of biodiversity resulted from the political and epistemological economy condition of Green Revolution with its economy of scale, high yielding varieties and export focus. The Green Revolution neglected the diverse varieties that may not have the same yield, but can withstand the pests and diseases, and changing climate conditions (Pattanayak et al., 2023; Saladino, 2022). How chemicals, farm machines and very simplified food systems are affecting habitats, living organisms in the soil like earthworms, and those living above the soil like bees, biodiversity and consequently dietary diversity is, obviously, underrepresented in the literature and discussion (Center for Biological Diversity Newsroom and Friends of the Earth, 2021; Fritijof, 2002; Hallmann et al., 2017; Jacques & Jacques, 2012). Due to conflict with those with vested interests and those of human health and environmental sustainability activists, the problem of the right farming system for the benefit of human health and environmental sustainability will remain a political issue (Chappell & LaValle, 2011; Lang & Heasman, 2004).

Food access may be a supply problem which cannot be solved by producing more food. Food access is a critical component of food security: encompassing not just the availability of food, but also the ability of individuals to obtain it bordering on the theory of failure of the exchange entitlement. Fritz (2011) argues that food access issues may not necessarily be resolved by merely increasing food production. This perspective invites a deeper exploration of the various dimensions of food access and the factors that influence them (Fritz, 2011). Hence, the focus of food and agricultural policies should not only be on quantity but also types of food supplied and food distribution within the system. Food system sustainability should concern us the more, given the problem of rising food related non-communicable diseases, micronutrient deficiency, malnourishment, and obesity. The question is "How is monocropping contributing to this problem?" (Chaudhary, 2019; de Oliveira Otto et al., 2018; FAO, 2022; Food Research and Action Center, 2015; Kaur & Kaur, 2016). The problems of poverty and inequality vicious circle in the food system has also showed the effects of production system on social justice (Von Braun, 1995). Monocropping in the middle of sustainability should not only be scrutinized for its ability to produce food in large quantity which can also be achieved using the excess labour from the increasing population, especially in developing countries. There is need to evaluate this monocropping system for environmental sustainability, due for the loss of biodiversity (Jacques & Jacques, 2012). "How is monocropping contributing to the ever-growing wealth gap?" (Braun, 1991; Von Braun, 1995; von Braun, 2003). It should worry us how we keep producing more food and still have many nutritional problems. We may also think about the simplified diets and our complex nature as humans, and the complex diseases surfacing over time. Is a human able to sustain himself through what science and technology is producing such as: food, drug, vaccine, and artificial environment, even though there are many things science is still working to understand?

Similar to how the Common Agricultural Policy (CAP) of the European Union overlooked small farmers, compelling them to either consolidate or cease farming operations ((Fritz, 2011) Pg 31), Nigerian agricultural policies also view small-scale farms and farmers as hindrances to development. This perspective is evident in various Nigerian agricultural policy frameworks, including the Agricultural Promotion Policy (APP) and the recent National Agricultural Transformation Implementation Plan (NATIP) (Care, 2023)**.** The shift to cash crop production in many developing countries cannot offset the burden of food import for the citizens (Fritz, 2011). Imported foods often go to the urban consumers. This takes a lot from the national food budget and so, leaves little budget for the support of small farmers for domestic food production. This means that the policies supporting the production of cash crops and farm commercialization through input subsidies may not be able to solve the problems of food security in the world but deepens import dependency.

Fritz (2011) claimed that by subsidizing inputs cost for the large farms, agricultural policies depressed food price and income of the small farmers. This support will favour the production and consumption of a few types of crops. So, the changing eating habit which may have contributed to the rise in non-communicable disease may be the emergence from the intervention in the food system over the years. If the policies supporting and feeding this food to consumers is not checked to give the indigenous diversity of food a chance in the farms, then human health and the natural environment may continue to degrade.

The dominant world capitalist system underpinning monocropping has worked to maximize productive forces that produce large quantity of food to maximise profit at the expense of other production systems that maximize resilience, traditional meaning, nutrition, taste, and other values. The consumption of traditional foods, which are produced locally, eaten as unprocessed or minimally process food is important for sustainability and the economy of the smallholder farmers. There is need for rich nutrients and variety of food produce in the human diet. According to FAO (2019a, 2022b) and research conducted by Makate et al., (2016) and Mango et al., (2018), it was demonstrated that the cultivation of diverse crops and increased biodiversity in ecosystems have a positive influence on the income of small-scale farmers and contribute to enhancing food and nutrition security.

Studying the interdependence of food security and food system will shed light on the relationship between farm level activities and other aspects of the food system and linking these activities to their outcome which is food security. Exploring how food security can be achieved through sustainable food systems will reveal the outcome of food production and dietary choices on the environment, society, and economy. Studying the interdependence of food security and the food system is essential because it illuminates the connections between farm-level activities and other aspects of the food system, linking these activities to their goal which is food security. By exploring how food security can be achieved through sustainable food systems, we can understand the impacts of food production and dietary choices on the environment, society, and economy. This comprehensive approach helps identify sustainable practices that balance production needs with ecological and social well-being.

Studies on the food system need to be more participatory, transdisciplinary, or multidisciplinary, and focus more on the interactions between the different elements of the system.

Participatory Research: Engaging farmers, consumers, policymakers, and other stakeholders ensures that diverse perspectives and local knowledge are incorporated into the study. This leads to more practical and acceptable solutions that are likely to be adopted and sustained.

Transdisciplinary Approaches: Integrating insights from various disciplines such as agriculture, ecology, economics, sociology, and public health provides a holistic understanding of the food system. This approach helps in addressing complex issues that cannot be solved by a single discipline.

Multidisciplinary Focus: Examining the interactions between different elements of the food system- such as production, distribution, consumption, and waste management enables a comprehensive analysis of how these components affect food security. This helps in identifying leverage points for intervention and improvement.

In essence, a collaborative, integrative, and holistic approach is crucial for developing effective strategies to achieve food security through sustainable food systems. This will ultimately contribute to a more resilient and equitable food system that benefits the environment, society, and economy.

1.2. Problem Statement

Food security of households in Nigeria has in most cases been estimated using secondary data on income and calorie, and anthropometric measures like, stunting, underweight and wasting ((Akinyele, 2009; Kemi et al., 2014; Owoo, 2020; Ozughalu & Ogwumike, 2013). Ecker et al (2018), have raised serious concern over the suitability of Nigeria food security secondary data. Primary data on calories, income, and expenditure have been adopted by researchers at state and local government levels a proxy for food security (Ahungwa, Umeh, & Muktar, 2013) A limited number of studies in Nigeria have used more direct measures of food security like the Household Food insecurity access score (HFIAS), Food

Insecurity Coping Strategies Index (CSI) and Dietary Diversity Score (DDS). Adewumi and& Animashaun (2013) used the DDS as a measure of food security of households in Kwara in southern Nigeria in studying the correlation between DDS, income, and farmers technical efficiency. Olaniyi (2014) used both DDS and HFIAS in measuring the level of food insecurity in Lagos, a southern Nigerian state. Paramount to achieving a food secure society is a proper measurement tool and reliable data for monitoring of food security, and this can be achieved by using the correct measurement and data.

Food security research has focused on measuring the status of food security and hunger at the different levels of society. However, there is little research into the linkages between food security and food systems and the importance of crop diversity in achieving food and nutrition security. The complex relationship within the food system which can be explored for sustainable development has had little attention from researchers, though it is considered very important in the fight against food system collapse and food insecurity (FAO, 2022b).

Despite the alarming food insecurity in Northeast Nigeria, published works on food security in the north have not covered the states in this region. The FAO calorie intake and food expenditure method in measuring the level of food insecurity has been used in capturing food insecurity in North central, Nigeria. Ahungwa et al., (2013), and Ike, Jacobs, & Kelly (2017b) worked on food security status of households of Taraba State which is in the Northeast. Though the work by Ike et al (2017) which adopted the DDS, HFIAS and CSI shed light on food security in Taraba state, it did not cover the entire Northeast and did very little on food system linkages. Also, there is little or no research on the linkages of food security and food system in Nigeria. There is a gap in literature on the effects of food production practices on food security and environmental sustainability in Nigeria.

Available literature has shown that there is need for a comprehensive assessment of food security situation in Northeast Nigeria using a tool that can produce reliable empirical evidence. There is a dearth of research on food systems and food security interaction, looking at the role of traditional diet and production in food security in Nigeria, especially in the Northeast zone. How the present agriculture system of large farms impacts on the ability of the food system to support biodiversity, food security and entitlements equity should be clearly investigated for the purpose of sustainable development (Khush, 2016; Sunderland, 2011a). The existing secondary data is not reliable and is inadequate to fulfil this objective and hence, primary data based on field surveys in the area is required. This study intends to fill these research gaps by using the system dynamic modelling tool to explore how the food system can be altered to yield increase biodiversity, farm income, food security and labour for sustainable development.

From production to consumption of food, there are many subsystems, activities, elements, interactions, and relationships that determine our food today. It is important to understand how different actions, activities, decisions, and systems component interact and the outcomes, and why these interactions affect the sustainability of the food system. Achieving food security under a sustainable environment has become necessary due to evidence of double-edged problems of obesity and malnutrition (Food Research and Action Centre, 2015). There is also increasing hunger and poverty with rising unemployment in the face of fast technological advancements as in the case of Nigeria (Akinbobola & Saibu, 2004). The rising unemployment and poverty, especially for the young, call for a practical way of solving the problems of food insecurity in Nigeria.

Studies have shown that about 70% of Nigerians are food insecure (Orewa & Iyangbe, 2009).Over 44% of the Nigerian population experienced moderate to severe food insecurity in 2018. Over 8% of the Nigerian population experienced severe hunger between 2016 – 2018 (FAO Commission on Genetic Resources for Food and Agriculture, 2020). Nigeria hosts about 50% of the food insecure population in West Africa in 2019 (Baquedano et al., 2020). The proportion of the population that experienced severe hunger increased to 9.1 percent by 2019, about 66 million Nigerians are food secure in 2020 and the number increase by 9.2 million when the effect of COVID 19 is considered (Baquedano *et al.*, 2020). Borno State alone, Northeast Nigeria, hosts about 400,000 severely malnourished children, and Yobe has 4.3 million children (under the age of 18) in need of urgent humanitarian assistance(Bulman, 2017). Food insecurity in a country like this may be an indication that the gains achieved from shifting from food to cash crop production in many developing countries cannot offset the burden of food import for the citizens. Government keeps spending on food importation which goes mostly to the urban consumers, with little or no support for the small farmers for domestic food production. This trend continues because there is a longer time lag between time of planting and harvest, than it is between eating times. This means that the policies supporting the production of cash crops and farm commercialization may not be able to solve the problems of food security in the world but deepens import dependency (Fritz, 2011).

Food security policies have changed with every new government in Nigeria (Iwuchukwu & Igbokwe, 2012). The rising food and nutrition insecurity couple with increasing poverty, and unemployment rate (Akinbobola & Saibu, 2004), show that these policies have failed not only in achieving their target but have had other unintended consequences. The Agricultural Promotion Policy (APP) of Nigeria is geared towards achieving food security under a sustainable development context (Federal Ministry of Agriculture and Rural Development, 2016). This policy goal is harder to achieve considering the number of hungry and poor people, and overexploited lands in Nigeria. APP which replaced the Agricultural Transformation Agenda (ATA) of 2011 was developed in 2016, with a focus on food security, import substitution and job creation, in addition to environmental sustainability. These two policies, ATA and APP were aimed at moving Nigerian agriculture to a commercial sector to ensure the creation of sustainable jobs and wealth. Fritz (2011) while examining the impact of the EU Common Agricultural policy (CAP), mentioned that CAP not only ignored small farmers but forces them to amalgamate or go out of farming. So, also, Nigerian agricultural policies see small farms and small farmers as obstacle to development.

However, little is known about the effectiveness of these policies on biodiversity, dietary diversity, and welfare of the small-scale farmers who form the greater proportion of the food producers (FAO, 2018b; Sabo et al., 2017). The importance of biodiversity to food and agriculture is receiving more attention in the international policy agenda. However, this recognition needs to be backed with action. A knowledge gap exists in terms of how existing policies affect the biodiversity components and the services and products they provide (FAO, 2019c). The effects of these policies on food security in terms of availability of varieties of food crops have also received very little attention (FAO, 2022).

1.3. Overview of the Aims and Objectives of this Study

The broad objective of the study is to explore the relationship between the food system and food security of Northeast Nigeria using System Dynamic Modelling with the aim of achieving sustainable development and to draw a causal/feedback loop diagram of the system. The study intends to identify interventions needed to achieve better employment and income opportunities, increased biodiversity, and food security in the food system. The study explored whether encouraging farmers and poor households with access to land to produce their own food using the farming method that gives them access to a range of crops and animals for consumption will help combat food insecurity.

In line with the scope of this study, the objectives of the study are as follows.

I. Assess households' perception of the effectiveness of the APP on sustainable development goals. This objective explored the APP policy thrusts for their ability to promote the cultivation of diverse crops and livestock, promote biodiversity and forest food harvest, diverse diet, and conservation, while concurrently generating employment opportunities, income for farmers, and bolstering food security.

II. Ascertain the food and nutritional security situations of households. This objective examined household consumption of different food groups, and important macro and micro-nutrients like iron rich foods, vitamin A rich foods, animal protein, or carbohydrate to shed light on the existence of hidden hunger. This objective also identified the main source of food in terms of purchase, owned production or gift and aid, and ascertained the contributions of forests and farm food to household food consumption. This objective also captured the consumption of traditional and western foods and food consumption outside the homes.

III. Explore the linkages between the food system components and food security pillars to understand their interactions and identify the main drivers and the key outcomes of the food system. The linkages and feedback loops within food system policy interventions, labour, farm practices, agrobiodiversity, household socioeconomic characteristics, and consumptions of diverse food were explored.

1.4. Key Research Questions

These following research questions are designed for an in-depth investigation into the complex interactions within the food system to facilitate a comprehensive understanding of the complex dynamics at play in Northeast Nigeria's food security situations, and to understand underlying patterns in the food system, causes, and implications. These research questions were largely derived from the literature discussed earlier in this chapter.

I. What strategies and policy interventions can be identified and assessed for their ability to promote the cultivation of diverse crops and livestock, while concurrently generating employment opportunities, income for farmers, and bolstering food security, in the context of increased biodiversity?

II. Based on the DDS measure, to what extent do households in Northeast Nigeria experience food insecurity, as measured by the DDS, particularly in relation to varying levels of access to diverse food groups and the occurrence of hidden hunger?

III. Is there hidden hunger in Northeast Nigeria?

IV. How do the complex interactions among food system biodiversity, labour utilization, and food insecurity in Northeast Nigeria shape the region's food insecurity patterns, and in what ways can a comprehensive understanding of these dynamic relationships inform and guide strategies to alleviate food insecurity and foster sustainable food systems?

1.5. Significance of the Study

Changing climate, globalization, and diminishing biodiversity may be a hindrance to the achievement of the sustainable development goals of attaining food security in Nigeria. Food secure Nigeria will remain elusive with the dearth of research on food security in Northeast Nigeria, and high level of food insecurity in this geopolitical zone. Having a food secure society will depend heavily on the interplay of set of dynamic factors specific to their food system. It is important for researchers to start focusing on understanding the interactions between the dynamic components of the food system as it affects food security. This will enable nuance and practicable evidence to support the fight against the complex problems of food insecurity.

The study aims at contributing to the ability of the food system to produce more nutritious and varied food in an environmentally sustainable manner that encourages biodiversity, while providing jobs and income increase and improved welfare in general. The study investigates how the local production and consumption of foods could improve food and nutrition security, and in the end sustainable development through labour and consumption markets. This study will contribute to the decision making and design of strategies in the ongoing fight against food insecurity in Nigeria. It will provide researchers with appropriate methodological approach for food system and food security research, and policy makers with reliable real-life evidence on the correct choices and actions to achieving a sustainable food system. Understanding the underlying structures of the food system and how it works will greatly improve efforts made against hunger in the world.

1.6 Thesis Outline

The rest of the thesis is organised as follows: Chapter 2 presents the literature review on the main concepts of the thesis - food and nutrition security of households in Nigeria, linkages between biodiversity, agrobiodiversity, and food Security. It also presents the literature review on theoretical and conceptual frameworks of the study and the methodology- system dynamic modelling. Chapter 3 presents a detailed description of the methodology used in the study. The fourth chapter is the first result chapter, which presents results on the focus group discussions on the effectiveness of Nigeria Agricultural Policy in achieving a sustainable food system. Chapter 5 presents the results on socio-economic characteristics of the households in the study area. The results on the food security situation of the households are contained in Chapter 6. Chapter 7 contains the Food system causal/feedback loop diagram analysis. Chapter 8 is the discussion and conclusion chapter and contains the highlights of the study, policy recommendations and areas for further study.

Chapter 2: Literature Review

2.1. Food and Nutrition Security of Households in Nigeria

Food security according to FAO ; IFAD ; UNICEF ; WFP ; WHO (2024) is "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". Based on this definition, four food security dimensions can be identified: "food availability, economic, social and physical access to food, food utilization and stability over time". Food availability looks at the physical availability of food which comes from food production, food from the wild, storage and food available in the market. Access to food looks at the physical, social and economic ability to access food, while utilization is about consumption of adequate nutrition by individuals which stems from good food preparation skill, feeding practice and patterns, dietary diversity, good personal care, and food distribution among household members. The stability dimension of food security is a condition of having availability, access, and utilization at all times (FAO et al., 2019; Ike et al., 2016).

Ajayeoba (2010) notes that there were over 53 million hungry people in Nigeria, and over 52 million people lived under poverty line in 2010. This is over 30% of a population of 160 million people in Nigeria. According to Food Security Information Network (FSIN) (2019), North Nigeria was among the eight worst food crises areas in 2018 and remained among the world's most severe food crises regions in 2019. These eight countries, Yemen, the Democratic Republic of Congo, Afghanistan, Ethiopia, the Syrian Arab Republic, the Sudan, South Sudan and North Nigeria make up about 72 million people suffering acute food insecurity, out of which, North Nigeria alone constitutes 22.7million. Although Nigeria has been removed from the countries with the worst food security situation, the situation did not improve, it is just that some other countries grew worst. According to the guardian (2024) more than 31.8 million Nigerians experienced acute food shortage in 2024. This is the highest in African and one of the highest globally. Only Nigeria accounts for 23% of the global increase in hunger. This represents an increase in food insecurity from the 2017 report. There is high level of malnutrition among Nigerian children, with about 84% of these affected children living in the north (Akinyele, 2009). According to the Global report on food crisis in 2017, the number of people suffering from acute hunger in northern Nigeria was estimated at 8.1 million individuals, with 4.7 million of them located in the Northeast region alone (Food Security Information Network, 2018; FSIN, 2017). The estimated number of people that will face acute food insecurity in the Northeast has risen to 6.4 million in 2023 (Care, 2023; FSIN, 2020). This figure is still increasing, as Care (2023), also estimated that around 17 million people were in critical food insecurity in 2022. It is anticipated that during the lean season of 2023, between June and August, approximately 25 million Nigerians may experience food insecurity (Care, 2023). Due to the escalating food insecurity crisis in the country, the Government declared a state of emergency on food insecurity in Nigeria on June 14, 2023.The Gaurdian puts the number of people facing crisis level of food security at 30.6million.

There is unacceptable level of poverty in the rural areas of Nigeria which has also contributed to their high-level of food insecurity. Nigeria is also the largest exporter of oil in Africa, and a gross food importer, with high level of unemployment. The unemployment rate surged from about 5% in 2006 to 23% in 2018. Despite this high unemployment rate, the cost of living, particularly the price of food, has continued to increase (National Bureau of Statistics Nigeria, 2019). Unemployment rate increased from 18.8 to 23.1 from the third quarter of 2017 to the third quarter of 2018 ("Nigerian Food Takes Backseat at 'Nigerian Flavour' Festival - Premium Times Nigeria," 2019). This amounts to a rise from 3.3 million to 20.9 million unemployed people in the third quarter of 2018 (Vanguard, 2018). Furthermore, it was estimated that the unemployment rate in Nigeria reached 37.7% by the end of 2022, and will reach 40.6% in 2023, and 43% in 2024 (Care, 2023; KPMG International, 2023).

Apart from the problem of unsustainable food system and gender inequality, the food insecurity problem in Nigeria has been attributed to lack of storage facilities for farmers to store their excess produce during the harvest. These have led to serious harvest loss, large household size, and less education (Akinyele, 2009; Omonona et al., 2007), lack of access to productive assets such as land, water, access roads, improved farm tools and machinery (UNDP, 2017), and *Boko Haram* insurgence that has resulted to loss of farm produce, land and lives of farmers in the northern part of the country (Reliefweb, 2015). Iwuchukwu and Igbokwe (2012) argues that food security objectives failed in Nigeria because of wrong agricultural policy strategies and abrupt withdrawal of fund for agricultural projects in the country.

The Federal Ministry of Agriculture estimated that Nigeria spends over three billion US dollars annually on food import, and still there is food insecurity in the country (Utebor, 2016). Nigerians' preference for foreign goods over domestic ones has implications for food production, and food security situation as well for the country. Folorunso (2013) shows that for every 10 goods sold in Nigeria six of them were foreign goods and concluded that Nigerian consumers have high taste for foreign goods. The result is the same for food. Premium times (2019) noted that Nigerian food fair held in Lagos was dominated by foreign food, which may be a discouraging factor to farmers producing traditional foods. The believe that traditional foods are inferior to Western food may have contributed to the food security problems as described in Onimawo (2010) that Nigerians' foreign rice syndrome despite the availability of hundreds of locally produced food and diet varieties has resulted to a decline in food production and consumption diversity.

2.2 Challenges of Farming in Northern Nigeria

The agricultural systems of Northern Nigeria are at a critical juncture, facing multifaceted challenges - ecological, climatic, and socioeconomic and political factors, notably the recurring conflicts between herders and farmers that significantly impact its productivity and sustainability. These conflicts have disrupted agricultural activities, leading to failure of exchange entitlements for both herders and farmers, and food insecurity. The disruption in farming activities not only limits food access but also diminishes the ability of farmers to participate in the market, thus reducing their income and food security (Chikaire et al., 2016). Most literature on the herder farmer conflict focus on the impact of this situation on the development and loss of human and material resources, little or none is focused on the impact of the situation on food security. This literature review delves into the complexity of these challenges, with a particular focus on the inadequacy of monocropping systems in this region. Through an exploration of the distinct ecozones, the adversities posed by arid conditions, the decline in soil fertility, and the invaluable role of traditional farming systems, this review underscores the imperative need for diversified farming practices. Additionally, it highlights how a food system approach can provide insightful explanations of the intricate relationships between agricultural practices and their outcomes, emphasizing the crucial role of maintaining diversity to mitigate food insecurity, poverty, and labour constraints.

Northern Nigeria is predominantly influenced by a Sahelian climate, marked by drought susceptibility and erratic rainfall patterns (Mailumo et al., 2022; Olasantan, 1992; Zhang et al., 2018). Ayanlade and Drake (2016) emphasize that these changing climatic conditions in the Sahel region of Northern Nigeria, have led to a significant increase in rainfall unpredictability. This variability disrupts traditional agricultural seasons and poses substantial risks to monocropping practices, underscoring the need for more adaptable and resilient agricultural systems to counteract these climatic changes.

The issue of declining soil fertility is exacerbated in Northern Nigeria due to persistent monocropping and inadequate soil management strategies. Gliessman and Tittonell, (2015) argue for the necessity of integrated soil fertility management practices that extend beyond monocropping to incorporate crop diversification and rotation. These practices are essential for rejuvenating soil health and boosting agricultural productivity, highlighting the detrimental effects of neglecting soil fertility on sustainable agriculture.

Historically, Northern Nigeria's traditional farming systems have leaned heavily towards diversity and risk management to navigate environmental and socioeconomic uncertainties. Stone and Flachs (2014), and Yeleliere et al. (2022) point out that these traditional agroecological practices, such as mixed cropping and cultivating a variety of crops, act as safeguards against crop failure, promote dietary diversity, and help maintain soil fertility. This approach not only needs to embody a wealth of indigenous knowledge, but it also presents viable strategies for sustainable agriculture in challenging conditions.

While the benefits of diversified farming systems are clear, labour constraints represent a significant challenge to their implementation. Kuyek (2000) discussed the potentials of labour-saving technologies and practices to enable smallholder farmers to transition towards more diversified and sustainable systems. The high rate of unemployment in Nigeria, paradoxically, provides an opportunity for labour-intensive practices like mixed cropping to thrive, offering pathways for the poor to convert labour into food through wages and labour exchange mechanisms.

Diversified farming systems in Northern Nigeria are not just a matter of agricultural practice but a holistic approach that encompasses ecological, climatic, socioeconomic, and labour considerations. The integration of traditional knowledge with modern agricultural innovations, guided by a comprehensive food system approach, offers a promising pathway towards sustainable agriculture in the region. Addressing labour constraints while pursuing sustainable agriculture and leveraging the high availability of labour due to high unemployment rate, can further ensure that the food systems of Northern Nigeria are resilient, productive, and sustainable.

Mixed cropping for small-scale Nigerian farmers is the planting of two or more crops together in the same piece of land at a given time. These crops are not planted haphazardly with the sole purpose of avoiding crop failure. These crops in addition to serving as risk protection and income sources (Adewumi & Animashaun, 2013; Kolawole & Ojo, 2007; Sabo et al., 2017), sometimes, have traditional and religious meaning to the farmer (Bharucha & Pretty, 2010; Kennedy et al., 2022), build social relations (Pimbert, 2008), and have nutrition and medicinal purposes (Johns & Eyzaguirre, 2006). Farmers practicing mixed cropping in Nigeria, plant one or two main crops with other complementary crops at different depths, spaces, and times. These crops grow together and are treated differently based on their needs. Sometimes, the main crop(s) is(are) planted alongside other complementary crops that support or do not disturb the performance of the main crop. Farmers, through their experience and the knowledge embedded in the system, plant water loving crops in the swamp/waterlogged area, crops that do not tolerate much water in the drier part of the field, and different varieties of the same crops on different soil types in the same field (Baker, 1978; Maiangwa, 2008). The seeds of these crops are preserved for next season planting. Selection of a rich diversity of the crops for different purposes and situations and the knowledge of planting them have been passed down through generations of farmers. Yams are planted between February and April, at the onset of rain. When the yam sprouts, and its tendrils are growing well, other supplementary crops will be introduced based on their planting calendar and rain needs (Baker, 1978). Melon and beans are planted in a yam mixed crop farm to cover the soil from heat and excess water loss. The cover crops also help in controlling weeds, erosion, and nutrient draining from the soil heaps during rains. The roots of these leguminous plants fix nitrogen, hold the soils together, and the remains of the legume after harvest is used for mulching. Mixed crop farms may not have specific row patterns like mechanized farms, but the seed for planting are not mixed up before planting and are not planted by spraying or sowing the seeds together without spacings, timing and depth considerations for each seed planted. Most of the crops found in the mixed crop farms have different lifecycles, and so, different harvest periods (Maiangwa, 2008; Bundy et al., 2018). Mixed cropping not only contributes to ecological sustainability but also provides stability to the food systems by improving the exchange entitlements of farmers, making it a critical approach for achieving food security in a challenging environment like the Northeast Nigeria.

2.3 The Concept of Agroecology and Regenerative Practices for Sustainable Farming Futures

The examination of alternative agricultural methodologies, including agroecology, nature-positive farming, and regenerative agriculture, reveals distinct ideological and practical differences. These methodologies share the common goal of enhancing biodiversity and food security with this study but differ in their approaches and focuses. Agroecology, for instance, merges ecological principles with agricultural practices, emphasizing local knowledge and sustainable food systems. While nature-positive farming and regenerative agriculture share some of these goals, their specific strategies and outcomes can differ.

Regenerative agriculture is becoming a key focus for practitioners, researchers, and policymakers globally, often linked closely with agroecology (Van den Berg et al., 2022). Both regenerative agriculture and agroecology share common ground, such as the restoration of soil and ecosystems, reliance on natural processes and ecosystem services, and the integration of plant and animal species to harness photosynthetic potential (Giller et al., 2021; Luján Soto et al., 2020, 2021; Schreefel et al., 2020). However, a distinct difference lies in the role of political activism within agroecology, particularly in its emphasis on the social aspects within a socio-ecological system. So, agroecology is more aligned with grassroots movements as it focuses on rights and access to resources (Rosset & Altieri, 2017). This is unlike regenerative agriculture, which is also adopted by commercial entities often less engaged with issues of resource access or food sovereignty. This divergence underlines agroecology's perception of sustainability as fundamentally a political challenge, a perspective less apparent in regenerative agriculture. Field observations suggest the existence of various interpretations of regenerative agriculture, each with different ties to agroecology, necessitating an exploration of these diverse definitions and their alignment with agroecology (FAO, 2018d, 2019c, 2019b).

The ambition for sustainable agriculture-whether through regenerative agriculture, agroecology, conservation farming, or organic agriculture-is to foster a system that meets current needs without compromising future generations. Regenerative agriculture aims not just for sustainability, but for an ongoing enhancement of the environment and farm economic viability; a concept initiated by Robert Rodale in the 1980s, advocating for "regenerative organic agriculture" as a step "beyond sustainable" (Elevitch et al., 2018; Ikerd, 2021). Despite the evolution of the term, the Rodale Institute has continued to champion regenerative organic agriculture (ROA), including developing an international certification focusing on social values like worker well-being (ROA, 2023). The regenerative narrative has gained popularity, particularly as the UN's Sustainable Intensification discourse failed to resonate with environmentally conscious stakeholders (Struik & Kuyper, 2017). However, the varied and sometimes vague definitions of regenerative agriculture, combined with a lack of regulatory oversight have led to disparate interpretations by different entities, raising concerns about greenwashing, especially among organizations opposed to chemical inputs (Schreefel et al., 2020).

Regenerative agriculture's flexibility stems from its practice-based definitions like no-tillage, soil cover, crop rotation by General Mills Inc., and principle-based definitions like holistic design and decision-making by Terra Genesis International, sometimes merging processes and outcomes (Newton et al., 2020). This flexibility might lead to varying practices and their environmental impacts. The original emphasis on organic processes in ROA, focusing on sustainable cycles and biodiversity, was somewhat diluted when "organic" was removed from the regenerative agriculture definition, broadening the concept's appeal, but also opening it to misuse for marketing conventional practices reliant on agrochemicals (ROA, 2023).

Agroecology, as defined by Gliessman and Tittonell (2015) offers a transformative approach to the global food system, emphasizing participation, locality, fairness, and justice, aiming for a restoration and protection of the Earth's vital systems. Agroecology inherently includes regenerative processes for ecosystems and communities. The UN Food and Agriculture Organization (FAO), through symposia between 2013 and 2018, crafted a working definition of agroecology based on ten elements combining social and ecological principles (Barrios et al., 2020; FAO, 2018d; FA0 2018; FAO, 2019c, 2019b; Wezel et al., 2020). These principles, fundamental to the Tool for Agroecological Performance Evaluation (TAPE), underscore agroecology's political dimensions, highlighting the need for political engagement and policy action to achieve its goals.

To critically assess the role of agroecology within the broader agricultural context, comparing it to other sustainable agricultural practices is important. The exploration of agroecology's history and its comparison to other methodologies elucidate the diversity of sustainable agricultural approaches. These approaches connect to extension support for precision farming, intercropping, and agroforestry, especially in dryland contexts, showcasing the range of strategies to promote biodiversity and food security. The selection of agroecology and related practices for this research is a strategic choice to investigate sustainable agricultural methods that can contribute to food system sustainability against environmental and socio-economic pressures.

2.4. Linkages between Biodiversity, Agrobiodiversity and Food Security

Tourism, forestry, fisheries, and agriculture depend heavily on ecosystem functions and biodiversity. There is a major concern about having enough food for the growing population of humans in the world. However, this concern is complicated by eroding environmental change that is threatening the limitless production of food (Ingram, 2011). To achieve sustainable development, Kuokkanen et al., (2015) opine that attention should be paid on how the present food system impacts on resilience and food security of the vulnerable. The impact of the present agriculture system of large farms sustained by chemical and genetically modified inputs, crop and animal specialization and monoculture, on the biodiversity and diversity in food consumption, and importantly entitlements equity should be clearly investigated for the purpose of sustainable development (Khush, 2016; Sunderland, 2011). Monocultural practice may negatively affect the food security situation of poor households by increasing their vulnerability to pests and diseases; limiting the availability of diverse kinds of food, and crop failure due to climate change problem (Ecker et al., 2018; Ndaeyo et al., 2001). Monoculture, if adopted by these poor farmers, also comes with very high input cost that the farmer may not have or get from a less risky source. This is a call for alternative agriculture where diversity, reduced environmental degradation, and social justices more than productivity, are promoted.

Alternative agriculture designed to promote biodiversity is crucial for improving food system resilience and achieving food security. This practice aims to reduce the use of synthetic chemical fertilizers, pesticides, herbicides, and antibiotics, increase profits, reduce costs, and mitigate the adverse environmental impacts of agricultural production (Council, 1989). According to Thrupp (2000), agrobiodiversity- using multiple species of crops and animals instead of monoculture- is increasingly recognized as essential for enhancing agricultural production and food security.

Using diverse crops and livestock improves food security and livelihoods while promoting food system resilience (FAO et al., 2019). Monoculture in intensive agriculture, however, leads to a decline in biodiversity (Frison, Cherfas, & Hodgkin, 2011). Conflicts between agricultural practices and food security arise under current farming systems, which often harm biodiversity (Seufert, 2012). This issue can be resolved with sustainable agricultural practices and policies supporting biodiversity (Thrupp, 2000). Lin (2011) notes that agrobiodiversity, including crop and animal diversity, is vital for achieving food system resilience.

Maiangwa (2008) found that crop diversification positively impacts agricultural productivity and welfare variables such as household food security and income. Frison, Cherfas and Hodgkin (2011), and Makate et al. (2016) affirmes that more diverse ecosystems often have higher productivity than simpler systems, whether agricultural or non-agricultural.

Mohammed and Mahmood (2023) provided a robust way of measuring biodiversity, defining it as all biotic variation in ecosystems, including genetic variation. Biodiversity can be assessed by species richness, species distribution, disparity, rarity, and genetic variability. Agrobiodiversity, therefore, captures the number of species or varieties of crops and livestock within a given area.

The contributions of biodiversity to food and nutrition security are increasingly recognized by local and international communities. The FAO's 2019 report, "State of the World's Biodiversity for Food and Agriculture," highlights biodiversity's role in achieving sustainable development goals related to hunger, food security, and labour. Biodiversity supports production systems and livelihoods resilient to shocks and stresses (FAO 2022b). It plays critical supporting, provisioning, and regulating roles needed for sustainable development.

Biodiversity's ecological contributions include pollination by bees, trees providing shade and habitats, edible insects as protein sources, and pest control by other insects (Barwise, 2019; Popescu & Popescu, 2016; Thrupp, 2000). Additionally, biodiversity maintains life through complex roles such as climate regulation, water purification, and nutrient recycling (FAO, 2019b, 2019c). Despite its importance, biodiversity's contributions to food security have been neglected (FAO, 2019c).

Biodiversity provides food and income insurance against risks and shocks, which help prevent deeper poverty and food insecurity. It also serves cultural purposes for both poor and non-poor communities (Adeola, 1992). Non-timber forest resources offer rural households' food during lean periods, contributing to poverty alleviation. More evidence is needed on the link between biodiversity and poverty reduction, especially at the local level (Convention on Biological Diversity, 2010).

Traditional agriculture, unlike the crops for cash industrial monoculture is used for household income, as well as traditional ceremonies, subsistence, building and maintaining social relations, and other socio-ecological relations. So, what crops are planted, what animals are raised and used can build or destroy the social structure, tradition, and local nutrition (Jacques & Jacques, 2012). The parallel extinction of rich biodiversity and cultural diversity manifested in the declining regional food traditions and diverse cuisines is more than the alarming extinction risk of birds and mammals (Adeola, 1992; Jacques & Jacques, 2012). This, in part, is caused by the endgame played by the forces supporting homogeneity in the global farms which has led to the serious loss of livestock breeds and crop varieties alongside the traditional knowledge for raising them embedded in the system.

Harris and Mohammed (2003) identified a total of 67 wild foods from 53 species of plants consumed in Northeast Nigeria. This shows that there are wide varieties of wild food from forest biodiversity available for household consumption in Nigeria. Despite the huge contribution of forests to the food and nutrition, Nigeria was said to have the worst deforestation rate in the world in 2005, having lost 55.7% of its primary forest between 2000 and 2005. Nigeria lost 3,771.59ha and 2,5531ha of its primary forest and tree cover respectively between 2002 and 2010. Between 2011 and 2018, Nigeria lost 10,000.49ha and 75,815ha of its primary forest and tree cover. So, between 2002 and 2020 Nigeria lost about 141,000ha of its primary forest and lost an extra 25,000ha between 2020 and 2022 (Butler, 2005; Global Forest Watch (GFW), 2023; Mongabay, 2020; World Resources Institute, 2021). This rapid disappearance of Nigerian forests has implications for not only climate change as is the fear of the international organisations like UN and FAO, but for food insecurity which is on the increase in the northern part of the country. According to Ruben and Verhagen (2019), urbanization, economic growth, information and computer technology and climate change are external factors that influence the food system. These external interventions, especially climate change has a large influence on the biological cycles of the food system, particularly in the Northeast Nigeria with its arid climate that is already water stressed.

There is still little information on the Nigerian food system and food security relationship even though this area seems to be the way out of food insecurity and environmental degradation problems. Food security should not be considered in isolation from the food system and the humans that manage the production system. Researchers working on food security in Nigeria have, in most part, focused on identifying the food insecure (Kuku-shittu et al., 2013), effects of socio-economic factors on food security (Kemi et al., 2014; Omonona et al., 2007; Owoo, 2018), the gap in food production (Igbozurike, 1978; Zhang et al., 2018), the impact of policies on food security (Iwuchukwu & Igbokwe, 2012). There is an urgent need for closure in the knowledge gap and evidence of the contributions of biodiversity to food and nutrition security in the face of severe threats to the world's biodiversity (FAO, 2019a).

2.5 The Interplay between Traditional Diets, Indigenous Knowledge, and Food Security

The growing interest in the nexus between food security and traditional diets underscore a vital research void in the contemporary food systems discourse. Traditional diets, and its associated indigenous knowledge play an indispensable role in food security, particularly among indigenous communities in low- and middle-income countries. These diets, characterized by their nutritional richness and biodiversity, offer sustainable pathways for food production and consumption. Sidiq et al. (2022) underscore this connection, advocating for an expanded research focus on how indigenous food systems contribute to food security. This literature highlighted the knowledge gap by exploring the role of traditional diets and the cultivation of underutilized crops in bolstering food security.

International institutions, like the World Vegetable Centre, and the International Institute of Tropical Agriculture, have documented the nutritional benefits of incorporating underutilized or traditional crops into diets. These crops are often superior in vitamins, minerals, and antioxidants, essential for a balanced diet. For instance, the World Vegetable Centre advocates integrating a wide variety of vegetables to combat micronutrient deficiencies: highlighting the role of crop diversification in enhancing dietary nutrition, and promoting biodiversity conservation (Oloyede et al., 2023a; World Vegetable Centre, 2022).

The restoration of degraded lands, and the emphasis on land rehabilitation in East Africa and the Sahel, demonstrate the crucial role of agrobiodiversity in food security and poverty alleviation. Research by the World Agroforestry and CIFOR-ICRAF, along with studies published by the International Livestock Research Institute, explore the connections between biodiversity and food security, suggesting that crop diversity can improve nutritional outcomes and income generation for communities (Mailumo et al., 2022; World Agroforestry Centre, 2008). The conservation of neglected crops, as explored by Oloyede et al., (2023b), highlights the role of these crops in sustaining biodiversity, nutritional benefits, and economic opportunities for smallholder farmers.

El Bilali et al. (2022) discussed the significance of agrobiodiversity in the sustainable transformation of food systems in West Africa, illustrating how agrobiodiversity enriches dietary diversity and is essential for the sustainable transformation of food systems. By incorporating the use of traditional crops and practices into agricultural policies, these studies indicate pathways towards more resilient and nutritionally adequate food systems. The research demonstrates how crop diversity has positive implications for food security at the local level, underscoring the crucial role of diversification and indigenous crop utilization in sustainable food systems.

The studies reviewed have shown traditional food systems and local knowledge help improve food and nutrition supplies as planned. The research from Sidiq et al. (2022) and international institutions like World Vegetable Centre and International Institute of Tropical Agriculture shows how traditional food sources fight hidden hunger in households, which supports this thesis' second objective. Research into restoring degraded land and promoting agrobiodiversity shows how food systems relationships work for both ecological and socioeconomic improvements underling the importance of the second objective. Traditional farming methods and local crops need to become part of our farming policies. These studies reviewed have shown that sustainable food security rely heavily on protecting traditional farming methods and crop varieties which need government backing.

2.6. Food Security and Labour in the context of sustainable food system

Many workers contribute to feeding the billion people on earth with some of these workers depending solely on the income from farms for their livelihood. Workers are needed to make the food system work and to feed the ever-growing population. Yet, from production to consumption they have the problem of decent work (voluntary employment that yield fair income for the social protection of the family and better prospect for the workers) (ILO, 2016). Some are even forced out of farming business by big commercial farmers and lack of market for their produce. For many families and individuals, decent work is all they need to be food secure and out of poverty. Decent work can stimulate economic growth, increased food production, processing, and income for the farmers to escape poverty (Braun, 1991; Von Braun, 1995). The success of modern farming in commercializing food in most times masked the externalities it puts upon natural environment and human health (Pérez-Neira et al., 2023).

Consolidation which yielded big farms has not favoured poor farmers, who form majority of African farmers. New technology, including agrochemicals and larger farm machinery drove the push to consolidate farms, and this allows farmers to work larger areas of land by substituting capital for labour (John Hopkins, 2014). Consolidation became attractive because larger farms had the advantage of economies of scale. These farms benefited from large market shares, functional specialization, and minimum fixed costs for their output. Most government and institutions favoured larger farms, giving them greater access to credit and capital with the justification that large farms are more efficient at transforming inputs to output, at least up to a point by substituting machineries and chemical for labour (Baltensperger & Tensperger, 1987). Development policy makers are torn between agricultural policies that promote more food production and those that promote more employment. On one hand, there is need to use tractors to produce more of few types of food for more people using less labour (Baltensperger & Tensperger, 1987), which will lead to more unemployment in developing countries like Nigeria. On the other hand, enough or less food can be produced using more labour who will derive their livelihood from producing greater varieties of crops and animals, which lead to more jobs, healthy environment, and diverse food available for the households (Baltensperger & Tensperger, 1987; Frison, Cherfas, Hodgkin, et al., 2011; Seufert, 2012).

Food and nutrition insecurity is a major challenge to households both in the urban and rural areas which depend on labour market for their livelihood. Hence, creating employment should be a very attractive programme in countries like Nigeria, with high incidence of food insecurity and unemployment (Molinero Gerbeau & Avallone, 2016). Considering the large proportion of poor and vulnerable people employed in the agricultural sector, making the food system sustainable is bound to result to sustainable development, through decent jobs, food security, and green economy. Making the food system sustainable is crucial because it directly impacts the large proportion of poor and vulnerable people employed in agriculture. Sustainable practices can create decent jobs by promoting fair labour conditions and improving livelihoods. Enhancing food security ensures that these populations have reliable access to nutritious food, reducing poverty and hunger. Additionally, sustainable agriculture supports a green economy by minimizing environmental damage, conserving natural resources, and promoting biodiversity. Together, these factors contribute to overall sustainable development by fostering economic stability, social equity, and environmental health.

Labour intensive public work has been widely employed in countries like China, India, and Bangladesh to achieve food security through employment. Labour intensive food system can help Africa solve the three major problems facing the continent – unemployment, food insecurity, and lack of infrastructure which will go a long way in ensuring a sustainable development (Braun, 1991). Large labour market, familiar and functional labour sharing and pooling, poor infrastructure, which lend itself to the use of local and manual equipment, and greater participation of women in farms and off-farm activities, unlike their Asian counterparts, are factors that favour labour intensive work in Africa. The impact of labour-intensive public work can be determined by their impacts on household incomes and individual household consumption and expenditure (Von Braun, 1995; von Braun, 2003).

There is need to look at the improvement of agricultural productivity and economic benefits that can be achieved when more labour-intensive green farming practices are adopted in the high food insecure regions of the world (Braun, 1991; Von Braun, 1995). It should be noted that the economic and productivity gains are in the areas of increased incomes for the farmer and farm output productivity. Other valuable benefits of a more labour-intensive food system that may be external can be realized, like, less environmental pollution, reduced poisoning of microorganism and insect, reduced pest pressures, reduced consumption of fossil fuel-based inputs and other positive economic externalities.

2.7 Food Systems Analysis: A Critical Review of Current Challenges and Future Directions

Various interpretations exist for the concept of a food system. Matchaya and Guthiga (2023), and Ingram (2019) like most food system studies, conceptualised the food system as a network of actors or players and their activities along the entire food value chain from inputs to production, distribution, and consumption. This understanding is in line with the UN Food Systems Summit (UNFSS) perspective which considers food systems to include all food-related actors and their interconnected activities from the point of production to the point of consumption or use (Ramanathan et al., 2022; Von Braun et al., 2021). In contrast to conventional definitions, the food system conceptualized within this work adopts a systems-thinking paradigm. Here, the food system is viewed as a complex network comprising various interconnected components, including inputs such as seeds and agrochemicals, production processes, and consumption patterns. While each component contributes to the overall function, the entire system transcends the mere sum of its individual parts. This conceptualization emerges from a systems-thinking perspective, emphasizing the connections, interactions, and relationships among all elements- both living and non-living- within the system. Thus, the focus extends beyond the profits and values of individual actors, prioritizing, instead, the critical inter-dependencies and linkages that define the system as a cohesive whole.

The study of food systems has gained momentum in recent years, evolving through various analytical approaches to address the complex interplay of factors influencing food production, distribution, and consumption. This research synthesizes the contributions of key scholars in the field, notably Matchaya and Guthiga (2023), Ruben and Verhagen (2019), Tutundjian et al. (2021), and others, to highlight the advancement in food system study and its implications for sustainable development. Through an exploration of descriptive, explorative, and interactive analyses, this discourse sheds light on the nuances of system approach frameworks, and their significance in enhancing the coherence, efficiency, and sustainability of food systems globally.

The study of food systems has undergone significant transformation, revealing three primary methodologies: a descriptive focus on food systems' structural elements, an explorative method evaluating policy options for improved system efficacy, and an interactive technique designed to support transitions and innovation for better alignment among crucial stakeholders (Ruben & Verhagen, 2019). The adoption of systems approach frameworks offers a more nuanced comprehension of food systems by integrating various perspectives, enabling a deeper understanding of the intricate dynamics and interconnections within these systems that might be missed by traditional single-discipline studies. Such comprehensive analysis is pivotal in enhancing the pertinence and efficiency of policy suggestions, taking into account factors like ecological sustainability, economic feasibility, social fairness, and nutritional results (Ruben & Verhagen, 2019). This approach aids in formulating more resilient policies with wider acceptance by the various actors involved.

Nonetheless, the analysis of food systems can be intricate and demand extensive resources. The challenge of integrating diverse methodologies, data sources, and theoretical views necessitates significant effort and expertise. The endeavour to merge different disciplines carries the risk of diluting each discipline's depth and subtlety (Ruben & Verhagen, 2019). Furthermore, despite aspirations for cross-disciplinary collaboration, practical barriers due to variations in academic culture, language, and priorities can impede effective cooperation. Overcoming these barriers demands more than a unified framework; it requires a shift towards true transdisciplinary approach rooted in a system thinking. Transdisciplinary approach extends beyond traditional academic disciplines to bringing together knowledge from both academic and non-academic sources (topic experts, communities, farmers, extension agents, food scientist and policymakers). There is a risk that developing integrative frameworks might be overshadowed by specific disciplines or viewpoints, leading to biases in the analysis and understanding of food systems. Therefore, there is a critical need to ensure equitable representation and include diverse viewpoints in data gathering to prevent biased analyses. The systems thinking approach addresses the need identified by Ruben & Verhagen (2019) for an in-depth exploration of the interactions and feedback mechanisms within food systems.

Ruben and Verhagen (2019) have utilized food system analysis in distinct contexts, such as enhancing public nutrition policies and supporting innovation networks within the food industry, necessitating the identification of different conceptualizations and leverage points for sustainable food systems.

The research by Matchaya and Guthiga (2023), and Zurek et al. (2022) centre on the roles of actors and stakeholders and the interactions across different food chain levels, recognizing drivers as potential opportunities or threats. Their goal was to find suitable incentives for sustainable diets and food systems, which is contrary to the systems thinking approach's methodical identification of system drivers and key outcomes. These studies also tend to overlook the physical and cultural aspects of food systems, such as changes in weed dynamics, microbial support for production, and alterations in food culture and traditions due to changes in inputs and production practices. The primary focus remains on maximizing stakeholder benefits, ensuring the availability of healthy diets, and identifying incentives for producing nutritious foods. In contrast, the systems thinking approach emphasizes understanding direct and indirect relationships and feedback loops, making it easier to grasp how actions lead to outcomes and how different components of the system affect each other. The system causal loop diagram analysis used in achieving the second objective of the study is very important in identifying system drivers and outcomes variables, which are contrary to the naming of factors of food systems like food security and climate change as a driver outcome because they are threats or offers opportunity**.**

Matchaya and Guthiga (2023) conceptualize the systems approach as a method for diagnosing food systems through a systematic analysis and assessment of various components and their interdependencies. Data collection spans national and international sources, with a focus on regularly updated indicators at both national and local levels.

Ruben and Verhagen (2019) discuss a shift in focus from traditional elements of food security-production, distribution, consumption, and access-to a more interconnected and nested analysis of food systems dynamics, emphasizing the importance of considering the multifaceted nature of food security influenced by technical, economic, social, and cultural factors. This shift challenges the linear perspective of food security analysis, which traditionally emphasized production intensification, and calls for attention to more complex causal mechanisms that address competing goals, emergent system properties, and dynamic feedback mechanisms.

The emphasis of most food system studies is now on external drivers such as climate change, urbanization, ICT, and economic growth, and their impact on the food system, with less attention to internal elements and drivers (Ruben & Verhagen, 2019). Systems thinking serves as a crucial instrument for grasping the inner structures and patterns and identifying the system drivers. A thorough understanding of a food system's structure, focusing on nutritional outcomes and the flow of materials and information, is essential for addressing the implications of food systems on diets.,

The global food system is at a crucial juncture, faced with challenges brought by climate change, population growth, and socio-economic disparities. The literature on food systems analysis, as discussed by Tutundjian et al. (2020), Ruben et al. (2018), and in the editorial of Nature Food (2020), provides invaluable insights into these challenges, advocating for a comprehensive research approach and innovative solutions to rectify the systemic issues of the current food system. These works collectively emphasize the need for a systemic revaluation and the active pursuit of innovative solutions that address the underlying causes of food system challenges, highlighting the importance of systems thinking for sustainable, equitable, and resilient food systems.

This comprehensive discourse on food systems analysis, synthesized from contributions by Ruben & Verhagen (2019), Matchaya & Guthiga (2023), Zurek et al. (2022), Tutundjian et al. (2020), and the editorial perspectives from Nature Food (2020), underscores the complexity of addressing global food security and sustainability challenges. The evolution of food system analysis through descriptive, explorative, and interactive methodologies reveals an increasing recognition of the need for systems thinking to effectively navigate and intervene in the multifaceted food system landscape.

The shift towards systems thinking in food systems analysis represents a significant departure from conventional, discipline-specific approaches. This paradigm shift facilitates a holistic view of food systems, enabling the identification and examination of dynamic interactions, feedback mechanisms, and the interplay between various system components. By adopting a systems approach, researchers and policymakers can uncover the underlying factors contributing to food system challenges, ranging from ecological degradation and socio-economic disparities to the impacts of global climate change.

Systems thinking not only enriches the analytical depth of food system studies but also enhances the formulation and implementation of policy recommendations through a transdisciplinary approach. By considering a broad array of factors, including ecological sustainability, economic viability, social equity, and nutritional outcomes, policy recommendations can be made more relevant, effective, and widely supported. This approach fosters the design of integrated policies that can address the complex realities of food systems, thereby contributing to the creation of more sustainable, resilient, and equitable food landscapes.

The ongoing evolution of food systems analysis, through the lens of systems thinking, holds promise for addressing the pressing challenges of food security, sustainability, and equity.

By bridging the gap between theory and practice, fostering transdisciplinary collaboration, and embracing innovative methodologies, there is the potential to transform the global food system into one that is more resilient, sustainable, and equitable. The collective insights from literature emphasize the importance of systems thinking in rethinking food systems, highlighting the need for a concerted effort among researchers, policymakers, and practitioners to co-create knowledge and implement evidence-based strategies for systemic change.

2.8 Theoretical framework

The study of food system sustainability for food security is a system science study that looks at the relationships and interactions between the elements of food security and food system. It focuses on how the food system is affecting the environment in terms of biodiversity and resilience of the ecosystem, the economy especially that of the poor farmers, and social justices in terms of employment and food and nutrition security. To assess the sustainability of a food system there is a need to clearly distinguish between two agricultural systems. First, the conventional/commodity farming system-farming is designed to produce as much food and fibre as possible at the least cost following the neoclassical optimum efficiency for maximum profitability in agricultural production (Hinrichs & Lyson, 2007). So, according to Keynes theory, the increase in profitability increases income and employment, which in turn increases consumption. This idea of maximum profitability and minimum cost contributed greatly to farm merging and the emergence of giant multinational agribusiness companies controlling the food system. As the farms grew larger, and the agribusiness companies enlarge the food choices facing households decreased. The second is sustainable agricultural practices- an agricultural practice designed to produce positive values along economic, environmental, and social dimensions.

This study reviewed the Failure of Exchange Entitlements (FEE) Theory, Keynes theory of income and employment, Complexity Theory and System Thinking. The problems of market failure and imperfections when it comes to real problems with uncertainties, necessitates the combination of Failure of Entitlement Exchange and Complexity Theories to Keynes Theory to capture the realities of the macroeconomics of the natural environment.

2.8.1. Keynes Income and Employment Theory

Keynes theory emphasizes the interconnection between output, income, and expenditure, suggesting that an increase in income leads to higher consumption. It explains that spending by one person generates income for another, creating a continuous cycle of economic activity. So, as demand for output increases, the need to produce more output will in turn increase employment and income of the employed. Rezai, Taylor and Mechler (2013), described the Keynes Theory as a potent vehicle to establishing economic system thinking in solving the problems of ecological economics as they applied it to the problems of climate change. In the case of food system sustainability, a sustainable food system will encourage equity in the production resources and food system. The production of more diverse food will in turn lead to more employment in the farm for smallholder farmers. Consumer demand is primarily influenced by the price of a commodity, as higher prices generally lead to lower demand, while lower prices increase demand. Additionally, factors such as consumer income, the availability of substitute goods, and individual tastes and preferences play crucial roles in shaping demand, as higher incomes and favourable tastes boost demand, while available substitutes can reduce it. There is little the consumer can do to increase food diversity or reduce consumption of unhealthy foods in the face of limited production of diverse foods. If the consumption of diverse food is encouraged, most households in farming communities have their income increase via increase in demand for local food.

2.8.2. Failure of Exchange Entitlement (FEE)

This theory looks at how people command food legally in a society. Most households depend on purchase as their main source of food due to globalization of the food system. So, failure of Exchange Entitlement more than reduction in food availability will, most likely, lead to food insecurity. In an exchange economy, the ability of the households to exchange their entitlement which includes labour and other possessions to other commodities, especially food will determine their food security status (Sen, 1976). For households that are already poor and vulnerable, a sharp fluctuation in food availability can lead to starving. In a food system where the poor depend on their own production and cheap starchy foods in the market, food insecurity results from lack of availability as well as lack of access to food. In Niger, Rubin (2009), observed that the famine of 2005 was not caused by lack of food but by unfavourable terms of trade that destroyed the entitlement of the poor in securing food, which gives credence to Sen's Failure of Entitlement Exchange Theory.

The concept of Failure of Exchange Entitlement (FEE) as articulated by Sen (1976) is highly relevant to understanding the multifaceted nature of food insecurity issues in the Northeast of Nigeria. This region, grappling with a myriad of social, political, cultural, and economic challenges, presents a stark illustration of how food insecurity transcends mere food availability, deeply rooted in the ability of households to access food through their exchange entitlements.

In Northeast Nigeria, as in many parts of the developing world, the majority of households depend on purchasing food as their primary means of sustenance. This reliance has been exacerbated by the globalization of the food system, which has shifted local economies from subsistence to market reliance. According to Sen's theory, the ability of households to exchange their entitlements, which include labour, land, and other possessions for food, fundamentally determines their food security status. In a region where many households are already at the brink of poverty and vulnerability, fluctuations in food prices, availability, or terms of trade can precipitate acute crises of food insecurity.

The situation in Northeast Nigeria is compounded by ongoing conflict and displacement, which further erode the ability of households to maintain or acquire the assets necessary for their subsistence. The loss of land to larger agricultural enterprises, often driven by external investments and a push towards large-scale farming, undermines traditional farming practices and exacerbates vulnerability to food insecurity. This is particularly devastating in a context where most households depend on their own production both for direct consumption and as a means of engaging in the market.

Drawing parallels with Rubin's observations in Niger, the famine of 2015 underscores the critical distinction between food availability and access to food (Rubin, 2009). In Northeast Nigeria, the challenge is often not the absence of food per se, but the deterioration of the terms of trade and market conditions, which render food unaffordable for the poorest segments of the population. This aligns with Sen's assertion that food insecurity results from a failure in exchange entitlements rather than a simple shortfall in food production.

The absence of social safety nets, characteristic of both socialist and advanced capitalist economies, leaves the poor in Northeast Nigeria particularly exposed to the vicissitudes of the market. The push towards wage-earning employment, driven by global consolidation and agricultural modernization, often translates into a precarious existence for smallholder farmers, who find themselves at the mercy of global market forces far beyond their control.

In addressing these challenges, it is recommended to empower the poor to become more self-reliant and to diversify their food production. Encouraging farmers in Northeast Nigeria to cultivate a variety of crops can mitigate the risk of crop failure while providing a more nutritious and secure food base. This approach not only addresses the immediate needs for food and nutrition security but also strengthens resilience against future economic or environmental shocks.

2.8.3. The General Theory of Complexity

Complexity theory has implication for how we understand the structure and management of a complex organization (Cilliers, 2000b). It is important to note that complexity do not allow for vague or chaos situation. However, the Complexity Theory made it clear that -the nature of a complex system is determined by the interaction among its elements. Complex systems are open systems that make a stable state undesirable, and the boundaries of the system are not clearly defined. The history and context of the system define its nature, there may be desirable or undesirable emergent, nonlinearity of the interaction which may lead to outcomes that are not proportionate to the causes, and the system organise itself to respond to events critical to its survival (Cilliers, 2000a; Emmeche, 2004). Complexity theory sheds light on the nature and limits of our knowledge and understanding of the food system. The food system, in this study are clear examples of a complex system and clearly reflects the characteristics of a complex system. So, there is the need to apply the lens of complexity theory in this study, looking at the interdependence and relationships within and between the systems.

2.8.4. System Thinking Theory

Systems thinking theory focuses on the interactions and connections between elements or components within a system. It is a philosophy that encourages awareness of how a system's structure contributes to the conditions we experience, emphasizing the identification of less obvious relationships and interactions. This approach helps us realize that our actions, or inactions, have consequences that may not be immediately apparent. By understanding these complex interdependencies, systems thinking allows us to make more informed decisions and anticipate the broader impact of our actions (Goodman, 2018).

System thinking is a diagnostic tool. It is used in examining problems beyond observation and data to find out patterns. It is used in identifying the structure underlying the patterns. It is a very important tool in understanding and changing unfavourable structure to create a more sustainable solution to complex problems. It is a helpful tool in making informed choices and telling compelling stories especially with the use of the causal loop diagram for effective policy implementation. Food system is made up of various elements that are interacting in dynamic ways to give us the conditions we see today. System thinking is needed to clearly understand the rich interactions in the system and the underlying structures supporting the present condition. It also provides valid and practical choices to changing or amending the structure to produce the desired outcome.

Applying system thinking to the intertwined challenges of food production, environmental degradation, inequality, and food insecurity in Northeast Nigeria reveals the depth and complexity of these issues. System thinking, as described by (Goodman (2018), offers a comprehensive approach to understanding and addressing the multifaceted problems faced by this region. By focusing on the interactions and linkages between different elements of the food system, this approach can identify less obvious relationships and the consequences of actions or inaction that contribute to the current situation.

System thinking enables a deeper analysis beyond surface-level observations to uncover patterns and structures underlying food insecurity and environmental issues in Northeast Nigeria (Goodman, 2018). This region, plagued by conflict, climate change, and socio-economic disparities, presents a complex puzzle where conventional linear thinking falls short. System thinking illuminates how the elements of the system interconnect, influencing and exacerbating each other, thus offering insights into the systemic roots of food and environmental crises. By understanding the structure contributing to adverse conditions, system thinking facilitates the development of sustainable solutions. It moves beyond temporary fixes to address the core of the problem, ensuring that interventions are not only effective in the short term but also sustainable in the long run. This is crucial in a region where temporary aid has often failed to produce lasting improvements in food security and environmental sustainability.

System thinking is instrumental in making informed choices and shaping policies that can effectively address the complex challenges of food production and environmental degradation. The use of causal loop diagrams can help policymakers visualize the feedback loops and causal relationships within the food system, leading to more effective policy implementation that targets the underlying causes of food insecurity and environmental issues, rather than just the symptoms (Goodman, 2018). In the face of uncertainty and changing conditions, system thinking supports adaptive management strategies. By continuously monitoring the system and its responses to interventions, stakeholders can adjust their approaches based on what is learned. This dynamic process is particularly relevant in Northeast Nigeria, where conflict, hunger, and other factors create a constantly evolving situation that requires flexible and responsive management strategies. By illuminating the interconnectedness of system components and the underlying structures that perpetuate these issues, system thinking provides a foundation for developing sustainable solutions, informing policy, fostering collaboration, and guiding adaptive management. As Goodman (2018) expressed, system thinking is not just a theoretical framework but a practical tool for creating meaningful change in some of the world's most pressing issues. The strength of a system dynamic model lies in its ability to estimate overall dynamics in a system Martin and Schlüter (2015), and facilitates controlled experiments Sterman (2001). It is important to know beforehand the advantages of strategies to be implemented especially in the case of food security as it concerns the health of the society and the environment. A SD model also permits an integration of both qualitative and quantitative analyses (Wolstenholme, 1999), which makes is suitable for the study of the food system (Ghaffarzadegan et al., 2011).

2.9. Conceptual Framework of Northeast Nigeria Food System Study

Figure 2.1, derived by the researcher, presents a sustainable food system framework diagram based on Keynes, FEE, complexity, and system thinking theories. The research framework presented here shows a detailed understanding of the multifaceted relationship between food security and sustainable food systems, particularly within the context of Northeast Nigeria. It employs a holistic approach grounded in a synthesis of insights from various disciplinary perspectives and models, drawing significantly from the foundational works of Ericksen (2008), Ingram (2011, 2019), Ingram and Zurek (2018); Zurek et al. (2022). Ericksen (2008), Ingram and Zurek (2019), and Ingram (2019), alongside the incorporation of Keynesian economic theory, the Failure of Exchange Entitlements (FEE) Framework, Complexity Theory, and Systems Thinking. This comprehensive framework endeavours to tackle the pervasive issue of food insecurity through the lens of agroecology principles of resilience, and support for small scale farming, agrobiodiversity, and socio-economic dynamics. This integrated perspective is crucial for addressing the multifaceted nature of food insecurity, especially in arid regions heavily dependent on agriculture for livelihoods. Food system resilience is important in the sustainability of diverse species which is a desirable state that can create many social and economic gains like the provision of valuable traditional medicinal herbs, timber, and non-timber forest harvest or even tourism and other ecosystem services.

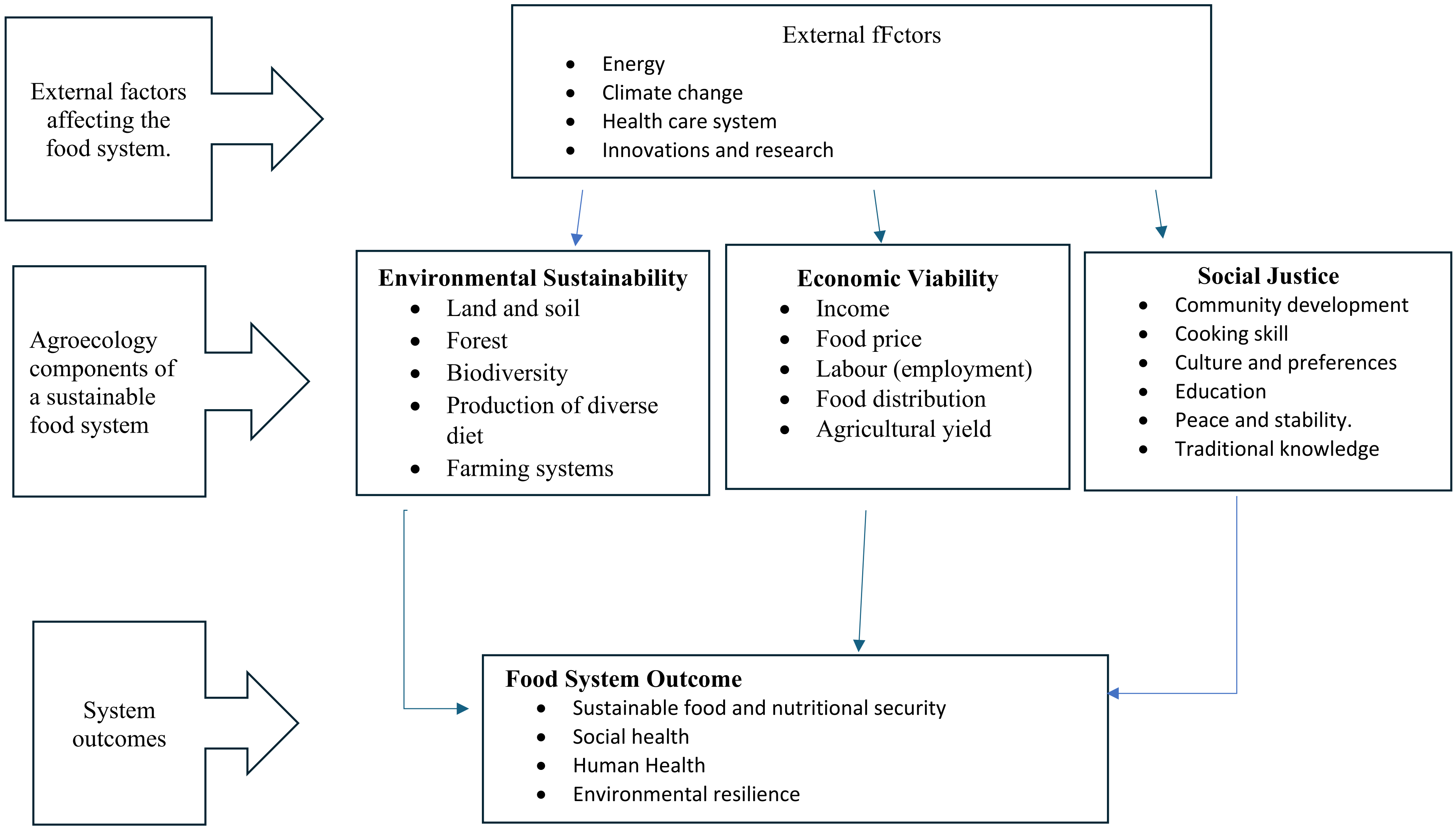


Figure 2.1. Conceptual framework showing the relationship between sustainable food system components- labour, food security and biodiversity (Agrobiodiversity) **Source: Author construct**

2.9.1 Discussion of Conceptual Framework: A Systems Thinking Approach to Sustainable Food Systems

The conceptual framework outlined in Figure 2.1 for this food system study adopts a Systems Thinking Approach, emphasizing the interconnectedness and dynamic interactions among environmental sustainability, economic viability, social justice, and external factors. Collectively, these components lead to the system outcomes of sustainable food and nutritional security, social health, and enhanced human health.

Environmental Sustainability

The environmental sustainability component of the framework emphasizes critical elements such as land and soil quality, forest preservation, biodiversity conservation, production of diverse diets, and robust farming systems. Soil health directly influences agricultural productivity and biodiversity, facilitating resilient farming systems. Forest ecosystems contribute significantly to biodiversity, supporting agroecological resilience by providing essential ecosystem services and diverse food sources. Biodiversity plays a pivotal role in ensuring food system resilience and adaptation, particularly in the face of climate variability and extreme events.

Economic Viability

Economic viability within the framework is tied to factors including income levels, food pricing, employment and labour stability, food distribution networks, and agricultural yields. Income opportunities for small-scale farming households and agricultural communities directly influence economic resilience. Efficient food distribution systems and stable employment contribute significantly to food price stabilization, enhancing overall economic sustainability. Agricultural yields, influenced by environmental sustainability practices, directly impact economic outcomes, underscoring the interconnectedness between economic viability and environmental health.

Social Justice

Social justice considerations in this framework are represented by community development initiatives, cooking skills enhancement, preservation of cultural and food preferences, education, peace and stability, and traditional knowledge. Community development fosters robust social networks and sustainable practices, significantly impacting food security. Enhanced cooking skills and traditional knowledge help preserve dietary diversity, nutritional security, and cultural heritage. Education plays a crucial role in addressing employment and labour market stability, ultimately enhancing community resilience and equity within the food system.

External Factors

The framework acknowledges the influence of important external factors such as energy availability, climate change, health care systems, and innovation and research. Climate change represents a major external driver affecting all components within the food system through its impacts on environmental conditions, agricultural productivity, and food availability. Innovations and research are integral to developing adaptive strategies and enhancing resilience across the system, while stable healthcare system is foundational to societal well-being and food security.

Agroecology Components and System Outcomes

Agroecology principles embedded within the framework underscore the integration of ecological science with agricultural practices to create resilient food systems. This approach supports diverse diets, social justice for the smallholder farmers, enhances soil fertility, and fosters sustainable agricultural practices. These agroecological components feed into the broader outcome of achieving sustainable food and nutritional security alongside improved societal wellbeing.

Employing a systems thinking approach, this framework highlights the complex, dynamic interactions and feedback loops among environmental sustainability, economic viability, social justice, and external factors. By addressing these intricate relationships, the framework provides a robust basis for developing interventions aimed at fostering resilience, sustainability, and equitable outcomes within food systems. Such an integrative and adaptive perspective is essential for effectively managing food system challenges in an increasingly unpredictable global environment.

Drawing from the contributions of Ericksen (2008), Ingram (2011, 2019), and Ingram and Zurek (2018), and supported by the insights from Currie et al. (2018), this research framework positions the enhancement of agrobiodiversity and ecosystem resilience at the forefront of sustainable food security strategies. It champions the adoption of mixed cropping and farming practices among smallholder farmers as a means to improve food availability and diet diversity, augment incomes, employment and foster biodiversity. By integrating the principles of Keynesian economics, the FEE framework, complexity theory, and systems thinking, this approach offers a robust foundation for exploring the intricate issue of food insecurity in Northeast Nigeria. Because there is high unemployment and food insecurity in Nigeria, encouraging poor farmers to produce diverse food crops on their lands will go a long way to providing them with the necessary food, and income from working in other people's farms and the sale of excess produce from their own farms.

The complexity of the food system and its influence on food security necessitates the application of System thinking and applying System causal loop diagram as a strategic analytical tool. This model facilitates a holistic examination of food systems as an open system, enabling the identification of dynamic interactions, system drivers and outcomes, and potential leverage points for policy intervention. Despite its challenges, including the delineation of system boundaries and overcoming participant resistance to changing mental models (Currie et al., 2018), CLD stands out as essential for crafting nuanced policy recommendations that resonate with the intricate socio-economic fabric of Northeast Nigeria. This methodological approach addresses the limitations of static models by capturing the dynamic feedback and nature of food systems, thereby providing a more accurate and comprehensive analysis of policy impacts over time. Furthermore, the integration of Complexity Theory and System Thinking enhances the ability of the framework to navigate the multifaceted relationships between food system components. This includes recognizing the external factors such as health status, educational attainment, climate change, and macroeconomic policies- in shaping food system outcomes. By considering these broader influences, the framework offers a holistic view of the challenges and opportunities within food systems.

The application of systems thinking, informed by the critiques of Currie et al. (2018), alongside a participatory learning approach, aims to bridge the gap between stakeholder perceptions and the complex realities of food systems. This methodology encourages stakeholder engagement in the modelling process, facilitating a collective understanding of food system intricacies and co-creating sustainable solutions. Acknowledging the limitations and potentials of a systems thinking model, as discussed by Currie et al. (2018), the research adopts a participatory learning approach while engaging stakeholders in the modelling process. This approach aims to overcome resistance to changing views.

The framework shows how improvement in the food system can promote sustainable development - food security, employment, and biodiversity. There are factors outside the scope of this study that influence the key factors of the study: food security, labour, and biodiversity. Outside agriculture, food security is affected by health of an individual, cooking skills and socioeconomic characteristics like education. Biodiversity is affected by climate, soil, population, and energy, while labour is affected by macro-economic factors like employment policies. This research framework underscores the critical need for a multidimensional approach to food insecurity, highlighting the interconnections between dietary diversity, agrobiodiversity, labour dynamics, and broader socio-economic factors. By elucidating the complex interplay of these elements within the context of Northeast Nigeria, the study aims to contribute valuable insights and policy recommendations for enhancing the resilience and sustainability of food systems in similar settings globally.

Considering this, the research focuses on key areas: the degree of food insecurity and dietary diversity (DDS measure), the interlinkages among food system biodiversity, labour, and food insecurity, and the potential of policy interventions to promote agricultural diversity, employment, and food security. By addressing these areas, the framework not only contributes to the scholarly discourse on food security, but also provides actionable insights for enhancing the resilience and sustainability of food systems in Northeast Nigeria and beyond. It seeks to identify policy interventions that can simultaneously promote agricultural biodiversity, generate employment, and enhance food security, thus contributing to the academic discourse on sustainable food security.

2.10. Review of System Dynamic Modelling Approach Applications

The earlier application of system dynamics was in business management (Shepherd, 2014), but it has been applied to health care (Atkinson et al., 2015; Bagnall et al., 2019; Carey et al., 2015; Cavana & Clifford, 2006; Currie et al., 2018) transportation (Wang & Zhang, 2017) auto mobile industry (Gorbea et al., 2011); government policy (Cavana & Clifford, 2006; Charalabidis et al., 2012; Currie et al., 2018), energy (de Mello, 1991; Musango et al., 2014, 2019), city and city welfare studies (Cavana & Clifford, 2006; Ghaffarzadegan et al., 2011; He et al., 2006), and Agriculture (Turner et al., 2015).

The importance of employing system dynamic modelling in food system studies for effective welfare and food security policy have been emphasized by several researchers (Guma et al., 2017; Hammond & Dubé, 2012)). Though food system and food security are fundamentally complex systems, most researchers have employed static models and studied each as a standalone subject. System thinking and complexity tools are needed to treat food security and food system as open systems to improve our understanding of the problems to be able to proffer appropriate solutions (Dunne & Edkins, 2008; Paterson Guma et al., 2016). One reason food insecurity has persisted may be as a result of limited research evidence, and more so, the limitation in methodology of the research evidence guiding the policy. Prevalent mathematical and econometrics modelling of the agri-food sector, largely, the macroeconomic general equilibrium model has been helpful in improving understanding and providing answers to food insecurity problems (Dunne & Edkins, 2008). However, these equilibrium models are not built to accommodate some of the uncertainties and dynamics of societal behaviour and economic development that characterize real-life situations (Dunne & Edkins, 2008). They are designed to make predictions based on unreal assumptions of non-equilibrium dynamics, rendering it unsuitable for capturing real-life rich interactions between components of systems, market failure dynamics, or any irrational expectations (Hammond & Dubé, 2012).

System Dynamic Modelling (SDM) has been applied in different aspects of studying food system and food security. Oliva and Revetria (2008) used the SDM to model the cold chain management of the supply of food with the aim of identifying how best the processing, package and distribution can be done to improve the safety of food. SDM has been instrumental in improving the understanding of food chain complexity and in addressing the challenges of sustainability policies in the food system (Pasqualino R et al., 2019.) . Tsolakis and Srai (2017) used annual cereal production and consumption ratio as a proxy for food security, concluding that small farmers will not only help achieve food security but also improve environmental sustainability.

Although SDM is an important tool in understanding complex system, it is important to note that there are limitations to the use of this tool. Currie et al. (2018) in their review of SDM application in different fields of study identified that there is unwillingness on the part of the participants to challenge their mental models and that the level of complexity which comes with system boundaries are not easy to set. But the problem of participants holding to their deep-rooted views, which is not an inherent problem of SDM, can be surmounted through a participatory learning process. These analytical tools will aid this work in making nuanced policy recommendations appropriate for the complex society.

The next chapter which is the methodology chapter presents the various data collection tools, methods and processes, and the data analytical tools used to derive the objectives of the study.

Chapter 3: Research Methodology

This section describes the study area, the sampling procedure, data collection and analysis. It also presents the justification for the methodology used for this research. This research used both qualitative and quantitative research methods as part of the transdisciplinary research methodology used to study the sustainability of the food system in Noth-East Nigeria.

3.1. Description of the Study Area

Nigeria lies between latitude 4°N and 14°N and longitude 3°E and 15°E. The study was carried out in Northeast Nigeria, which comprises of six (6) states, Borno, Yobe, Taraba, Gombe, Bauchi and Adamawa (Figure 3.1). The selected case-study states, Gombe and Taraba are marked in purple. Worldometer (2019) projected the population of Nigeria to be about 202, 211,000 on the 27th of September 2019, out of which about 13% (25,554,800) live in Northeast Nigeria. The Northeast geopolitical zone of Nigeria covers 280,419Km^2, which is about 33% of Nigeria's total land area (923,769Km^2)(National Population Commission, 2006; Sources & Traits, 2010).

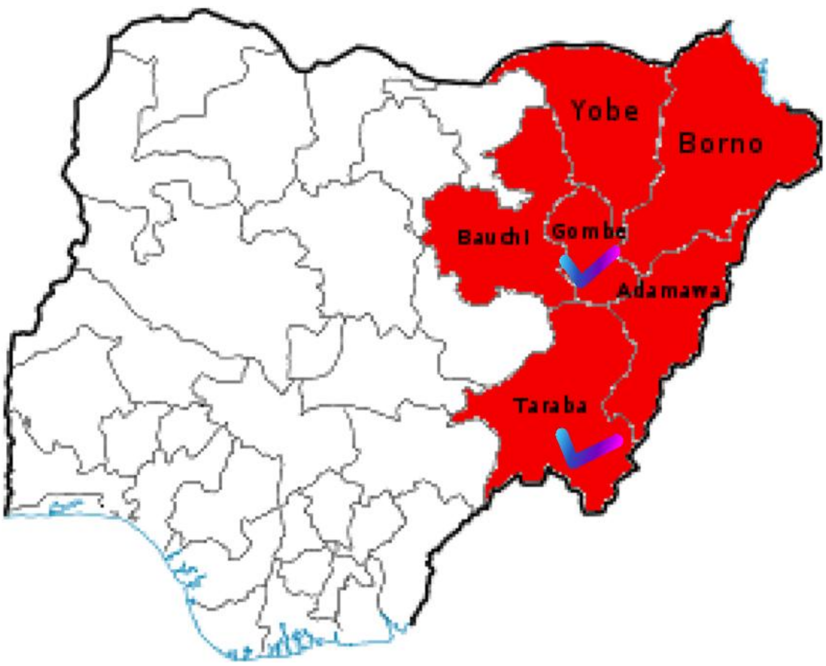


Figure 3. 2 A map of Nigeria highlighting states in the Northeast Zone in red

Annual rainfall in the Northeast is about 25 inches, and average temperature is about 34°C (Dunbar & Udo, 1972). This geopolitical zone shares international boundaries with the Niger Republic to the North, Republic of Cameron to the East and Republic of Chad to the Northeast. The average absolute poverty rate in the Northeast is 69 % as against the 60.9%

national average making this region the poorest region in Nigeria. The situation is not improving. In 2021, The Punch newspaper, noted that over 70% of the people in the northeast are poor. In Adamawa, 74% of the people were poor, and 70% of the people in Yobe were said to be poor, and the poverty rate in this area was said to be as high as twice the other regions of Nigeria which was 38%. Coupled with the conflict in this region, food security has remained a major concern (Nyako, 2015). Livestock including poultry, pigs, fish, cattle, sheep, and goats are reared by households in Northeast Nigeria. Many households keep different small livestock like local fowls in their homes for subsistence and traditional ceremonies. The main crops produced in Northeast Nigeria include cereals such as rice, maize, millet, guinea corn; vegetables such as fluted pumpkin, pumpkin, *amaranthus*, and pepper; roots and tubers like potatoes, cassava, yam, legumes including melon, cowpea, pigeon pea, yam bean, kidney beans etc. Though crops harvested in Nigeria are largely seasonal due to dependence on rain for farming, most foods are available at all times due to storage. According to the USDA crop calendar for Nigeria, there is the main harvest season and mid harvest times. So, harvest for different foods happens at different time due to the mixed cropping season practice by farmers in Nigeria. These different harvest seasons also make food available all through the year for the farming households.

Sources of food in the Northeast Nigeria food system is dominated by forest food harvest, food purchased from local markets, and food produced by small-scale farmers practicing mixed farming and mixed cropping. Although there is little monocropping going on in this area, mixed crop farms provide most of the foods eaten in Nigeria (Sabo et al., 2017).

Most of the households in northern Nigeria are in polygamous relationships and, consequently, have larger household sizes and more people to feed compared to other regions of the country (Owoo et al., 2017). The Northeast records the highest poverty, illiteracy, food insecurity and civil unrest rate in Nigeria. Consequently, it has been the focus for international humanitarian assistance for some time. Households in Northeast Nigeria generally consist of farmers, who, predominately practice mixed farming and a mixed cropping pattern like most Nigerian farmers (Ndaeyo et al., 2001). Most Nigerian farmers depend solely on rain-fed agriculture for their livelihoods. So, most foods, especially fruits and vegetables, are seasonal (Ecker et al., 2018). Farm holdings are generally less in size than five hectares of land in Nigeria and, have mostly a combination of inherited and purchased land (Liverpool-Tasie et al., 2011).

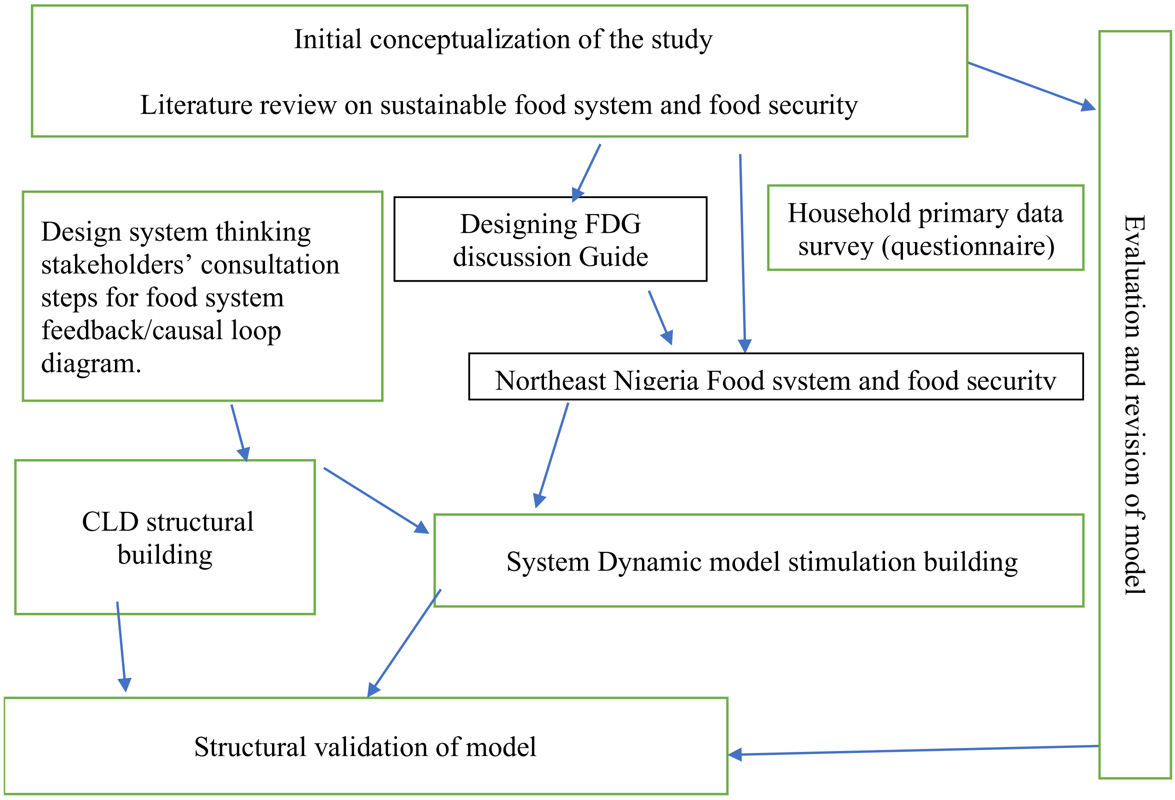


Figure 3. 3 Methodology for developing a sustainable food system dynamics model for food security in Northeast Nigeria

The research methodology diagram shown in Figure 3.2 represents a structured approach used in this study to analyse the food system in Northeast Nigeria, from initial literature review to the evaluation and revision of the system dynamics model. The process flows from quantitative and qualitative data collection to more detailed modelling and testing, followed by validation and iterative improvement. Below is a step-by-step discussion, integrating the literature review as a possible initial step:

Prior to the data collection, a literature review was conducted to establish a foundation of the existing knowledge about the food system and food security in Northeast Nigeria. This step informed the subsequent design of the data collection, system thinking process for the food system feedback loop diagram development, analysis and the discussion of the research findings. System thinking is used to map out the feedback loops and causal relationships within the food system. This step involved engaging with stakeholders to understand the food system's dynamics. The steps help to facilitate the identification and understanding of the system elements, drivers and outcomes, feedback loops and causal relationships within the system. The information derived from stakeholder consultation is used to construct a CLD, which visually represents the feedback loops and causal relationships identified. This structural framework serves as a blueprint for the study of the systems interactions.

A discussion guide for Focus Group Discussions (FDG) was employed to steer the conversations with the researcher to extract detailed insights into Nigerian Agricultural policies and the food system. The focus of this discussion was on Nigerian food security policy thrusts and the sustainable food system goals which covers the first objective of the study. Questionnaires were used to collect household level primary data on food production and sources, consumption patterns and the food security situation from the households in the study area. Data from the focus group discussion and household survey used in realising the second objective of the study, were employed in supporting the development of the system feedback loop diagram.

The final step in the flowchart shown in Figure 3.2 is the evaluation of the model and making necessary revisions. This involved adjusting the model based on the outcomes of the validation and tests to better reflect the reality, and to ensure that the model is useful for decision-making. This iterative process with the model development participants helps to refine the model for better accuracy and reliability. The process is iterative, particularly the final steps involving model validation and revision, suggesting the use of a feedback loop to refine the model continually. The methodology used is iterative and dynamic, incorporating continuous feedback and adjustment to refine the model. This iterative loop ensures the model remains relevant and accurate as new data and insights are gained in the process.

3.2. Sampling methods used

A multistage random sampling technique was employed in picking the households for the study. First, two out of the six states were selected. Second, two agricultural zones were randomly selected from the selected states, making a total of four agricultural zones. Third, two Local Governments Area were randomly selected from each of the zones, making a total of eight Local Government Areas (LGAs). Fourth, two communities were selected from each of the LGAs, making a total of 16 communities. Finally, 25 households were randomly selected from each of the selected 16 communities to give a total of 400 households for the study. However, eventually, the study obtained data from 375 households, as data collection was seriously interrupted by the COVID 19 lock down. The study used regular households base on the National Population Commission, (2006), which exclude the homeless and people living in the Internally displaced person (IDP) camps. Hence, institutional households like orphanages and the homeless did not form part of this study. Six focus group discussions were also held in the four selected agricultural zones. The stakeholder's consultation was also used in developing the mental model for the causal loop diagram of the food system.

3.3. Data collection

The study used both qualitative and quantitative primary data. The qualitative data were gathered through focus group discussions in the study area. These focus group discussions looked at the effectiveness of the current agricultural policy thrusts on food security, in terms of achieving the needed sustainable food system goals. The results on the effectiveness of the policy trusts are employed in the dynamic modelling of the food system that followed to identify potential sustainable food system interventions. This discussion is important in forming a relevant mental model of the food system. This study also carried out a field survey on households' socioeconomic characteristics, farming activities, forest food harvest and food security in Northeast Nigeria. The data analysis used both inferential and descriptive statistics.

Hence, data for this study was collected through three sources- households survey data collection using a structured questionnaire which served as an interview schedule, focus group discussions and stakeholder consultation. Prior to data collection, the planned methods and nature of data to be collected, analysed, and stored went through the University of Reading's ethical clearance procedures successfully.

3.3 Impact of COVID-19 on Households in Nigeria and the Survey Result procedures

The COVID-19 pandemic had profound effects on household in Nigeria, reshaping their livelihoods, agricultural practices, and overall well-being. The disruption in supply chains, limited access to markets, and the challenges of adhering to health guidelines have significantly affected their productivity and income levels. Furthermore, the pandemic has exacerbated pre-existing vulnerabilities such as limited access to agricultural inputs and information, financial services, and technology. These adversities have likely influenced their perceptions and responses in these surveys, potentially highlighting an increased awareness of risks, a greater appreciation for food system and resilience-building measures such as diversification and innovation and, possibly, a shift towards more sustainable practices. Understanding these shifts is very important for interpreting results, especially the emotions and enthusiasm in the selected quotes, as the experiences during the pandemic could have altered farmers' priorities, concerns, and their outlook towards agriculture and external support systems.

To minimize the risk of COVID-19 infection and spread during the survey and data collection, several safety measures were implemented: (a) discussions were held outdoors, (b) hand sanitizers, face masks, and handwashing facilities were readily available, (c) social distancing was maintained during interviews, and (d) participants' temperatures were checked before they took part, with instructions to report any COVID-19 symptoms to the organizer.

Table 3. 1.Timeline and Methodology of Sustainable Food System Research in Northeast Nigeria (2020-2021)

Data collection method	**Data collected**	**Units**	Date
Household survey	Demographic characteristics, Food sources, farming practices, forest food, DDS, food consumption patterns	Households	March – April 2020
Focus group discussion	Effectiveness of Nigerian agricultural policies in achieving sustainable food security	Agroecological zones	October – November 2020
Stakeholders' consultation	Food system modelling data	Farmers, extension agents, agricultural policy makers and researchers working in the Northeast Nigeria	December 2020 – February 2022

3.3.1 Household survey data collection

Due to inadequate and unreliable food security secondary data in Nigeria, this study collected household level primary data from sampled households. DDS module was used to capture the number of food groups the household consumed in the last 24 hours before survey.

Semi-structured questionnaires were used in collecting detailed quantitative data from the households by the researcher and other trained field workers (See Questionnaires listed in appendices). Household level data collection lasted for three months, between February and March 2020. Data were collected on the demographic characteristics of the households, crop and animal production, food distribution, food consumption, food sources, subsistence share of food, farm labour, dietary diversity, crop and animal production diversity, income, land ownership and tenure. This data was used to study the food security situation of the households and build the system dynamic model of the food system.

The Dietary Diversity Score (DDS) module was used in assessing households' food security status. Standard statistical tools, and system feedback loops in Vensim were used in exploring the interactions between the food system and food security. Vensim is a specialized system dynamic software for system modelling.

3.3.2 Setting and participants for focus group discussions.

The research was carried out in Taraba and Gombe states located in the Northeast geopolitical zone of Nigeria. The zone is plagued with food insecurity and also *Boko haram* insurgency. In the Northeast, 83.6% and 68.6% of the households are involved in crop and livestock farming respectively. There are multiple languages in use in this region, with Taraba state alone having over 80 languages (Online Nigeria, 2003). After consulting with the Agricultural Development Project Offices in Gombe and Taraba State, two enumerators conversant with the language common in area of study were contacted for assistance. The areas selected for the study covered three agricultural zones in each of the states. The focus group participants were adult males and females. The inclusion criteria required that participants were over 18 years of age, responsible for their household's food provisioning and actively involved with their household and farm decision-making. As it has been reported that there are underage marriages, household heads below the age of 18 years were excluded. Persons below the age of 18 are not an adult and the discussion was designed for an adult who is capable to give their consent. To account for this, our criteria for participation was physical observation and self-confirmation of age. The age range of the participants was 22 to 56 years; the average age was 47 years. The groups comprised of adults with, and without, formal education. Most of them had a primary school education (28%) but very few had University education (6%).

Participants were recruited through the support of their village heads (*Mee angwa)*. The participants were randomly selected from the list of farmers provided by the village heads. The participants were informed about the study a week before the meeting, and a reminder was sent a day before the discussion. Each identified participant who expressed interest was met by the enumerators to inform them of the topic of the discussion. To ensure that the topic of discussion and procedure would be well accepted in the communities, the content of the discussion guide was presented to the community heads. Additionally, the researcher visited the six sites for the discussions to explain the study to the interested participants who were invited for a pre-discussion meeting. Through these pre-meetings, the researcher took note of concerns and contributions that the community thought is important for the study. Most of them indicated labour subsidy and free medical treatment as a way out of their problems.

Two young natives of Taraba State, fluent in both the multiple languages of Taraba and Gombe and English, led the discussion alongside the researcher[1]. These fieldworkers were trained for three days in qualitative research methods and research ethics. For each focus group discussion, there was a Facilitator and a Notetaker. The training covered the overview and objectives of the study, note taking, and how to facilitate discussion without leading the opinions of the discussant and not to be judgmental. The last day of the training was used for field testing. They were to get the discussants focused on the topic of the discussion, keep timing, and to carry along the members of the group in the discussion. They were to be observant and take notes of important points. The discussion guide was used for the training. In addition to the researcher, the enumerators present were

[1] The discussions were conducted largely in Hausa, Jukun, Tiv, Fulani, Tangale, and Mumuyi languages with occasional translation to and from English.

individuals that have experience working as research field workers in this area whom the participants trusted. Back translation was used to ensure accuracy and consistency in the meaning of the key terms in the discussion guide. Qualitative data on food systems and food and nutrition security was collected from stakeholders and through focus group discussion in the study area and prepared for analysis between October 2021 and April 2022. The focus groups consisted of household members in charge of food provisioning. The qualitative data was designed to provide deeper understanding of the interactions in the system, and mutually and socially appropriate mental models of key information for dynamic modelling.

Given the number of groups and the large amount of information that would be gathered from the six focus groups discussions using the interview guide (see discussion guide in appendices), a 5-point Likert scale was used to help manage the data. The 5-point scale (1– very ineffective, 2– ineffective, 3- moderately effective, 4- effective and 5- very effective) was used to get a nuance understanding of the difference in categories of effectiveness of the policy thrusts. The scale also was used to gain insight into how the participants feel and make sense of the policies and its level of impacts. The recorded discussion gave more meaning to the numbers on the scale. The scale gave clear distinction in the perceived effectiveness of the different policy thrusts. So, with the scale, it was clear whether a policy thrust is effective or not, and the extent of its' effectiveness. It also helped to reduce the impact of the researcher's view on the interpretation of the discussions.

3.4 Selection of Thematic Quote

The selection was done under the different policy thrust themes which made it easy to discuss the outcomes and the rankings from the focus groups. The discussion outcomes were presented based on the clusters of concepts identified within each of the policy thrusts using Nvivo. In the results presentation, attention is given to comments and concepts that participants showed intense emotion or enthusiasm in their responses, and concepts that were brought up by different people and different groups. The themes were checked against the dataset to ensure the purpose of the study is achieved, and the selected quote accurately represents the collected data. Understanding the essence of what the data captured about the theme, and how it relates to the research question, compelling quotes TO COVER THE POSITIVE AND THE NEGATIVE ASPECT OF THE THEME, from the data within each theme that best illustrate or represent the core of the theme were selected and presented. The selected quotes provide clear examples that convey the participants' perspectives or experiences relevant to the theme. The selected quotes were used in the final analysis and report to support the thematic findings from the discussions. This thematic selection process brings the participants' voices to the forefront, enriching the research findings with direct evidence from the data. The discussions behind the categories were used to get as many nuances as possible rather than just reducing the discussions to few quantifiable codes.

Likert Type Scale for the Coding of the Effectiveness of APA

The modal of the scale was reported alongside the mean scores from the scale. The mean score of the scale rating for any policy thrust was calculated as the sum of the number of respondents (groups) multiply by the number on the scale rating. For each of the policy thrusts, the level of effectiveness was calculated by multiplying the number value of each point on the scale by the number of group(s) and then divided the outcome by the total number of respondents (groups). For this study, six focus group discussion were conducted. So, the mean score for each policy thrust is calculated as presented in Table 3.1.

Table 3. 2 Policy thrust effectiveness scale rating and the example of how it was calculated

Scale	Scale value	Number of groups	Total (number of group x scale value)
Very ineffective	1	2	2
Ineffective	2	1	2
Moderately effective	3	1	3
Effective	4	0	0
Very effective	5	2	10

To get the mean score for this example, the totals (2+0+3+0+10 = 17) is divided by the number of groups = 17/6 = 2.8

To determine the mean cut-off for this analysis, the sum of the scale value was divided by the number of groups ((1+2+3+4+5)/6 +15/6 =2.5). A score below 2.5 is considered ineffective, a score above 2.5 is considered effective and a scale of 2.5 is moderately effective. However, since the score is calculated from five points on a scale, using the interval scale of 0.05, the upper limit cut-off is 2.5+0.05 = 2.55 and the lower limit is 2.5-0.05 = 2.45. So, any mean score above 2.55 is considered effective and any score below 2.45 is considered as ineffective, while those between 2.45 and 2.55 are considered moderately effective. Given that the scores were derived from a five-point scale, an interval scale of 0.05 was used to define a more precise range around the mean score. This method accounts for minor variations in the data, ensuring a clearer differentiation between categories. This approach ensures a rigorous and clear interpretation of the data, allowing for more accurate assessments and decisions based on the established cut-off points.

A total of 33 participants distributed from 5 -7 persons per focus group were involved in the study across the six study sites. There were three sites in each of the selected states - Jalingo, Gassol, and Gashaka in Taraba and Kaltungo, Billiri, and Gombe in Gombe state. The discussion guide was designed to elicit information and participants' views about the policies driving the food system. Each discussion session lasted between 90 – 120 minutes and was held in the evenings in rented halls or open spaces that belonged to the primary schools central to the participants place of residence.

Due to the low literacy level in the study area, informed consent was obtained verbally from each participant in the preferred language of the participant. The participants were informed that they could leave the discussion when they wanted. Participants were given a meal cost and travel cost to the study site equivalent. All names in this study are pen names The recorded discussions were transcribed verbatim traditionally (by humans) to text in the English language.

The researcher met with the enumerators before and after each discussion to go through the recorded discussion and learn the concerns raised and then sent the recordings to the enumerators for transcription. The research instruments procedure and discussion guide were approved by the University of Reading Research Ethics procedure.

3.5 Consultation with Stakeholders Using System Thinking in the Dynamic Modelling of the Food System of Northeast, Nigeria

The development of the food system model for Northeast Nigeria utilized a comprehensive stakeholder consultation approach, integrating inputs from a diverse group of participants, including two farmers (small and medium scale), an Agricultural Extension agent, an agronomist, a food scientist, and an agricultural economist from Nigerian universities. This collaborative effort was designed to accurately represent the complexities of the real system. Stakeholders ranged in age from 38 to 73 years of age, and engaged in the modelling process through online discussions via Zoom, phone calls, and emails from October 2020 to February 2022. This iterative process was crucial for refining the mental models of the system, ensuring they closely mirrored reality and facilitated stakeholder participation in modelling, which is vital for fostering confidence and building in the system, clarifying misunderstandings, and, through a system thinking approach, enhancing the participants' understanding of the system.

Ruben and Verhagen (2019) emphasize that food systems analysis benefits significantly from interdisciplinary support, leading to innovative outcomes and more relevant insights. Involving non-scientific stakeholders in the research process enhancing feedback and creating stronger linkages to policy and practice. Broad stakeholder consultation and knowledge exchange are essential for understanding the adaptive processes reliant on the interaction between technical and behavioural drivers of food system change.

System thinking approaches play a pivotal role in bridging the knowledge gap within the food system: connecting experts in research and policymaking with farmers to facilitate a comprehensive understanding of the system. This approach ensures the elicitation of relevant information from stakeholders, enabling proactive exploration and identification of the needs of all stakeholders in the food system, thus building connections, trust, confidence, and buy-in for research outcomes.

One challenge of the system thinking approach is the difficulty in defining the system's boundaries at the start of the model-building process. However, unlike the adoption of pre-developed models, which limits stakeholder participation to providing feedback on existing structures, the system thinking approach allows for a more detailed and insightful representation of the system. This leads to emergent properties within the system, which are considered strengths of this approach. It is crucial for exploring system information, history, memory, and relationships within the system. The application of system thinking was motivated by the observed disconnect between policy targets and achievements, highlighting a gap between the needs and knowledge of the people, and the perceptions of policymakers.

The stakeholder consultation described above was instrumental in gathering information from the involved parties, enabling the collection of diverse, real-life insights. Addressing the issue of food insecurity requires comprehensive information on the relationship between food insecurity and the food system. The application of system feedback/causal loops diagrams, based on qualitative data from stakeholders, aims to enhance understanding of the system's linkages, interactions, and relationships, as well as the balancing and reinforcing loops, thereby informing the behaviour of the entire system.

The study leveraged data from causal loop diagrams, focus group discussions, and literature reviews to identify adaptive policies for improving the food system's behaviour towards achieving desired outcomes such as food security, improved biodiversity, and income. This approach provided insights into the root causes and consequences of the current food system issues, enabling the identification and correction of faulty mental models that have perpetuated these problems and identifying necessary interventions to achieve food security.

The focus of the main researcher conducting this research has been on addressing food insecurity in Northeast Nigeria, leveraging her expertise in Agricultural Economics and Sustainable Agriculture. Having lived in the region, she brings firsthand knowledge of the local culture and food practices into her research on food security. Throughout her study, she practiced reflexivity, critically examining how her academic and social backgrounds might influence her research outcomes, ensuring the integrity and reliability of her findings.

The study highlights the significant role of politics and power dynamics in engaging with stakeholders across various sectors and levels. The researcher took deliberate steps to acknowledge and mitigate potential power imbalances by fostering transparent communication with all participants. This approach facilitated respectful and equal participation and dialogue, with each stakeholder having the opportunity to present and contribute, enhancing the study's cultural sensitivity and relevance. The discussion was carried out in a way to ensure that the engagement does not reinforce existing inequalities or marginalize certain voices.

To further ensure the study's integrity, the researcher adhered to the steps for developing the Causal Loop Diagram (CLD) meticulously, aiming to minimize any bias her background might introduce into the results. Managing these dynamics was crucial for co-creating knowledge and empowering participants. By addressing ethical considerations, power dynamics, and political issues with a keen awareness of her positionality, and adhering to approved research ethics, the researcher aimed to conduct a study that was ethically sound, culturally sensitive, and impactful.

3.6. Data Analysis

This study employed both descriptive and inferential analytical tools. The study used DDS, descriptive statistics, and system causal/feedback loops to study and understand the food system.

Table 3. 3 Alignment of Research Objectives with Analytical Tools

Research Objectives	Data	Data collection tool	Analytical Tools
I. Explore the perceived effectiveness of the APP policy interventions to sustainable food system goals.	Alignment of policy thrust to sustainable food system goals	Focus group discussions.	Descriptive statistics (Likert scale) and **Selection of thematic quote using Nvivo**
II. Ascertain the food and nutritional security situations of households.	Access to diverse diet, presence of hidden hunger, food sources for household, food consumption patterns	Household food system and food security questionnaire	DDS, descriptive statistics (percentage and frequency)
III. Estimate from causal/feedback loop diagram, the key outcomes and driver variables of the food system, and the intervention opportunities in the food system to realize sustainable food security.	The dynamic relationships within the food system. Identify the Main drivers and key outcome variables of the food system	Stakeholder consultation	System thinking tools - Mental Model - CLD

Table 3.3 presents the study of objectives, and the analytical tool used in achieving the objectives. In line with the objectives of the study, the data analysis was designed to provide insights into the food and nutritional security situations of households in Northeast Nigeria. Interlinkages between various components of the food system and food security, were explored to identify the drivers and outcome variables of the food system. Following a rigorous data cleaning process to ensure the integrity and accuracy of the collected data,

a detailed analytical approach was adopted to address the objectives of the study and key research questions.

To ensure all data entries were complete and logically consistent, missing values were identified and appropriately handled through imputation techniques or exclusion, depending on their extent and nature. Outliers were identified and assessed to determine whether they represented legitimate variability or errors, and appropriate actions, such as removal, were taken based on their impact on the analysis. Data was converted into the required format or structure, including encoding categorical variables, aggregating data points, and creating new variables to better capture the constructs of interest. Consistency checks and audits were conducted to ensure that the data cleaning steps were applied correctly and uniformly across the dataset.

With a clean and reliable dataset, a comprehensive analytical approach was implemented to address the study objectives and research questions. Descriptive statistics were used to summarize the basic features of the dataset, including measures of central tendency (mean, median, mode); measures of variability (standard deviation, variance, range), and frequency distributions; providing an overview of the data characteristics, and identifying initial patterns. Exploratory data analysis was carried out by visualizing the data through graphs and charts such as histograms, box plots, scatter plots, and heat-maps. This helped to uncover underlying structures, relationships, and trends within the data, guiding the subsequent phases of analysis.

Objective I: Assess Households' Perception of the Effectiveness of the APP on Sustainable Development Goals.

This objective explored the APP policy thrusts for their ability to promote the cultivation of diverse crops and livestock, promote biodiversity and forest food harvest, diverse diet, and conservation, while concurrently generating employment opportunities, income for farmers, and bolstering food security.

Objective 2: Ascertain the Food and Nutritional Security Situations of Households

To evaluate the food and nutritional security situations of households, we analysed consumption patterns across different food groups, focusing on macro and micronutrients such as iron, vitamin A, animal proteins, and carbohydrates. This analysis aimed to shed light on the presence of hidden hunger. We also investigated the main sources of food- whether through purchase, self-production, gifts, or aid- and evaluated the contributions of forest and farm foods to household consumption. The assessment extended to the consumption of traditional versus western foods and food intake outside the home. The Dietary Diversity Score (DDS) was employed as a key metric to ascertain household food and nutrition security, effectively highlighting instances of hidden hunger.

Following Kennedy et al. (2011), guidelines for measuring household and Individual Dietary Diversity Score (IDDS), this study employed the adapted DDS module in Ike (2015).The adapted module was developed and used in capturing food security in Taraba state located in Northeast Nigeria (see Appendix 1: Food system and food security Household questionnaire). The adaptation process took place in Taraba State, located in Northeast Nigeria, to ensure relevance to local conditions. Ike (2015) employed seven focus groups and visited two food markets to identify foods consumed in the region. The selected markets included one urban location, Jalingo Main Market, and one rural location, Dananicha Market. Food sellers in these markets were interviewed to document the names of the foods available. For this study, the adapted questionnaire from Ike (2015) was presented to enumerators during training sessions conducted across the Northeast states where the study was carried out, to ensure its validity. During these training sessions and subsequent pilot testing, it was confirmed that no further adaptations were required.

Descriptive statistics, including percentages and frequencies, facilitated a comprehensive analysis of household and farm characteristics, enabling a nuanced understanding of food and nutritional security dynamics of North East Nigeria.

Objective III: Identify the Drivers and Outcome Variables of the Food System

Using a Causal Loop Diagram, we identified key intervention opportunities within the food system that could lead to sustainable food security. This analytical tool helped in understanding the interrelationships and linkages between different elements of the food system, highlighting main drivers and key outcomes. The analysis focused on identifying sustainable practices and policy interventions that could enhance food security while maintaining ecosystem health and socioeconomic well-being. The study analysed causal feedback and the use/cause tree diagram of the dominant loops of the food system.

3.7. Key research questions

These following research questions were designed for an in-depth investigation into the complex interactions within the food system to facilitating a comprehensive understanding of the complex dynamics at play in Northeast Nigeria's food security situations, and to understand underlying patterns in the food system, causes, and implications. These research questions were largely derived from the literature discussed earlier.

1. What strategies and policy interventions can be identified and assessed for their ability to promote the cultivation of diverse crops and livestock, while concurrently generating employment opportunities, income for farmers, and bolstering food security, in the context of increased biodiversity?

2. Based on the DDS measure, to what extent do households in Northeast Nigeria experience food insecurity, as measured by the DDS, particularly in relation to varying levels of access to diverse food groups and the occurrence of hidden hunger?

3. How do the complex interactions among food elements in Northeast Nigeria shape the region's food insecurity patterns, and in what ways can a comprehensive understanding of these dynamic relationships inform and guide strategies to alleviate food insecurity and foster sustainable food systems?

3.7.1 DDS Measurement of Food Security

Food security is a complex state with different dimensions which has resulted in about 250 definitions and 450 indexes and indicators in the literature (Headey & Ecker, 2013). Over the years, food security has been measured using proxies like income, food expenditure, calorie intake, anthropometric data, and food production data. However, it is important that a food security measure should be able to capture the availability and access to nutritious food at the household or individual level to be able to reflect the reality masked in the national/macro level data. Few food security indexes are designed to capture food insecurity with focus on the four pillars of food insecurity: availability, access, utilization, and stability (Ike et al., 2016). Food security literature reviewed have shown that some measures captured a dimension of food security while others captured a combination of two dimensions (Jacobs, 2010; Rose & Charlton, 2002).

To improve the comprehensiveness of these measures, attempts have been made to develop composite measures to capture different dimensions of food security using a single indicator. Some of the composite measures include: the Food Insecurity Multidimensional Index (Napoli et al., 2011), the Rose - Charlton composite measure developed in South Africa (Rose & Charlton, 2002), and the Global Hunger Index (Kuku-shittu et al., 2013). These composite measures are still limited in their ability to directly measure food security and access inequality due to reliance on macro level data and indirect measures. Composite measures have remained limited due to the choice of indicators to be included in the measure and the difficulty in assigning weights to the components of the measure (Ike et al., 2016; Jacobs, 2010).

The fourth-generation measures were found to provide more comprehensive results on food security. The fourth-generation food security indicators - HFIAS (Household Food Insecurity Access Scale), CSI (food insecurity Coping Strategies Index) and the DDS (Dietary Diversity Score) as proposed in (Maxwell et al., 2003, 2014) for a better measurement of food security situation have not been effectively used in African food security studies. These measures were developed to be time sensitive, cost effective, and effective in identifying those that are food insecure. The CSI is meant to capture the behaviour of the food insecure, what they do when there is no or little food (Jones et al., 2013). The HFIAS adapted from the USDA Household Food Security Survey Module (HFSSM) is designed to capture the predictable reaction of households experiencing food insecurity (Coates et al., 2007; Opsomer et al., 2003). So, the HFIAS captures lack of food access and anxiety over lack of food and perceived insufficient quantity or quality of food. The HFIAS is designed to clearly group households into food security categories- high food security, marginal food insecurity, low food security and very low food security. Although these three key food security measures are designed to produce comprehensive information on food security, the DDS proposed for this study is well adapted to reflect the diversity needed in the food system to achieve food and nutrition sustainability. Having a more diversified diet and a more diverse food system is an important outcome in, and of, itself. DDS measure has been used by several researchers on food security measurement (Guasa, 2005; Ike, Jacobs, & Kelly, 2017b; Mjonono et al., 2009).

Why the DDS

The DDS was developed by the Food and Nutrition Technical Assistance (FANTA) project of the FAO to focus on the access and nutrition aspect of food security (Swindale & Bilinsky, 2006b). DDS is a very good instrument for measuring food security as it has been identified as a valid instrument for measuring inter and intra household food and nutrition security (Becquey et al., 2010; Faber et al., 2009; Hoddinott & Yohannes, 2002; Kennedy et al., 2011; Swindale & Bilinsky, 2006b). The consumption of diverse foods has been found to correlate well with nutritional status (FAO, 2010). There is very strong correlation between DDS and utilisation indicators of anthropometric measures like birth weight (Hoddinott & Yohannes, 2002). There is a very strong relationship between DDS and other desirable nutritional outcomes like improved concentration of haemoglobin, reduced hypertension occurrence and improved cardiovascular health (Becquey et al., 2010; Webb et al., 2006). DDS also has a strong linear relationship with food access, availability, and nutritional adequacy at both individual and household levels (Becquey et al., 2010; Hoddinott & Yohannes, 2002; Kennedy et al., 2010; Swindale & Bilinsky, 2006b; Webb et al., 2006). The correlation between DDS and other food security related factors like income of the household, and protein consumption, adequacy of micronutrients and calories is also strong (Becquey et al., 2010; Hoddinott & Yohannes, 2002). DDS is effective in identifying hidden hunger, which stems from micronutrient deficiency (Kennedy et al., 2011; Kennedy, Razes, Ballard, & Dop, 2010). In addition to being a valid measure of food security, the DDS was developed to meet the need for a cost effective, easy to use, simple to understand and comprehensive measure of the actual access and quality aspect of food security (Ike et al., 2016). DDS is designed to be less subjective and time sensitive as it takes less survey and analysis time than most food security measures (Hoddinott, Yohannes & Division, 2002). It takes about three to ten minutes per household to collect the data (Swindale & Bilinsky 2006; Ike et al, 2015). DDS, which captures the consumption of the different groups of food, can very well reflect the production or available in the market of different varieties of food.

Dietary Diversity Score (DDS) Module Description

DDS captures the varieties of food consumed by members of a household within the last 24 hours prior to the research interview (Kennedy et al., 2010, 2011). The score for a household using this indicator ranges from zero (0) for households that ate nothing within the 24 hours, to 12 for households that ate all 16 food groups. The 16 food groups in the DDS module are: (1) Cereals, (2) white roots and tubers, (3) Vitamin A rich vegetables and tubers, (4) dark green leafy vegetables, (5) other vegetables, (6) vitamin A rich fruits, (7) other fruits, (8) organ meat, (9) flesh meats, (10) eggs, (11) fish and seafood, (12) legumes, nuts and seeds, (13) milk and milk products, (14) oil and fat, (15) sweets, (16) spices, condiments, and beverages. The DDS is used to derive the Household Dietary Diversity Score (HDDS), Women Dietary Diversity Score (WDDS) or Individual Dietary Diversity Score (IDDS). For the analysis here, these 16 food groups are further aggregated into 12 different groups of food to form the HDDS in line with DDS user guide (Kennedy et al. 2011; Kennedy et al. 2010), used in this work. All the vegetables, fruits and meat are aggregated separately, so, for the analysis the HDDS food groups becomes (1) Cereals, (2) White roots and tubers, (3) vegetables, (4) fruits, (5) meats, (6) Eggs, (7) Fish and seafood, (8) Legumes, nuts and seeds, (9) Milk and milk products, (10) Oil and fat, (11) Sweets, (12) Spices, condiments, and Beverages.

3.7.2. The system approach measurement of sustainable food system

According to Sheane, McCosker, & Royston (2017) the most important elements of the food system are the linkages, interactions and feedback and causal loops between the component parts of the food system- environment, economy, and the society. The Institute of Food Science and Technology (IFST) advocates that the complexity of the food system means that a system approach is necessary if any meaningful and effective policy is to be designed for sustainable development (Sheane et al., 2017). At the macro level, IFST identified and reviewed six approaches used in food system research. These include resource pressure, sustainable diet, sustainable economic model, sustainable economic model of recycle and reuse, equity and decent jobs and transparency, traceability, and trust in the food system (Sheane et al., 2017). However, at the micro level where the incidence of food insecurity and food system inequality are felt, Sheane et al. (2017) noted that there is no clear demarcation in these different aspects of the food system. In most cases, the households experience the consequences of the unsustainable food system at the same time. The problems of food insecurity, unemployment or underemployment, poverty, poor health, and environmental hazards exist together in most cases.

Life cycle assessment (LCA) was employed by Heller and Keoleian (2003), in assessing food system sustainability. LCA is a material and energy resource flow analytical method employed in assessing the resource consumption from acquisition to retirement and its environmental burdens. This method focuses on the lifecycle stages of physical input and output product lifecycle in the system, and their impacts on the environment, economy, and society, with little emphasis on biodiversity in terms of agrobiodiversity and diet diversity at the consumption stage. Value chain approaches look at the food system as a system that is connected based on the value added at the different stages of the product life cycle. However, according to FAO (2018b), this approach tends to focus on a particular product, while neglecting other products and the relationships shared with these products.

There is no consensus about the tools that should be employed to assess sustainable diets and food systems. To understand the relationships between elements within the food system, detect gaps and problem areas that need to be addressed, monitoring progress in addressing those gaps and helping community, stakeholders, and policymakers in identifying the areas of concern and investments, system thinking approach has been suggested (Hammond & Dubé, 2012; Sheane et al., 2017).

Potentials of SDM in Assessing a Complex System

The determinants of food insecurity are complex, which may be the reason undernutrition is existing together with obesity. The dynamic complexity inherent in the food system makes policy making exceptionally challenging (Hammond & Dubé, 2012). Focusing on an aspect of the food system as the main cause of the problem may fail because changes in one aspect of the system may be offset or reversed by responses at another point in the system (Hammond & Dubé, 2012). For instance, if food security is promoted through farm intensification that encourages monoculture, though food productivity may increase, but food insecurity may also increase due to less diversity of diet and so, malnutrition and obesity can result. Sometimes important feedback in the system that can be exploited for improvement might go unnoticed or even overlooked without considering the dynamic interaction of the system. The reasons many are using the SDM for a complex system analysis are listed as follows: the ability of the SDM to identify and account for causal relationship, uncertainty and long-term delays between actions and effects, ability to show the source of endogenous system behaviour, and link effects of policy to structure and behaviour of the system (Currie et al., 2018). The ability of the SDM to integrate multiple kinds of information to inform policy and capture the effects of proposed policies at a given timescale makes SDM a great tool for making sense of a complex system.

System Dynamic Modelling (SDM)

System Dynamics Modelling was originally developed by Forrester around 1950 as a powerful tool for the analysis of complex problems. This methodology was developed from system thinking, complexity theory, information science, cybernetics, control system, military games, organizational theory, and tactical decision making (Shepherd, 2014). It uses a standard causal/feedback loop to develop qualitative models of a system that can be used further for a dynamic hypothesis for a quantitative stock flow model (Pruyt, 1999; Shepherd, 2014).

The causal loop is important in presenting the mental model of an issues to show how and what people (relevant stakeholders) think of the causal links between concepts (Pruyt, 1999). The mental model is important in eliminating barriers to implementation of a given policy. SDM, unlike standard statistical models, thinks of all elements in a system as continuous quantities interrelated in causality and feedback loops with nonlinear relationships. SDM is an interactive model capable of reproducing, on its own, the complex problem being studied, producing appropriate real-life evidence for effective policy recommendations. Through simulation of complex interactions in the systems, points of intervention and opportunities will be identified with appropriate options and actions for achieving food security in Nigeria.

The model was reviewed by experts in food science, agricultural economics, agronomy, as well as farmers and agricultural extension agencies. These experts provided insights into the model's validity based on their extensive knowledge and experience with the real system, ensuring that the model's assumptions and structures are credible and realistic.

A structural Validation process ensured that the relationships and feedback loops within the model accurately represent real-world processes. Expert judgment from Ventana Systems Inc., a renowned organization in system dynamics, was utilized alongside empirical data to validate the model's structure. This approach aligns with the recommendations of Sterman (2000), ensuring that the model's internal logic and interactions are sound and reliable.

The subsequent chapters, which contain the results and result discussions, will illustrate how the various tools described in the methods section have been used to derive conclusions from the household survey, focus groups and the systems dynamic modelling.

To achieve the objectives of the study, both qualitative and quantitative primary data were collected and analysed. The qualitative data was gathered through focus group discussions in the study area. The focus group discussions looked at the effectiveness of the current agricultural policy thrusts on food security, in terms of achieving the needed sustainable food system goals. The FGD result is presented in Chapter four. Chapter five and six present results and discussions on the socioeconomic characteristics of the households, the results on the food and nutritional situation on households in Northeast, Nigeria, and subsequently the contributions of farms and forest to food security. The seventh chapter presents the results of the food system feedback and causal loop. The seventh chapter sheds light on the relationships and positive and negative feedback within the food system of the study area.

Chapter 4: Results and Discussion

To achieve the first objectives of the study, both qualitative and quantitative primary data were collected through focus group discussions in the study area and analysed. The focus group discussions looked at the effectiveness of Nigerian agricultural policy thrusts on food security, in terms of achieving the needed sustainable food system goals.

4.1 Assessing the Effectiveness of Nigerian Agricultural Promotion Policy (APP) in Achieving a Sustainable Food System

These two policies, ATA and APP, are aimed to move Nigerian agriculture to a commercial position to ensure the creation of sustainable jobs and wealth. However, little is known about the effectiveness of these policies on biodiversity, dietary diversity, and employment and income of the small-scale farmers who form the greater proportion of the food producers in Nigeria. Consumption of few varieties of food is a problem in achieving nutrition security. It has, therefore, been suggested that encouraging farmers and poor non-farming households with access to land to produce their own food, using labour already in abundance due to the high rate of unemployment, and a farming method like mixed farming and mixed cropping that gives them access to diversity of crops and animals for consumption will help combat food insecurity (Ecker et al., 2018; Perrin & Phillips, 1978; Tsolakis & Srai, 2017). Farms with mixed crops/animals have been found to be more resilient, improve productivity and stability, improve soil fertility, and provide the more diverse diet needed for nutrition security (Frison et al., 2011).

Recognising the complex problems of food insecurity, there is need to explore participants' opinions at the household level on the food security policy and its effectiveness. Discussing the directions and strengths of these policy thrusts at the grassroots level, where food decision-making happens, will help policy makers understand the food system better.

This study specifically assessed the effectiveness of APP food security thrusts taken from the policy document in achieving- social justice, economic viability, and a sustainable natural environment in the food system. A food production system will be considered just if it provides greater benefit to the poor and vulnerable groups in the society, reduce poverty through food security while providing a broader economic opportunity for development (von Braun, 2003). The study adopted a qualitative research methodology to explore the effectiveness of APP food security in achieving a sustainable food system.

4.2 Focus Group Discussion Results and Discussions

The theme of lack of support for small-scale farmers and the mixed cropping system that is prevalent in this area arose earlier in the group discussion. Probing was further made on how these farmers could be supported to achieve a sustainable farming system that will cater for the needs of the poor farmers. Discussions were made around the following eleven selected food security policy thrusts of the APP:

1. Fortification of food crops with vitamins and micronutrients,
2. Creating balanced diet awareness in schools and social gatherings,
3. Strategic national food reserve,
4. School feeding programme,
5. Encouraging the use of agrochemicals and tractors,
6. Increase focus on forest conservation and forest foods,
7. Encouraging organic farming,
8. Supporting small farmers practicing mixed farming/cropping system with credit and labour subsidies,
9. Supporting large scale and specialised farming,
10. Promoting commercial seeds to farmers, and
11. Allocation of 10% of Nigerian land to nomadic pastoralists for cattle grazing.

Discussions were made on how effective these policy thrusts are in achieving desirable sustainable food system goals of food price stability, access to and availability of diversity of food for improved nutrition of households, biodiversity, and improved environment benefits, increase employment for the poor farmer, improved soil health and providing income support for poor households. So, each policy thrust was assessed on participants' views on its effectiveness in achieving these goals. To conclude the discussion, the degree of effectiveness of each policy was determined by the participants using a scale of one to five, with being 1 very ineffective and 5 being very effective. A mean score decision rule presented in the methodology (Chapter 3) was applied to determine the cut-off points of rating. So, a score below 2.95 is considered ineffective. A mean score above 3.05 is considered effective and having a mean score of between 2.95 and 3.05 is considered moderately effective. The results are presented according to their relevance to the five sustainable food system goals.

4.2.1 Food Price Stability

As shown in the results presented in Table 4.1, all six focus groups indicated that strategic national food reserves, encouraging organic farming, and supporting large scale and specialized farming are effective for food price stability. However, 3 and 4 groups out of the 6 groups indicated that forest conservation and food harvest, and the proper use of agrochemicals are effective in achieving food price stability, respectively. Food fortification, school feeding, and allocation of 10% of Nigerian land for grazing were placed on a scale of 1- very ineffective by 3, 4 and 5 groups out of the 6 groups respectively out of the six groups in the study. The mean scores of the policy thrusts, presented in Table 4.1, indicated that national food reserves (3.8), use of agrochemicals (3.5), encouraging organic farming (3.1), and supporting large-scale farmers (4.3) were effective. Forest conservation and food harvest (3) were considered moderately effective.

Table 4. 1. The Effectiveness of APP Food Security Thrusts for Food Price Stability as Assessed by Six Focus Groups

Scale of Effectiveness	**Number of Groups**										
	Fortification of food crops	Creating balance diet awareness	Strategic national food reserve	School feeding programmes	Forest conservation and foods harvest	Use of agrochemicals and tractors	Encouraging Organic farming	Supporting small farmers	Supporting large scale and specialised farming	Promoting commercial seeds	Allocation of 10% of Nigerian land for grazing
1	3	2	0	4	0	0	0	0	0	2	5
2	3	4	0	0	3	2	0	4	0	4	1
3	0	0	2	1	0	0	5	2	1	0	0
4	0	0	3	1	3	3	1	0	2	0	0
5	0	0	1	0	0	1	0	0	3	0	0
Mean Score	**1.5**	**1.7**	**3.8**	**1.8**	**3**	**3.5**	**3.1**	**2.3**	**4.3**	**1.6**	**1.2**

Participants were asked about their perceptions of the effectiveness of each of the eleven food security policy thrusts of APP in achieving food price stability. It is important to note that most Nigerian households buy food from an open market where farmers have free access to sell their produce. Food price was often linked to quantity of food produced, crop seasonality, crop failure, changing climate, and pest and disease. The participants were generally sensitive to seasonality of their enterprises and its impact on price. They described interventions on food prices as very important as a poverty alleviation instrument for farming households. The food price stabilizing policies identified were said to need lots of effort from the Government. This effort should be to grant farmers a minimum price enough to cover their cost of production, and to control the price of other non-food products. The farmers know that they have little influence on the price they get for their produce and so want the Government to do more in this area. They suggested that Government should buy the excesses during harvest and store them up for a lean period. They also suggested a community-managed food storage system which they lack the resources and security to establish. Below is a list of some example statements from participants in the focus groups.

If there is food stored up by the Government for food emergency, and households are aware that this food will be made available in emergency, then traders will be less extortive. That is if our government is sincere o o o! -Male, smallholder farmer, 47 years old.

If the excess food during the harvest time is bought from us and removed by the Government and price will not fall and might not even increase during the lean period due to available of food from the reserve. – Male, Yam mixed-crop farmer, 50 Years old.

Is very difficult to store your farm produce as an individual due to lack of storage facilities or high cost of establishing one. So, communal or government efforts is needed for this. Most households can't store enough to survive a crop failure. Female, smallholder mixed crop farmer, 38 years old.

I believe that having a working food reserve that will help store food during excesses and fill the gap during lean period is the best way to stabilize food price. Male, Primary school teacher and farmer, 40 years old.

While supporting large scale and specialised farming was considered very effective for price stability, the proper use of agrochemicals and tractors just like national food reserves were frequently pointed out by participants as ways to promote price stability. They argued that increased food production using agrochemicals and tractors will reduce the risk of crop failure cause by pests and diseases. This might even reduce the seasonality in crop planting due to the opportunity for irrigation. Also, having food released from the reserves during a food crisis will also prevent unnecessary rise in price. For example:

Tractors and proper agrochemical use are a big man farming system. They turn food production into business. Their aim is to make profit, is not about food… So, they can use the land for anything that gives money, but we need our lands to survive. – Male yam farmer, 40 years old.

*If this big farming system is in place (*Monocropping system producing crops in larger expanse of land*), it will give more power to few farmers to produce most of the food. So, if you produce most of the yam in the market, you can control the market for this food. We are not their competitors at all.* – Male yam mixed crop farmer, 49 years.

They will produce more using better technology and so can control the bigger market and price also. Female rice farmer, 41 years old.

The responses from the focus group discussion reveal significant concerns about the impact of large-scale, profit-oriented farming systems on traditional, subsistence-based agricultural communities. The failure of exchange entitlement was reflected in the concerns the participants raised. Sen's theory put it that famines and food insecurity often lead to a failure in the ability of individuals or groups to exchange their entitlements, such as their labour or farm produce, for food. This failure according to the FEE theory is most times not due to the absence of food but rather the lack of food access to certain populations due to economic or structural inequalities.

In this context, the local farmers express a fear that the support for large-scale farming systems- such as those employing monocropping and extensive use of agrochemicals-threatens their traditional, more sustainable mixed cropping systems. They perceive these large-scale systems as prioritizing profit over food security and as having the capacity to dominate food production and market control. This control could lead to a situation where smallholder farmers might lose their ability to exchange their labour and smaller-scale crop outputs for sufficient food and income, thereby eroding their entitlements.

The shift towards large-scale farming, as described by the focus group participants, represents a structural shift that could severely disrupt local food systems. According to Sen's theory, this disruption could lead to a failure in exchange entitlements for smallholder farmers, who may find themselves incapable of competing in a market controlled by a few large-scale farmers with the power to control prices and production. This situation could worsen food insecurity and weaken the livelihoods of local farming communities, who rely on their land not just for income but for their very survival.

The discussants pointed out that forest foods will provide an alternative to farm foods. So, competition from forest food will affect the general price of food. Forest food was generally talked about as being free and a way for the poor to keep surviving. The discussants also emphasised that supporting organic farming will lead to price stability. The effects of organic farming were generally considered to be a more gradual, lasting, and less costly process compared with the use of agrochemicals and tractors. For example:

Organic farming is really very good, but our lands are already killed, dead and polluted by these chemicals and continuous farming. If the land is corrected and cared for using natural regeneration, then we can always achieve the same level of production as chemical farming with better health for every living things … - Male smallholder farmer, 47 years old.

The outcome of the discussions suggests the need to focus on strategic national food reserves, organic farming, large-scale specialized farming, and the proper use of agrochemicals for food price stability.

The effectiveness of strategic national food reserves in achieving food price stability is well-documented. According to Barrett, (2002) in "Food Security and Food Assistance Programs," strategic grain reserves can buffer against price volatility, especially in countries where agriculture faces significant seasonal and annual production variability. This aligns with the sentiments of the focus group participants who value the role of Government in storing excess harvest to stabilize prices during lean periods. Janvry and Sadoulet (2010) in "Development Policies and Agriculture in Sub-Saharan Africa" discuss the significance of national food reserves in stabilizing food prices during periods of fluctuation. This suggests that such reserves can mitigate the volatility of food prices by smoothing out the fluctuations in supply.

The advocacy for organic farming as a means to food price stability can be connected to the sustainable agriculture paradigm, which emphasizes environmental health, economic profitability, and social and economic equity (Altieri (1999). Organic farming is argued to reduce dependency on synthetic inputs, thereby potentially lowering production costs and stabilizing prices in the long term. Seufert (2012) in their work "Comparing the yields of organic and conventional agriculture" published in Nature, discuss the potentials and limitations of organic farming in sustaining global food demands. On the other hand, some studies on agricultural sustainability and intensive production practices, argue for the necessity of large-scale farming to meet global food needs efficiently, with an emphasis on innovative practices to mitigate environmental impacts. Pretty and Hine (2001) detail how organic farming practices can enhance food security by improving soil fertility and biodiversity which, in turn, can contribute to more stable food supplies.

Supporting large-scale and specialized farming as a mechanism for price stability is tied to the economies of scale and the potential for increased efficiency and productivity. According to Pingali (2012), the adoption of modern agricultural practices and specialization can lead to significant yield improvements and potentially lower food prices. This is reflected in the participants' views that large-scale farming, equipped with modern technology, could control market supply and prices. EURACTIV (2012) argues that supporting large-scale farming, when done alongside sustainable practices, can increase productivity and efficiency, leading to greater food availability and, potentially, more stable prices.

According to Sunderland (2015), forest foods provide critical nutrition and income for rural households, which can be an important factor in stabilizing food prices by providing alternative food sources. The moderate effectiveness attributed to forest conservation and food harvest reflects a nuanced understanding of the role of ecosystems in food security. Works like Sunderland (2011b) "Food Security: Why is biodiversity important?", highlight the complex interplay between biodiversity conservation and food availability, emphasizing the potential of forest foods in supplementing diets and providing livelihoods.

Pretty et al. (2018) explore the necessity of integrating agrochemicals with sustainable agricultural practices to increase food production while minimizing environmental impacts. Their findings can underpin our FGD observations on the role of agrochemicals in achieving food price stability. The proper use of agrochemicals, while seen as effective by some groups, raises concerns regarding sustainability and health. (Pretty & Hine, 2001) discuss the transition to sustainable agriculture, emphasizing the need for reduced chemical input for long-term ecological and economic viability. The mixed responses from focus groups highlight the tension between immediate productivity gains and long-term sustainability. These findings can be linked to the discourse on sustainable agriculture as discussed by (Tscharntke, Clough, et al., 2012) (2012), who highlight the importance of integrating landscape management with agricultural practices to sustain productivity while conserving biodiversity. The effective use of agrochemicals, as pointed out by Pingali (2012), needs to be managed carefully to avoid adverse environmental impacts while enhancing crop yields.

The scepticism towards food fortification, school feeding programs, and the allocation of land for grazing as less effective measures might be contextual to the Nigerian situation, where direct interventions in food production and market stability are more pressing. These findings invite a comparative analysis with studies by (Black et al., 2013) on food fortification and Bundy et al. (2009) on school feeding programs, suggesting that while these policies can have positive health and educational outcomes, their impact on food price stability may be indirect and less immediately observable.

The suggestion for community-managed food storage echoes the sentiments of some grassroots-level studies. Maxwell and Caldwell (2008) underline the importance of community-based approaches in enhancing food security and resilience against shocks.

The nuanced views on the effectiveness of various policy measures for stabilizing food prices in Nigeria underscore the importance of context-specific strategies. The mixed responses regarding the effectiveness of forest conservation, food harvest, and the use of agrochemicals suggest a need for policies that balance agricultural productivity with environmental sustainability. This reflects a broader understanding in the literature that achieving food security and price stability requires a multifaceted approach that considers ecological, economic, and social dimensions. Encouraging the adoption of organic farming practices, as they can contribute to environmental sustainability and, potentially, reduce dependency on expensive agrochemicals. As Pretty et al. (2018) have shown, organic farming can also support long-term soil health and biodiversity, contributing to more resilient food systems.

4.2.2. Access to, and Availability of Diversity of Food

Availability of diversity of food, and households having access to diverse groups of food is very important in achieving food security. Eating a diet consisting of diverse groups of food has been confirmed to correlate highly with food security indicators like birth weight, haemoglobin concentration, and serious health issues such as hypertension, and cardiovascular diseases. More dietary diversity leads to better food security and health outcomes (Swindale & Bilinsky, 2006a). So, more dietary diversity, is an important outcome in, and of, itself (Ike et al., 2016). Creating balanced diet awareness in schools and social gatherings, focusing on forest preservation and forest foods, encouraging organic farming, and supporting small-scale farmers through credit and labour subsidies were considered very effective in securing access to, and availability of diversity of food, biodiversity, and employment.

Table 4. 2. Effectiveness of APP Food Security Thrusts for Improved Access to, and Availability of Diversity of Food

Scale of Effectiveness	Number of Groups										
	Fortification of food crops	Creating balance diet awareness	Strategic national food reserve	School feeding programmes	Used of Agrochemicals and tractors	Forest conservation and foods harvest	Encouraging organic farming	Supporting small farmers	Supporting large scale and specialised farming	Promoting commercial seeds	Allocation of 10% of Nigerian land for grazing
1	2	0	2	4	1	0	0	0	3	3	5
2	4	1	3	2	4	0	0	0	3	3	1
3	0	3	1	0	1	1	1	2	0	0	0
4	0	1	0	0	0	3	2	3	0	0	0
5	0	1	0	0	0	2	3	1	0	0	0
Mean score	**1.7**	**3.3**	**1.8**	**1.3**	**2**	**3.3**	**4.3**	**3.8**	**1.5**	**1.5**	**1.2**

The FGD scale of effectiveness for the policy thrusts presented in Table 4.2 shows that these five policy thrusts, creating balanced diet awareness with a mean score of 3.3, focus on forest conservation and food harvest (3.3), encouraging organic farming (4.3) and supporting small scale farmers with credit and labour subsidies (3.8), are effective in achieving access to and availability of diversity of food. These five policy thrusts were indicated by 1, 2, 3 and 1 group(s) respectively as a very effective policy thrust for food diversity. However, more than half of the groups, 4, 3, 3, and 5 put School feeding, supporting large and specialised farming, promotion of commercial seed to farmers, and allocation of 10% of Nigerian land for grazing respectively, on the scale of 1- very ineffective.

In the discussion in the FGDs, the participants frequently agreed that creating balanced diet awareness is effective in achieving availability of diversity of food and access to these foods. Some of the participants indicated that most people are not aware of the need to eat diversity of food. The general thinking was that you should eat three times a day and to eat to your fill. However, the content of the food has always been neglected and sacrificed for taste and convenience. The discussants mentioned that most households prepare maize, rice, cowpea, yam, and other produce in different ways and with the same ingredients for their three meals a day. Those of them who are mothers and had been pregnant mentioned that nurses usually sound it as warnings that they must eat fruit and vegetables and that you must eat a balanced diet. However, very few of them understood why they must eat diversity of food as shown by the statements below:

Many people do not know the different food groups and what they do in our bodies. However, we understand the different meats- goat, chicken, cow and bushmeat, and fruit and vegetable food crops and eat them in different ways. If we are aware, it will make us plant many of these food groups knowing we are not big men who can buy anything they want. At least we can produce our own food for our health. – Female mixed crop farmer, 41 years old.

People might not see the difference in the number of different foods consumed by the big man and the small man because of the food we get from our farms and forest. ... Who will *give us free vegetables and fruits or the money to buy them like the rich people?* - Female farmer, 22 years old.

Yesterday we drank kunu (maize porridge) in the morning, ate masa (corn and rice ball) for lunch and tuwo masara (thick Maize porridge) for dinner and we do this most days. We also eat lots of rice. For a change when we have money, we buy indomie (noodle) and mineral (soft drinks) to enjoy. Female farmer, 35 years old.

Most local foods like cocoyam, vegetables and Ariel yam are considered inferior, so to belong we need to eat rice, indome noodle, snacks, soft drinks, and lots of meat. – Female Farmer, 48 years old.

If we know better, we will do better. We will produce these crops to improve our diet if we know they are important to our health. If a poor man doesn't have money for a better hospital, but we still have land to plant good food to keep us from hospital. We need this information. Female farmer, 35 years old.

An organic farming system was generally agreed to be a very effective means of achieving access to, and availability of, diversity of foods. The discussants believed there is more diversity of crops and animals in organic farming than on farms that depend on inorganic herbicides, pesticides, fertilizer, and heavy machines for farming. This agreement is in line with (Woodward et al., 2010). In this type of farming, the farmer plants different types of crops with different heights, root systems, pests, vegetative cover, and harvest timeline to maintain the ecology of the farm. Hence, it is expected that organic farming systems will make diversity of food available, as shown in the example statements from the focus group participants:

*Yes, because farmers that use these systems (*Organic farming and mixed cropping*) produce more varieties of food as an insurance against crop failure. It gives the farmers more money to produce more different types of crops from a small piece of land*. – Female farmer, 58 years old.

Forests are a very important repository of food and other resources needed for food. In the case of Nigeria, most forest harvest of non-timber products are done by the poor. Forests provide diversity of foods for the household and are an important source of food during a period of food shortage. Food and agricultural policies are increasingly adopting ecosystem approaches. However, policy measures focusing on wild foods are not widespread (FAO et al., 2019). (Harris & Mohammed, 2003) identified a total of 67 wild foods from 53 species of plants, 33 of which are found in farms in Northeast Nigeria where this study took place. This shows that forest food is very important in achieving food security in Nigeria. In addition to getting variety of fruits, vegetables, seed and nuts for food, the forest is a major source of other products that contributes to food security. The discussants mentioned that they get honey, fish, snail, mushrooms, edible insects, and shea butter from the forest. These products contribute immensely to the food and income of their households. However, the participants argued that Government conservation plans have not been effective in keeping their forests from over exploitation. Government control of some of their forests also prevents the poor in the community from accessing the forest for their need.

They believed that the age-long community control of the forest was better. The community used to protect the forest from intruders who have no stake in the forest by regulating the harvest to prevent over exploitation and felling of immature trees. However, with the modern world these regulations have broken down and the community are now offered large amounts of money to sell their forests or are forced by the Government to give it up for "development". Government protection has only focused on environmental sustainability with little consideration for the poor who need this forest to live. The FAO (2019) recognises the importance of indigenous knowledge and practice sustained through a long history in conservation and sustainable use of forests (Vidal, 2019). Traditional and indigenous knowledge in the food system are skills, knowledge, understanding, practice, ideology, and experiences learned, developed, sustained through a long history of interactions with the environment and passed on through generations within the community (Mistry, 2009; Vidal, 2019). In Nigeria, forest lands are held in trust by the state government for the people. So, some of the forest lands are reserved to protect the trees, thereby restricting access to forest food (Babalola & Hull, 2019). This is backed up by the following comments of the focus group participants:

The forest has more plant and animal varieties than can be found in man-made farms. So, protecting the forest will provide more varieties of food especially to poor people who can't afford imported apples. Male farmer, 49 years old.

*The Gumti national park is still around us, but we have no control, contribution, or legal benefit from the forest. What most people do now is to sneak in and get as much as they can from it despite the cost of this action to the forest or the people around it… There is too much hunger and the safety net used by the people of old is now illegal (*searching for plants, firewood and animals for food has been prohibited for certain forests by the Government*). People can only survive, but this is now at the destruction of the forest that use to be monitored and sacredly preserved.* – Male farmer 59 years old.

Like organic farming, supporting small-scale farmers with credit and labour subsidies was seen by the discussants as a very effective way of promoting access to, and availability of, diversity of food. Providing the farmers with a labour subsidy was a reoccurring theme throughout the discussion. The participants argued that most foods eaten by most Nigerians were produced by small-scale farmers who lack the resources to mobilize enough labour for their farms. These small-scale farmers produce wide varieties of crops using manual labour. It was argued that supporting these farmers will impact positively on food security.

From the focus group discussions, it is obvious that most of the food eaten in Northeast Nigeria come from the forest and small-scale farmers who practice mixed cropping. The farmers said the decision to plant any crop is dependent on what they wanted as a household for food and part of a society, the location of the farm (distance from home), money value of the crop, soil nutrient level, water holding capacity of the soil, and the production history of the land. So, within a plot of land, farmers make experienced and complex decisions on what to plant. This can be seen from some of the statements by the focus groups participants below:

Oh yes, supporting small farmers who are into mixed cropping and mixed farming as against the Government initiatives to support commercial farmers will boost the production of more *varieties of food. This is specially for those indigenous foods that are not imported or produced by large scale farmers.* – Female secondary school teacher and farmer, 40 years old.

Now if you are unable to show that you will be producing rice, soya beans, sesame, maize or any other cash crop or animal in a commercial quantity there is no guarantee that you can get a loan even from informal credit facilities. The way our Government is favouring big farms is not good for our local foods and the poor farmers still struggling to eat. - Soya bean and Sesame farmer, 47 years old.

It can be seen from the discussions that most of the households in the study area source their food from their own farms. Farming households may do well with their food if they have the knowledge of what they should eat, and which will also encourage the production of these foods. Many poor households also depend on the forest for food and income. They require support from the Government in terms of labour, dietary diversity awareness, and low-cost farming systems like organic farming. If environmental sustainability, and social justice are to be achieved, the importance of the forest in the livelihood of these poor households requires the involvement of the communities in the management plans of the forest.

The discussion reveals significant insights into the importance of dietary diversity for achieving food security and enhancing health outcomes. This is in line with the findings of Swindale & Bilinsky (2006a), who emphasized that dietary diversity is strongly correlated with food security indicators such as birth weight, haemoglobin concentration, and the prevention of serious health issues like hypertension and cardiovascular diseases. Ike et al. (2016) also stressed the intrinsic value of dietary diversity both as an outcome and a goal in itself, underscoring the critical role of a varied diet in ensuring food security and promoting health. This assertion supports the findings from the FGDs, where policy thrusts aimed at enhancing dietary diversity were rated highly effective by participants. These findings contribute valuable insights to the ongoing discourse on food security and underscore the need for integrated approaches to ensure access to a diverse range of nutritious foods.

The consensus among participants that strategies like creating balanced diet awareness, conservation of forests for food harvest, encouraging organic farming, and supporting small-scale farmers through credit and labour subsidies are effective in promoting access to and availability of diverse food groups, aligns well with existing literature on food security and dietary diversity.

The data presented in Table 4.2., echoes the broader literature's acknowledgment of the multifaceted approaches needed to ensure food security, encompassing both agricultural practices and broader ecological conservation efforts. Initiatives like creating balanced diet awareness, focusing on forest conservation and food harvest, encouraging organic farming, and supporting small-scale farmers through credit and labour subsidies are deemed effective by focus group discussions (FGDs).

The discussions also underline the significant gap in public awareness regarding the importance of dietary diversity. Many participants noted the lack of understanding among the general population about the various food groups and their nutritional benefits, indicating a critical area for intervention. This insight aligns with the broader literature, which suggests that increasing awareness and knowledge about dietary diversity is essential for improving public health outcomes and ensuring food security (FAO et al., 2019).

Organic farming is highlighted as a particularly effective method for achieving food diversity, supporting the findings of Woodward et al., (2010). This approach not only promotes the availability of a wide range of food products, but also supports sustainable agricultural practices, and contributing to both environmental conservation and food security. The importance of forests in providing a diverse array of foods and other resources is similarly emphasized, reflecting the findings of Harris and Mohammed (2003) on the role of wild foods in ensuring food security in Northeast Nigeria.

The FAO, (2019c) highlight the crucial role of forests as sources of diverse foods and other resources essential for food security. They mention that ecosystems approaches are increasingly being incorporated into food and agricultural policies, though policies specifically targeting wild foods are less common. This aligns with the FGD participants' views on the importance of forest conservation for food diversity, particularly in providing a safety net during food shortages and contributing to the dietary diversity and food security of households.

The emphasis on supporting small-scale farmers and recognizing the value of indigenous knowledge and practices in forest conservation is particularly noteworthy. This approach is backed by literature that advocates the inclusion of community-based strategies in environmental conservation and food security efforts (Babalola & Hull, 2019). The discussion suggests that such strategies not only enhance access to diverse food sources but also contribute to the sustainable management of natural resources. This notion was reiterated by FGD participants who stressed the need for community control over forest resources to prevent over-exploitation and ensure their availability for future generations.

The FGD findings highlight the importance of policy measures that promote dietary diversity through awareness creation, sustainable farming practices, conservation of natural resources, and support for small-scale farmers. These measures are essential for achieving food security and improving health outcomes, as they ensure access to and availability of diverse food groups. The literature corroborates the effectiveness of these policy thrusts in contributing to dietary diversity and, consequently, food security and health improvements.

4.2.3. Biodiversity and Improved Environmental Benefits

The importance of biodiversity in reducing hunger, food insecurity, and providing income support for the poor cannot be over-emphasized. Declining biodiversity will force humans to depend on fewer crops and animals for food which will undermine food security. Less biodiversity will simplify the ecology making plants and animals more vulnerable to pests and disease attacks. The policy thrusts found to favour access to, and availability of, diversity of food, were also applicable in promoting biodiversity and improved environmental benefits. In addition to forest conservation and food harvest with a mean score of 4.6, organic farming (4.7), creating balanced diet awareness (3.7), supporting small-scale farmers with credits and labour subsidy (4.3), and having a strategic national food reserve (3.8) were also considered effective in promoting biodiversity and environmental benefits.

Table 4. 3. Effectiveness of APP Food Security Thrusts for Biodiversity and Improved Environmental Benefits

Scale of Effectiveness	Number of Groups										
	Fortification of food crops	Creating balance diet awareness	Strategic national food reserve	School feeding programme	Use of Agrochemicals and tractors	Forest conservation and foods harvest	Encouraging organic farming	Supporting small farmers	Supporting large scale and specialised farming	Promoting commercial seeds	Allocation of 10% of Nigerian land for grazing
1	1	0	0	5	3	0	0	0	6	4	4
2	4	1	0	0	3	0	0	0	0	2	2
3	1	1	2	1	0	0	0	1	0	0	0
4	0	3	3	0	0	3	2	2	0	0	0
5	0	1	1	0	0	3	4	3	0	0	0
Mean score	**2**	**3.7**	**3.8**	**1.3**	**1.5**	**4.6**	**4.7**	**4.3**	**1**	**1.3**	**1.3**

To understand the subtle differences in the degree of effectiveness of the different policy thrusts on biodiversity and environmental benefits, the discussants were asked to place each policy thrust on a scale of 1 – 5 as presented in Table 4.3. The results showed that 1, 1, 3, 4, and 3 groups identified creating balanced diet awareness, strategic national food reserve, forest conservation and food harvest, encouraging organic farming and supporting small-scale farmers with credit and labour subsidies respectively as very effective policy thrusts. However, 5, 6, 3, 4, and 4 groups placed school feeding and supporting large and specialised farming, the proper use of agrochemicals, promoting commercial seeds, and allocation of 10% of Nigerian land for grazing respectively, on a scale of 1-very ineffective.

For the policy on forest food, and a national food reserve, the discussants reasoned that encouraging forest conservation and harvest of forest food will make communities and individual owners protect their source of livelihood and, so, biodiversity. Less disturbance or sustainability, planned management of the forest and land, will make the forest produce more food. Species loss due to indiscriminate bush burning, clearing of forest for housing and other industrial development purposes, and the rise in commercial farming with widespread monoculture due to support from Government were pointed out by the participants. Also, making food available in the market during food crises through a national food reserve was opined to be effective in reducing the incidences of people sourcing food through means that will harm the environment and the society, as shown in the statements made by the focus group participants below:

Since the forest close to our house was bought and cleared about three years ago, oh boy, we lost the bush meat we used to get from there, firewood is now hard to get, the edible ants used to give us lots of free money but now is gone too. - Male farmer, 28 years old.

Bringing out stored food especially beans (cowpea) prematurely from the store when the harmful chemicals used for storage is still very active and harmful to humans and the environment has been happening. We all know this story and the death it has caused. – Female food *bukateria* seller and farmer, 36 years old.

The use of manual labour instead of tractors in organic farming and by smallholder farmers practicing a mixed farming system will help preserve the soil and particularly the trees in the farm. There is less pollution as there is no chemical run-off to the streams during rain and no air pollution due to chemical sprays. – Female teacher and farmer, 50 years old.

Imitating nature's way of farming as in organic farming produces different varieties of crop on a piece of land than the conventional farming monoculture. There are some weeds that are edible and some pests that are foods too. These things are mostly overlooked. – Female farmer, 45 years old.

The discussants highlighted biodiversity as an important foundation that underpins the structure, function, and process of the food system. The discussions around organic farming, supporting small-scale farmers who plant mixtures of crops and keep different animals, a national food reserve, and forest conservation and food harvest emphasised the need to protect biodiversity with focus on its impacts on socioeconomic and biological factors.

The results presented in Table 4.3 and the associated quotations provide a comprehensive look at the intertwined relationships between biodiversity, food security, and environmental sustainability. Insights from the focus group discussions also shed light on the complex socio-economic and environmental factors shaping food systems and biodiversity. These discussions highlight the interplay between biodiversity and traditional farming practices, and the pressures from current agricultural policies and changes in land use, painting a detailed picture of the food security landscape in Northeast Nigeria. The quotes illustrate the strong connection between community livelihoods, access to diverse food sources, and efforts to conserve biodiversity, all influenced by shifts in land access, food preferences, and the politics of forest and agricultural management.

The dialogue on wild foods, changes in land access, and shifting food preferences underscores the intricate relationship between socio-economic transformations, environmental policy, and food security strategies. Governmental and commercial decisions leading to the sale of forests and restrictions on access impact biodiversity and traditional food sources, essential during crop failures. This scenario is shaped by power dynamics and political choices, often favouring immediate economic benefits over environmental sustainability and community welfare (Young et al., 2016; Sunderland, 2011).

The reduction in access to wild foods due to commercial land acquisitions and governmental restrictions, highlights broader concerns around environmental justice and food sovereignty. The reliance on biodiversity for food security and nutritional needs underlines the importance of policies that uphold community rights to their natural resources (Coomes & Lines, 2020; Young et al., 2016 Moving away from traditional, diverse farming practices to monoculture and large-scale agriculture not only diminishes biodiversity but also increases the vulnerability of local ecosystems to pests and diseases, threatening food security (Altieri, 1999; Tscharntke et al., 2012).

The findings suggest that while policies promoting organic farming, forest preservation, and support for small-scale farmers are beneficial for biodiversity and food security, their success requires a deep understanding of local conditions and community socio-economic realities. Effective policies must tackle the fundamental issues behind biodiversity loss, including the undervaluation of traditional crops and the economic forces driving changes in land use (Altieri & Nicholls, 2012; Chappell & LaValle, 2011)..

Additionally, the focus on organic farming and small-scale farmer support showcases the benefits of these practices in sustaining soil health, minimizing pollution, and promoting ecological balance. The preference for manual labour and reduced agrochemical use aligns with the broader advocacy for agroecological practices as cornerstones of sustainable food systems and biodiversity conservation (Wezel et al., 2009, 2014, 2020).

The discussion also raises concerns about the premature release of food from individual storage treated with harmful chemicals, pointing to the need for improved food storage and distribution management. Such practices pose risks to both human health and the environment, highlighting a gap in ensuring the safety and sustainability of food reserves.

Moreover, the discussants' experiences underscore the vital role of biodiversity in food system resilience. Biodiversity enhances ecological services like pest control, pollination, and soil fertility, essential for sustainable agriculture. By fostering organic farming and forest conservation, these ecological benefits can be preserved, supporting the livelihoods of communities reliant on these resources (Tscharntke et al., 2012).

The focus group discussions emphasize the indispensable role of biodiversity in achieving food security, nutritional diversity, and environmental sustainability. The need for policies that value traditional crops, promote sustainable practices, and guarantee fair access to land and resources is clear. Addressing the interconnected challenges of food security, biodiversity loss, and climate change can help cultivate resilient and sustainable food systems. Reflecting on the complex food security challenges in Northeast Nigeria reveals the necessity for a holistic approach that integrates environmental sustainability, social equity, and biodiversity conservation into food security strategies.

4.2.4. Employment and income support for poor households

Most poor people depend on food and income from their labour for survival. Decent labour for the poor for food security has not been properly addressed in the policies of many countries (FAO, 2012e). As important as decent work is to sustainable development and food security in particular, several factors limit the success of efforts in this area. Low returns in agriculture, low wages, drudgery, multiple job holding, casual job schedules due to seasonality, and gender inequality were identified as problems to achieving decent jobs. Decent work will help developing countries like Nigeria to solve three of their pressing problems**, high unemployment, poverty**, and **food insecurity**. Agriculture is an important sector in the Nigerian economy. About 80% of Nigerian households are involved in farming. In the Northeast, 83.6% and 68.6% of the households are involved in crop and livestock farming respectively. Small-scale farmers constitute about 65% of the population, over 90% of Nigerian farmers produce 98% of foods and 99% of crop output in Nigeria (Mgbenka et al., 2015; Sabo et al., 2017). The implication of these statistics is that more than half of the Nigerian population depend on their farms for their livelihoods. Even with the contributions of these farmers, most of the poor and food insecure Nigerians are farmers (National Bureau of Statistics Nigeria, 2005). If food security is to be achieved in Nigeria, decent and productive employment for the poor should be taken seriously. A socially just food system is very important in ensuring that policies and interventions in the food system will benefit these farmers and not make them worse-off.

When it comes to the policy thrusts that are effective in achieving more employment for poor farmers and households in the food system (see Table 4.4), all the groups indicated that focus on forest conservation and food harvest with a mean score of 3.1, encouraging organic farming (4), and supporting small-scale farmers with credit and labour subsidies (4.2), respectively, are effective. Creating balanced diet awareness was considered moderately effective by 3 groups. The results presented in Table 4.4 shows that three groups indicated that encouraging organic farming and supporting small-scale farmers are very effective policy thrusts for achieving more employment for poor farmers. However, 4, 4, 3, and 4 groups, which makes up more than half of the focus groups involved in the study pointed out that food crop fortification, school feeding programmes, promoting commercial seeds and allocation of 10% of Nigerian land for grazing respectively, are very ineffective in achieving more employment for the farmers.

Table 4. 4. Effectiveness of APP food security thrusts for Employment for poor farmers

Scale of effectiveness	**Number of Groups**										
	Fortification of food crops	Creating balance diet awareness	Strategic national food reserve	School feeding programme	Use of Agrochemicals and tractors	Forest conservation and foods harvest	Encourage organic farming	Supporting small farmers	Large scale and specialised farming	Promoting commercial seeds	Allocation of 10% of Nigerian land for grazing
1	4	0	2	4	1	0	0	0	0	3	4
2	1	2	3	2	4	0	0	0	4	3	2
3	1	3	1	0	1	5	3	2	2	0	0
4	0	1	0	0	0	1	0	1	0	0	0
5	0	0	0	0	0	0	3	3	0	0	0
Mean score	**1**	**2.8**	**2**	**1.3**	**2**	**3.1**	**4**	**4.2**	**2.3**	**1.5**	**1.3**

Encouraging organic farming and providing credit and labour subsidy support for the smallholder farmers were agreed to be very effective in securing employment for the poor (see Table 4.4). This is because most of the production done in these systems uses manual labour. Smallholder farmers usually practice mixed cropping and mixed farming systems which lends itself to the use of manual labour. In the FG discussions, it was clear that creating balanced diet awareness and an increased focus on forest conservation and forest foods will be effective in creating more employment for the poor households. The participants frequently talked about the importance of having regular work for farm labourers and more money to hire the labour and pay them well. This, they said, will help the poor among them to train their children in schools so their children could have a better chance at working in other sectors of the economy. The participants argued that the poor will remain poor if there is no support for the small-scale farmers who cannot afford good skill training or formal education for their children. There was much concern on the lack of support for small-scale farmers for credit from financial institutions and the Government. The discussants suggested that farmers will fare better if the Government supports them with labour subsidies instead of subsidizing the cost of fertilizers and herbicides which they hardly have access to, and tractors, which are depriving the farm labourers of their jobs. This is reflected in some of the statements from the focus group participants on their need for support for farm labour presented below:

If every farmer in our state can afford and depend on manual labour for clearing, tilling, planting, weeding to harvesting without the use of tractors or chemicals, much labour will be required. - Male farmer, 54 years old.

Yes, if labour is subsidized, then the farmers' problems are over. This is the biggest problem of our food production activities. It will encourage farmers to do more and so more labour can be hired. - Male Yam farmer, 56 years old.

When discussing the promotion of large-scale farming which involved the cultivation of over two hectares of land, and promotion of the use of commercial seed, the discussants sounded very distant from the concept, using the pronouns "they" and not "we or I". Large-scale farming systems have been largely supported by the Government through input subsidies, credits, training, and export supports as food security and sustainable development measures. Large-scale and specialised farming are promoted as efficient systems that bring about more food, more employment, and a better environment. However, listening to the discussion in the focus groups in this food insecure Zone (Northeast, Nigeria), it was clear that promoting large-scale and specialised farming may not improve the lot of these poor farmers. Some of them were also willing to work as labourers on big farms but they are afraid of not being able to secure the jobs as the following statement shows:

I am just thinking about the big rice farm they are taking our lands to do now. How many people will be employed on it and how many people will go hungry because they lost their land and could not even get employed as a labourer on the farm that used to belong to them? Rice might be cheap through this system but how do you buy it if you have lost your source of income and food. – Male farmer, 37 years old.

The discussions and data encapsulated in Table 4.4 articulate a holistic approach to enhancing food security in Northeast Nigeria by bringing together the creation of employment opportunities for economically disadvantaged farmers with environmentally sustainable agricultural techniques. This narrative underscores the vital link between generating job opportunities through innovations in agriculture and ensuring the availability of food, particularly in the light of changing access to land.

The critical role of supporting smallholder farmers and embracing agroecological methods is advocated by De Schutter (2010) and Altieri and Toledo (2011) who argue for the indispensability of these strategies in augmenting food security and fostering resilient food systems. This perspective is mirrored in the focus group discussions that confirm the positive impact of policies encouraging organic farming and providing labour subsidies to small-scale farmers, thereby boosting both employment and biodiversity for a more robust food system.

The FAO report (2012b) highlights the dynamic relationship among economic policies, agricultural employment, and food security, pointing out the necessity of inclusive economic growth to aid the most vulnerable sections of society. The preference for manual labour instead of mechanized farming techniques is identified as a valuable avenue for creating broader employment opportunities in the agricultural sector, as noted by the focus group participants. Barrett et al. (2001) emphasized the significance of diversifying income sources for rural households, including the pursuit of non-agricultural income opportunities. This insight is particularly pertinent in view of the participants' concerns regarding the lack of adequate support for small-scale farmers from financial institutions and governmental agencies.

Mgbenka et al. (2015) illuminate the challenges and potentialities of smallholder farming in Nigeria, calling for policy interventions to enhance this vital sector. The expressed concerns over job security for small-scale farmers in the face of expanding large-scale agricultural operations reflect these findings, indicating the necessity for policies that balance food production with employment generation. Sustainable intensification as a means to boost agricultural yield while safeguarding environmental integrity as proposed by Pretty et al. (2011), aligning with discussions that favour labour subsidies instead of subsidies for fertilizers and machinery to encourage more sustainable and labour-intensive agricultural practices.

The concern over large-scale farming projects displacing smallholder farmers and impacting their employment prospects underlines the broader issue of how alterations in land access influence food security and job opportunities in rural areas. The fear of losing livelihoods to major agricultural projects accentuates the critical need for policies that ensure a fair allocation of resources and opportunities.

Overall, the insights from the focus group discussions advocate for a comprehensive strategy towards food security in Northeast Nigeria, focusing on supporting small-scale farmers, promoting sustainable agricultural practices, and expanding income sources. This strategy requires a careful navigation of local conditions and economic challenges faced by communities, with policies aimed at addressing the decline in biodiversity and changes in land utilization at their heart.

Table 4. 5. Effectiveness of APP food security thrusts for Income support for poor households

Scale of effectiveness	Number of groups										
	Fortification of food crops	Creating balance diet awareness	Strategic national food reserve	School feeding programme	Use of agrochemicals and tractors	Forest conservation and foods harvest	Encouraging organic farming	Supporting small farmers	Supporting large scale and specialised farming	Promoting commercial seeds	Allocation of 10% of Nigerian land for grazing
1	0	0	3	2	1	0	0	0	4	3	4
2	3	4	1	0	5	1	0	0	1	2	2
3	2	2	2	4	0	2	0	1	1	1	0
4	1	0	0	0	0	1	5	2	0	0	0
5	0	0	0	0	0	2	1	3	0	0	0
Mean score	**2.7**	**2.3**	**1.8**	**2.3**	**1.8**	**3**	**4.2**	**4.3**	**1.5**	**1.7**	**1.3**

For income support for poor households, 5, 6, and 6 groups indicated that forest conservation and food harvest with a mean score of 3.7, encouraging organic farming (4.2), and supporting small-scale farmers with credits and labour subsidies (4.3), respectively, as effective policy thrusts. The results presented in Table 4.5 show that 2, 1, and 3 groups considered forest conservation and food harvest, encouraging organic farming, and supporting small-scale farmers with credits and labour subsidies very effective. However, 3, 4, 3 and 4 groups indicated national strategic food reserve, supporting large and specialized farming, promotion of commercial seeds and allocation of 10% of Nigerian land for grazing respectively, as very ineffective policy thrusts for income support for poor households.

Fortification of crops gives farmers a new variety to produce which leads to an increase in the demand for the crops. There are fortified crops like the Vitamin A cassava, maize and Orange-Fleshed Sweet Potato available in Nigeria (Oteh et al., 2023) They generally agreed that money realised from the sale of forest products has mostly been a means of sustenance for the poor households. It was clear from the discussion that many households in the Northeast part of Nigeria who are poor depend heavily on the income from food harvested from the forest. Wild fishing from the rivers in the community, harvesting of wild fruits, nuts, oils, vegetables, and animal hunting has sustained many households.

It was clear from the discussions that labour costs constitute the largest expenditure of the small-scale farmers and subsidizing it will impact positively on their output and income. So, encouraging organic farming and supporting smallholder farmers with a labour subsidy will reduce the cost of production for the farmers, and increase profit and self-reliance for them. Poor farmers will benefit when they spend very little on farm inputs and are able to use their labour and access extra labour when they need it. The discussants clearly mentioned that farming is a very tedious work with a lot of danger. They generally highlighted that modern technology is meant to reduce the problems of farming and to produce food at minimum risk of injury, and bites from poisonous snakes and insects. However, they consistently argued that you can only think about protecting yourself from these dangers when you are not hungry. The small-scale farmers need to feed their households from the resources available to them, in most cases, this is their labour and may be their land. This is brought out by the following statements from some of the participants:

….Many households depend solely on the income from harvesting forest products like wild fish, vegetables, fruits, seeds, and animals for their livelihood. … . Without the forest, so many wouldn't be able to survive. – Male farmer and fisherman, 46 years old.

The sales from the forest have sustained many homes in our community. Many of them depend solely on the income from harvesting forest product like wild fish, vegetables, fruits, seeds, and animals for their livelihood. I have a neighbour that depends on ogbono, achi and other forest products to train their sons in school. Without the forest so many wouldn't be able to survive. – Female farmer, 31 years old.

It is not as if we do not want to look good and have smooth skin, but what befalls us is more than we can bear and still be thinking of competing with those in townships for smooth skin. I like my nails painted in different colours, my mouth shining with lipstick. I want to work in the office far from snakes and scorpions. But you know what, you need to feed first before checking the skin and its pains. I still choose to go to the farm than beg or die in hunger. Female rice farmer, 34 years Old.

Yes, organic farming will make poor farmers who already lack money for the ever-improving seed and chemicals spend less money. They will not spend their money on chemicals and can use up their unemployed labour to make money. However, if these things, I mean fertilizers, herbicides and all those improved things are free, then I would not mind using them. - Male farmer, 43 years old.

The discussions reflect a nuanced perspective from the groups on the effectiveness of different food security and income support measures in Northeast Nigeria. The discussion surrounding food security in Northeast Nigeria, as reflected in the selected text and the results presented in Table 4.5, opens a complex landscape where socio-economic, ecological, and political factors intersect. This analysis aims to deepen the understanding of the issues at hand, particularly focusing on the role of wild foods, forest products, and the implications of various agricultural practices and policies.

The prioritization of organic farming and support for small-scale farmers over the promotion of commercial seeds and land allocation for grazing illustrates the preference of the community for sustainable, accessible, and inclusive agricultural practices. This preference is grounded in the realities of the local socio-economic and environmental context. The emphasis on organic farming and supporting small-scale farmers suggests a community-oriented approach that values ecological sustainability and resilience. This is particularly relevant in a region where agriculture plays a crucial role in livelihoods but is threatened by various challenges, including climate change, land degradation, and socio-political instability.

The reliance on wild foods and forest products underscores a critical coping strategy for many households in Northeast Nigeria, particularly in the face of crop failure and during the lean period. This reliance is shaped by changing land access and food preferences, which are themselves influenced by broader socio-political and environmental contexts. The mention of "power and politics of forest sales and government restrictions" hints at the complexity of forest access, which can significantly affect the availability of these crucial resources. Such dynamics are not static; they evolve over time, influenced by policies, land use changes, and socio-economic pressures. Literature on traditional ecological knowledge and food systems in similar contexts suggests that changes in land access and use can lead to alterations in the availability and types of wild foods, impacting local food security and dietary diversity (Bharucha & Pretty, 2010; Fernández-Llamazares et al., 2021; Fernández-Llamazares & Cabeza, 2018). This reliance not only reflects the importance of biodiversity and ecosystem services but also highlights the need for policies that balance conservation efforts with local livelihoods and food needs. The intersection of conservation and livelihoods highlights a complex relationship that requires policies to align with the goals of environmental sustainability, food security, and economic resilience (Sunderland, 2011).

The effectiveness of various policy thrusts for income support, as highlighted in the discussion, provides an interesting insight into local perceptions of agricultural and conservation strategies. Policies encouraging organic farming and supporting small-scale farmers with credits and labour subsidies were seen as effective, with mean scores of 4.2 and 4.3, respectively. These policies resonate with the broader discourse on sustainable agriculture, which emphasizes reducing external inputs, enhancing ecological benefits, and supporting local livelihoods (Altieri, 2002; Pretty, 2008).

The ineffectiveness perceived in strategies like promoting commercial seeds and allocating land for grazing highlights concerns around the suitability of these approaches for smallholder farmers, who often lack the resources to invest in commercial agriculture or are adversely affected by land allocation policies that may prioritize large-scale agriculture over smallholder and community needs. Such perspectives are supported by literature that emphasizes the importance of agroecological approaches and community-based resource management for enhancing food security and resilience in the face of environmental and economic challenges (Altieri & Toledo, 2011; Pretty, 2008).

The discussion above highlights a crucial tension in small-scale farming concerning the need to balance labour intensity and costs with the potential benefits of modern agricultural technology. While technology is seen as a means to reduce the "problems of farming" and minimize risks, its accessibility and applicability for smallholders remain challenging. The emphasis on labour costs and subsidies points to the significant burden of manual labour on small-scale farmers, suggesting that interventions aimed at reducing these costs could have a substantial impact on productivity and livelihoods. This aligns with findings from the literature that stress the importance of labour-saving technologies and practices in enhancing smallholder productivity and food security. (Beuchelt & Badstue, 2013; Kassie et al., 2010; Koppmair et al., 2017)

4.2.5. Soil health improvement

A healthy soil will produce healthy foods, enhance biodiversity and ecosystem services for a healthy society. The FAO (2015) highlighted that many soils used for food production are already degraded. Therefore, food security policies should aim to ensure food security while also promoting the health of agroecosystems and combating soil degradation. The discussants suggested the use of organic fertilizers like animal dung and crop wastes, mulching, crop rotations, fallow systems, cover crops, and the use of less invasive agriculture to reduce the disruption of the soil organism activities to improve soil health. The discussions frequently highlighted the importance of organic manure in sustaining the microorganisms and their activities, and beneficial weeds and insects in the farm. Leaving farmland fallow and regulating forest timber and non-timber harvest were considered by the discussants as a means of improving soil quality. The use of agrochemicals was generally thought to be unsuitable for biodiversity and will harm soil organisms. Gunstone et al. (2021) found that all type of pesticides is harmful to soil organisms. The discussions emphasised that agrochemicals have reduced the number of beneficial ants, wild plants and even earthworms. So, soil organisms should form part of the focus when assessing the risk of any agrochemical. Healthy soils will also provide more benefits to poor households who depend on these lands for survival.

To improve soil health, which looks at the quality of soil, the discussants agreed that focusing on forest conservation and food harvesting will positively improve the knowledge of the importance of forest to our life. Leaving the farmland fallow and reducing the deforestation of communal forests will greatly improve the soil quality and increase the benefits poor households can derive from the land. Supporting smallholder farmers, and encouraging organic farming, were said to be a very effective policy thrust towards the achievement of good soil health. The discussants argued that tractors are not commonly used by these smallholder farmers, so there will be more vegetative cover from trees and the leaves left in the soil, and the roots of the trees will help hold the soil together. They also frequently mentioned that the use of manual labour means there will be more care for the soil.

Table 4. 6. Effectiveness of APP food security thrusts for Soil health improvement

Scale of effectiveness	**Number of groups**										
	Fortification of food crops	Creating balance diet awareness	Strategic national food reserve	School feeding programme	Use of agrochemicals and tractors	Forest conservation and foods harvest	Encourage organic farming	Supporting small farmer	Supporting large scale and specialised farming	Promoting commercial seeds	Allocation of 10% of Nigerian land for grazing
1	2	0	3	5	2	0	0	0	1	4	3
2	4	4	2	0	3	1	0	1	4	2	2
3	0	2	1	1	1	2	0	1	1	0	1
4	0	0	0	0	0	1	3	4	0	0	0
5	0	0	0	0	0	2	3	0	0	0	0
Mean score	**1.7**	**2.3**	**1.7**	**1.3**	**2**	**3.7**	**4.5**	**3.5**	**2**	**1.3**	**1.7**

For soil health improvement, results in Table 4.6 show that forest conservation and food harvest with a mean score of 3.7, encouraging organic farming (4.5), and supporting small scale farmer (3.5) respectively were thought to be effective policy thrusts. Forest conservation and food harvest and encouraging organic farming were considered by 2 and 3 groups respectively as very effective policy thrusts for soil health improvement. The policy thrusts that were placed on the scale of 1- very ineffective for soil health by 3 or more groups out of the 6 focus groups involved in the study were a strategic national food reserve (3 groups), school feeding (5 groups), promoting commercial seeds (4 groups) and allocation of 10% of Nigerian lands for grazing (3 groups). The following statements from the focus groups participants bear this out:

Organic farming gives the living organisms in the soil the time to follow a natural process of rebuilding itself. It is protective of the earthworms, crickets and other insects that live under the soil's surface. When you touch a good soil, you will feel the spaces for air, and it breathes. A soil with high organic manure is always dark and doesn't stick together like gum. You can even smell the life in it. Soils that are not polluted with chemicals do not grow bad weeds even. … . *what else does a farmer need to produce food*. – Female farmer, 56 years old.

Unless the Government will give us fertilizers free and enough every year, organic farming will save many from going hungry and becoming destitute. Though it takes time, it will save the soil. – Male farmer, 23 years old.

It is obvious why we still use chemicals even when we know they are bad. It is cheaper than labour and faster in giving results… . As we are reducing the labour needed in the farm, we have succeeded in reducing the honey in the forest, … even made our soil dependent on agrochemicals to produce food, and this is not going to last. It costs more. Now without the chemicals some of the lands will give you nothing, so you spend and spend. Each subsequent year is worse. – Male farmer, 44 years old.

It is evident from the discussion that soil health emerges as a critical foundation for sustainable food security. The results emphasize the importance of organic farming practices, forest conservation, and the reduction of agrochemical use as key strategies. This stance aligns closely with the concerns raised by the Food and Agriculture Organization (FAO) in 2015 about the widespread degradation of soils crucial for food production, thereby underscoring the urgency of integrating soil health into food security policies.

The advocacy for adopting less invasive agricultural practices- emphasizing organic fertilizers, mulching, crop rotation, fallow systems, cover crops, and a general reduction in agrochemical use- reflects an ecological sensibility geared towards nurturing biodiversity and ecosystem services. This approach aligns with the observations of Gunstone et al. (2021), who noted the detrimental impacts of pesticides on soil organisms, highlighting the importance of ecological considerations in farming practices that foster soil biodiversity and health, thereby enhancing the resilience of food production systems.

Supporting smallholder farmers through the encouragement of organic farming and minimal use of heavy machinery like tractors to avoid soil compaction is important. This approach, which benefits soil health and supports the livelihoods of poor households that are dependent on these lands, also aligns with the observation of Gunstone et al. (2021) observations on the negative effects of agrochemicals and mechanized farming on soil organisms and structure.

The discussion further highlights the critical role of forest conservation and reduced deforestation in preventing soil erosion and maintaining soil fertility, as corroborated by Reed et al. (2014), and Reganold and Wachter (2016). These practices, alongside the emphasis on organic farming methods, support soil biodiversity and structure, contributing significantly to soil health and food security.

However, the strategies and discussions must be contextualized within the unique socio-economic and environmental challenges of Northeast Nigeria. This region, marked by conflicts and climatic stresses, demands agricultural and food security policies that can navigate the challenges of restoring degraded land while sustaining vulnerable populations. The climatic challenges faced by Northern Nigeria, characterized by a Sahelian climate with susceptibility to drought and erratic rainfall patterns, underscore the urgency for adaptive and sustainable agricultural practices to mitigate these vulnerabilities

(Mailumo et al., 2022; Olasantan, 1992; Zhang et al., 2018). The emphasis on increasing rainfall unpredictability by Ayanlade and Drake (2016) further accentuates the critical need for resilience in farming methods. In this context, the results indicating the effectiveness of forest conservation, food harvest, and particularly the encouragement of organic farming, as effective policy thrusts for soil health improvement, resonate strongly with the need for sustainable agriculture practices. Organic farming, as highlighted by the focus group participants, not only fosters a healthier soil ecosystem crucial for the Sahelian region's unpredictable climate, but also enhances soil fertility and productivity in the long term. The integration of forest conservation and promotion of fallow practices reflect a deep understanding, by the participants, of the interplay between ecological health and human well-being.

In summary, the sum of groups that indicated moderately effective, effective, and very effective are presented in Table 4. 7 to show the number of groups that considered a policy thrust effective. Two food security thrusts were considered completely ineffective for all the sustainable food system goals by the participants. The discussants generally mentioned that these two policy thrusts- promoting commercial seed and allocation of 10% of Nigerian land for cattle grazing will contribute very little, or nothing to environmental sustainability and the livelihood of the poor farmers. Creating a balanced diet awareness is effective for access to, and availability of, diversity of foods, and improved biodiversity and environmental benefits. A strategic national food reserve is effective in achieving food price stability and biodiversity. School feeding programmes designed to provide primary school children one meal per school day are effective for income support for poor households. Supporting large scale and specialised farming and increasing food production using agrochemicals and tractors are effective for food price stability. Supporting small farmers, mixed farming and mixed cropping systems are effective for all studied food system goals, except food price stability. Increased focus on forest conservation and foods harvest and encouraging organic farming are effective for all the six sustainable food system goals studied.

Table 4. 7. Distribution of Focus Groups Findings by Effective APP Policy Thrusts

Policy Thrusts	**Number of Groups**					
	Price Stability	**Access and availability of diversity of foods**	**Biodiversity**	**Employment for farmers**	**Soil health**	**Income support for poor households**
Fortification of food crops	0	0	1	1	0	**3***
Creating balance diet awareness	0	**5***	**5***	**4***	2	2
Strategic national food reserve	**6***	1	**6***	1	1	2
School feeding	2	0	0	0	1	**4***
Increasing food production using agrochemicals and tractors	**3***	1	0	0	1	0
Increase focus on Forest conservation and foods harvest	**4***	**6***	**6***	**6***	**5***	**5***
Encouraging organic farming	**6***	**6***	**6***	**6***	**6***	**6***
Supporting small farmers mixed farming/cropping system	2	**6***	**6***	**6***	**5***	**6***
Supporting large scale and specialised farming	**6***	0	0	2	1	1
Promoting commercial seeds	0	0	0	0	0	1
Allocation of 10% of Nigerian land for grazing	0	0	0	0	1	0

*Effective policy for sustainable goal

Ball, Hargreaves, and Watson (2018) in agreement with the opinion of the discussants noted that agroecological farming systems can produce as much food as conventional systems in addition to promoting environmental sustainability and a healthy population. The argument has been between producing more food for the ever-growing population using the conventional farming system and producing food in agroecological farming systems which support environmental sustainability. There is also the problem of supporting large scale farming systems as against the small-scale farming that is prevalent in developing countries. However, Ball et al., (2018) argued that agroecological farming systems which take care of the soil are two to four time more energy efficient than conventional systems. Sustainable intensification is also an approach being considered. In the quest for commercialisation of food production, scaling up of production, and maximizing profit or output from a given space. Thus, there is need to think about biodiversity and environmental sustainability as well as the entitlements needed to access food by the poor. It is important that the food system strengthens the ability of the poor and food insecure households to be able to access food.

The discussion on the effectiveness of Agricultural Policy Program (APP) policy thrusts in enhancing food security in Northeast Nigeria, as presented in Table 4.7, indicates that promoting commercial seeds from seed industry, and allocating 10% of Nigerian land for cattle grazing were considered completely ineffective for all sustainable food system goals by the participants. This reflects concerns about the compatibility of such policies with environmental sustainability and the livelihoods of poor farmers. The scepticism towards these policy thrusts aligns with the broader critique within the literature on the risks of commercialized agriculture (M. A. Altieri, 2018; Tscharntke, Clough, et al., 2012).

Creating balanced diet awareness and establishing strategic national food reserves were identified as effective for improving food diversity, price stability, and biodiversity. This underscores the importance of, not just food availability, but also food quality and stability in prices as essential components of food security (FAO, 2018). These findings resonate with the literature that highlights the role of diet diversity in nutritional outcomes and the stabilizing effect of food reserves on prices (Headey & Ecker, 2013). School feeding programmes were noted for their effectiveness in providing income support for poor households, emphasizing the multifaceted benefits of such initiatives, including educational, nutritional, and economic impacts. The effectiveness of School feeding programme is supported by the literature, which suggests that school meals can boost school attendance, improve nutritional status, and have a positive economic impact on communities like (Bundy et al., 2024; P Bundy Nilanthi de Silva Susan Horton Dean T Jamison George C Patton et al., 2018)).

Encouraging organic farming and supporting small farmers, mixed farming, and cropping systems were highlighted as effective across all studied food system goals except food price stability. The emphasis on organic farming and small-scale agriculture underscores their potential to improve soil health, biodiversity, and food access, aligning with the literature that posits these practices as sustainable pathways to achieving food security (Ball et al., 2018).

Increased focus on forest conservation and sustainable food harvesting was identified as effective for all six sustainable food system goals, emphasizing the critical role of ecosystems in supporting food security, biodiversity, and livelihoods. This perspective is supported by research advocating for the conservation of natural habitats as vital for sustainable agricultural practices and food systems (Chazdon et al., 2016).

The outcomes from the discussion point towards a preference for policies that support ecological sustainability, soil health, and the livelihoods of smallholder farmers over those that promote commercialization and monoculture practices (Chazdon et al., 2016). These findings suggest a need for Nigerian policymakers to prioritize organic farming, credit, and labour subsidies for smallholder farmers, healthy diet awareness, and forest conservation to achieve comprehensive food security and environmental sustainability. The analysis underscores the importance of integrating indigenous knowledge, supporting small-scale agriculture, and ensuring environmental conservation within the agricultural policy framework to address the unique challenges of food security in Northeast Nigeria. The emphasis on agroecological practices over conventional agricultural systems offers a path towards sustainable intensification (a process of increasing agricultural productivity on existing farmland while minimizing environmental impacts and preserving resources for future generations), balancing the need for increased food production with environmental sustainability and social equity.

4.3. Conclusion and Recommendation on the Effectiveness of APP Policy Thrust

The outcome of these discussions, as summarized in Table 4.7, is important for shaping the Nigerian food system. Though the APP thrusts are geared towards achieving sustainable development, Nigerian policy makers should focus more on encouraging organic farming, credit provision, labour subsidies to support smallholder farmers, forest conservation and food harvesting to achieve food security, environmental sustainability, and employment. They should also focus on creating balanced diet awarenesss amongst the population.

It is clear from the discussion that most of the farmers survive on their labour and food from forest and their farms. They are poor but are still able to eat food from their farms. Having access to land and being able to depend on their indigenous knowledge, previously stored seeds, the forest, and labour for food and wellbeing is paramount to their survival. The shift to commercialization of farms and commoditization of food may not favour the majority of Nigerian farmers. These farmers are mostly poor and not educated and may not be able to take advantage of the new opportunities presented in commercial farming. These farmers have very small farm sizes and may not be able to buy more land or get support from financial institutions. The probability of losing their small lands which they depend on in the face of this policy push for large farm sizes to accommodate commercialized farms is high. Hence, food insecurity in this area might be worsened by lack of entitlement resulting from farmers losing their lands, not being able to compete with rich farmers, unemployment, and deforestation that will come with large scale farming.

By subsidizing inputs cost for the large farms, agricultural policies depress food prices and income of small farmers. This support will favour the production and consumption of a few types of crops. So, the changing eating habit which may have contributed to the rise in non-communicable disease may be the emergence from the interventions in the food system over the years. If policies continue to support the mass production and consumption of a limited variety of foods, without giving indigenous food diversity a chance on farms, both human health and the natural environment will suffer increasingly negative consequences.

The concern raised by the participants on conservating the forests should be considered diligently. There is need to balance forest conservation for the good of biodiversity and the livelihoods of those who depend on the forest. Community-based forest management might be a good way to bring about the balance needed. Food diversity, biodiversity, soil health, increased employment and income support for the households will benefit from the provision of credit and labour subsidies, organic farming, forest conservation and sustainable food harvesting.

Chapter 5: Household Food System Survey Results and Discussions

A field survey was carried out on households' socioeconomic characteristics, farming activities, forest food harvesting and food security in Northeast Nigeria. A questionnaire was used in collecting primary data face-to-face from 375 households. The data collection process was interrupted by the COVID 19 restriction which had effect on movement in Nigeria around the first week of April 2020. The data was collected between 10th of March and the first week of April 2020. Due to COVID 19 restrictions, only 375 households out of the 400 households originally proposed were covered.

5. 1. Household demographic and food security survey results and discussions

The results presented in Table 5.1 summarises the socioeconomic characteristics of the households. The household is a very important social unit for farm decision making, sourcing food, food preparation and consumption. Hence, the household is an important unit for food system and food security studies. The socioeconomic characteristics covered in the study were: gender; marital status; educational qualifications; occupation, age; household size; and presence of children within the household below the age of 18 years. In addition, the survey captured data in relation to their food sources, income and expenditure of the households. Further analysis on how these factors contribute to food security were explored in Chapter 6.

Table 5. 2. Socioeconomic Profile of Households in Study Area of Northeast Nigeria 2020

Socioeconomic Characteristics	Freq	%	Min	Mean	Max	SD
Gender of the Household (HH) Head						
Male	306	81.6				
Female	69	18.4				
HH with children below 18	258	68.8				
HH size			1	8.25	30	4.91
Number of persons employed in a HH			0	1.19	9	1.57
HH Dependency ratio	185	49.3	0	3.18	18	3.36
HH without employed member HH size	190	50.7	1	8.76	27	5.49
HH with employed member HH size	185	49.3	1	7.69	30	4.17
Marital Status of the HH head						
Married	293	78.1				
Single	25	6.7				
separated/divorced	57	15.2				
Age			25	50.57	82	12.87
Highest educational qualification in HH						
No education	74	19.7				
First School living	34	9.1				
O level	93	24.8				
NCE/OND	94	25.1				
First degree/HND	64	17.1				
Postgraduate degree	16	4.3				
HH head formal education in years			0	10.56	18	6.046
HH head Primary occupation						
Civil servant	80	21.3				
Farmer	219	58.4				
private sector employed	9	2.4				
Trader	48	12.8				
Artisan	4	1.1				

students/unemployed	15	4				

Table 5. 1 Socioeconomic Profile of Study Households in Study Area of Northeast Nigeria (continued)

Socioeconomic Characteristics	Freq	%	Min	Mean	Max	SD
HH head Secondary occupation						
Civil servant	86	23				
Farmer	151	40.3				
private sector employed	15	4.0				
Trader	79	21.1				
Artisan	21	5.6				
students/unemployed	23	6.1				
Years of farming experience			0	22.39	60	12.98
Primary source of food						
Borrowed, bartered, exchanged for labour, gift from friends or relatives	24	6.4				
Own production, gathering, hunting, fishing	218	58.1				
Purchased	133	35.5				
Cost of planting materials/year			0	73063.73	1500000	156880.8
Farm income/year			0	982773.6	6800000	1393346.4
HH income/month			0	149824.64	570400	184608.3
HH total expenditure/month			3000	56236.56	540000	72445.27
HH Food expenditure /month			1000	37746.19	340000	45711.04

The results in Table 5.1 reveal that 81.6% of the households were male headed, with 78.1% of household heads being married. Additionally, 68.8% of the 375 households had children under 18, who are considered dependents and as a result increase household expenditure. The mean household size was 8.25 (SD 4.91), and on average, 1.19 persons were employed per household. The job dependency ratio, calculated by dividing the number of non-working members by the number of working members, showed that 190 households had no employed members, while 185 had at least one employed member. Households with employed members had a mean dependency ratio of 3.2 (SD 3.33), with working members supporting between 0 and 18 persons. In contrast, households without employed members had a household size ranging from 1 to 27 persons, with a mean size of 8.8 (SD 5.49), higher than the 7.7 mean size (1-30 persons) of households with employed members. The average age of household heads was 50.57 years, with ages ranging from 25 to 82 years.

The result of household members highest educational qualification showed that most of the households had member(s) with NCE/OND (Nigerian certificate of education/ ordinary national diploma) (25.1%). This was closely followed by those with O level certificates (24.8%). Notably, 19.7 % of the households did not have any member with any educational qualification. However, 4.3% of the households had a member with a postgraduate degree. The result on the number of years the household head had spent in formal education showed a minimum of zero and a maximum of 18 years. The mean years of formal education for the household heads was 10.56 years. Like the highest educational qualification result, 19.6% of the household heads had zero year of formal education.

When the occupation of the household heads was assessed, the results showed that a greater proportion of the household heads were primarily farmers (58.4%), civil servants (21.3%), and few artisans (4%). Greater proportion of the household heads that had secondary occupation did farming (40.3%) and worked as civil servant (23%).

The mean farming experience of the households in the study area was 22.39 years. Some of the household heads had no farming experience. The households had a maximum of 60 years farming experience. Being a farming community, a greater proportion of the households indicated that their main source of food is their farms and harvest form the wild (58.1%). About 36% of the households depended mainly on purchase for their consumption. There were still people who got food mainly by borrowing, bartering, exchange for labour, gift from friends or relatives (6.4%).

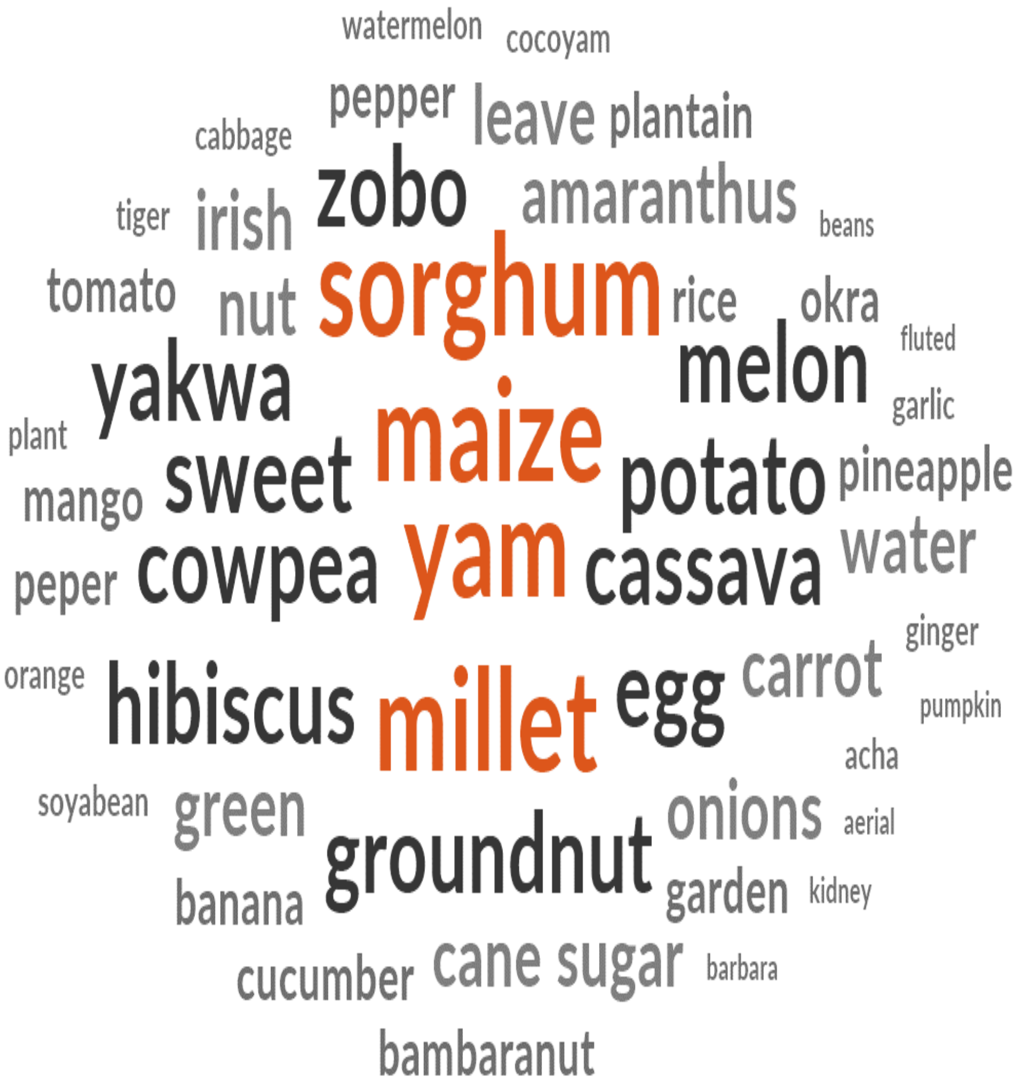


Figure 5. 1. Crops Planted in the Study Area

The results presented in Figure 5.1 showed that farmers in the study area planted 47 different kinds of plants for food and for sale. This result shows the crop produced by the households and the four most planted crops are in the middle of the figure in red fonts. The main crops produced in this area was sorghum, maize, yam, and millet. Some of the farmers indicated that they planted cassava, yam, maize, melon, pepper, tomatoes, cocoyam, and ariel yam in the same plot of land. Some were planted together in the same soil heaps. Some mounds had only two or three crops and some had up to five different crops depending on the location of the mounds in the farm.

Figure 5. 2.: Soil Mounds for Planting Cassava and other Crop Mix

Figure 5 3 : Soil Mounds for Planting Yam

Table 5. 3. Farm Practices of the Study Households

Farm Practice	Frequency	percentage
Non-farmers	8	2.1
Farm types		
Crop farming	105	28
livestock farming	52	14
mixed farming	210	56
Crop farming system practiced		
mixed cropping	269	85
monocropping	46	15
Main source of your planting materials		
None	10	2.7
own stored from previous harvest	194	51.7
seedling from breeding companies	20	5.3
buy from neighbours or farmer in local market	151	40.3
* Crops produced		
Vegetables and fruits	16	4.3
Ornamental plants	2	0.5
Plantation plants	10	2.7
Food crops	299	79.7
Cash crops	110	29.3
*Under-utilised crops		
Ogbono	6	1.6
Yam bean/ariel yam	9	2.4
Fio fio (cajanus cajan)	0	0
Cocoyam	232	62

*Multiple response

The results presented in Table 5.2 showed that 56% of the farm households practiced mixed farming, followed by crop farming (28%) and livestock farming (13.9%). The results showed that about 98% of the households were involved in farming. Those involved in mixed farming systems kept both livestock and crops. Crop farmers indicated in this study kept no farm animals. The livestock farmers which include the cattle herders, and other livestock farmers that kept sheep, goats, pigs, poultry, grass-cutters, snails and other livestock, did not do crop farming. When the cropping system was further explored, the results showed that a greater proportion of the crop farmers practiced mixed cropping (85%). Those involved in monocropping constituted only 15% of the crop and mixed farmers.

The study assessed the types of crops produced in this area. The results presented in Table 5.2 showed that 79.7% of the farmers produced food crops which help to supply their family's food. This was followed by cash crops producers (29%). These cash crops, benniseed, groundnut, soybeans, and sugar cane, are crops produced mainly as a source of income. About 3% of the households produced plantation crops like palm, mango, and bush mango. Very few households were involved in ornamental plants (0.5%).

The main source of planting materials like seeds and stems was assessed. The result showed that most of the farmers got their planting stock from their own preserved previous harvest (51.7%). Many of the farmers bought their planting materials from neighbours or farmers in their local markets (40.3%). Few of the farmers patronised the seed and breeding companies (5.3%).

Farming of some neglected and underutilized crops were assessed. The result showed that there were still many farmers planting cocoyam in the study area (61.9%). Although pigeon pea (*Cajanus cajan*) is widely consumed in Nigeria, none of the study farmers planted it. More than 2% of the households still planted aerial yam on their farms. Planting of these underutilized crops would be important for food and nutritional security and biodiversity.

5.2 Household Farm Size and Labour

As shown in Table 5.3, households in this area owned small parcels of land mostly measured in plots (50ftx100ft). The households owned a mean of 12.07 such plots of land. This includes households that had no land and those that had up to 1000 plots of land. The study also looked at the sizes of cultivated lands by the households over three years, 2017, 2018, 2019. The farmers cultivated a mean of 6.81 plots in 2017, 6.69 plots in 2018 and 6.75 plots in 2019. The maximum number of plots cultivated by the farmers in 2017, 2018, and 2019 were 90, 85, and 100 plots, respectively.

The number of animals kept by livestock farmers involved in the production of pigs, cattle, poultry, sheep and goats was recorded. Some households were involved in bee keeping for honey production. The results presented in Table 5.3 showed that pig farmers kept a maximum of 940 pigs and a mean of 25 pigs. Cattle farmers kept a maximum of 3200 cattle and a mean of 78.6 cattle. Those involved in poultry production which includes chicken, quail, guinea fowl, turkey and ostrich, kept maximum of 1020 birds and a mean of 61.47. The households that kept sheep and goats had a maximum of 800 animals and a mean of 28.64. Beekeepers had a maximum of 3 beehives.

Table 5. 4. Land Size and Livestock Farming

Land and Livestock Variables	Min	Max	Mean	SD
Total farmland owned by the household in plots	0	1000	12.07	56.191
Distance between home and closest farm in KM	0	50	9.21	7.503
Number of crop plots farmed in 2019 (50ft x 100ft)	0	100	6.75	11.265
Number of farm plots on 2018	0	85	6.69	10.713
Number of crops plots on 2017	0	90	6.81	11.362
Number of pigs on the farm	0	940	25.12	119.34
Number of cattle on the farm	0	3200	78.6	321.744
Number of poultry on the farm	0	1020	61.47	130.631
Number of sheep and Goat on the farm	0	800	28.64	85.556
Number of beehives do you keep	0	3	0.02	0.22

The study looked at the different activities carried out on the farm and the labour needed to carry out these activities. The cost of doing each of these activities were captured in Naira/person day. The farm size was measured in plots as this was the most common measure of land in Nigeria, and the labour was measure in person days because farm labourers were mostly paid a daily pay rate. The result showed that from clearing to harvesting the farmers needed a mean of 13.5 person days/plot/year. A minimum of 3 person days and a maximum of 31 persons days were needed by farmers to farm a plot of land. The labour needed for clearing a plot of land was between 1 and 5 person days. Clearing requires a mean of 2.73 person days. The cost of hiring labour for clearing was between ₦700 and ₦2000/person/day. This variation in labour cost mainly reflected the location of the farms. Farms in the urban areas paid more for labour than the ones in the rural areas. The mean cost of hiring labour for clearing was ₦1027.24/person. To till the soil, farmers required the minimum of 1 and maximum of 3-person days. The mean of 1.48 person days was required for tilling. To hire labour for tilling, farmers paid between ₦1000 and ₦2600/person day. They paid the mean of ₦1712.38 to hire labour for tilling. It took between 1 and 6 persons to plant a plot of land. Labour for planting had a mean of 3.66 persons day. The labour cost for planting ranges from ₦1000 to ₦2000/person day. The mean cost of hiring labour for planting was about ₦1435/person day (see Table 5.4).

Table 5. 5. Farm Activities and Cost of Labour for Different Farming Activities of the Study Household Farms

Labour Variables	**Freq**	**%**	**Min**	**Mean**	**Max**	**Std**
Labour person day/plot/year			3	13.5	31	3.167
Clearing labour			1	2.73	5	0.93
Clearing cost			700	1027.24	2000	298.44
Tilling labour			1	1.48	3	0.55
Tilling cost			1000	1712.38	2600	303.55
Planting Labour			1	3.66	6	0.92
Planting cost			1000	1435.29	2000	345.86
Weeding labour			1	3.31	4	0.68
Weeding cost			1500	1839.94	2500	294.43
Harvest labour			1	7.02	22	3.74
Harvesting cost			1500	1731.58	2100	273.9
**Sources of your labour* (see note)*						
Family members	274	73.1				
Voluntary service	59	15.7				
Hired labour	250	66.7				
Availability of farm labour						
Rarely	53	14.1				
Always	139	37.1				
Often	170	45.3				
Main source of farm power						
Animal traction	67	17.9				
Manual labour	195	52.0				
Tractors machines	3	0.8				
Tractors machines and manual labour	96	25.6				
Production system used by the farmers	12	3.2				
Complete manual handling	308	82.1				
Semi-automated	55	14.7				

*Multiple response (respondent could select more than one answer)

Weeding required between 1 and 4 person days/plot and a mean of 3.66 person days. The cost of hiring labourers for weeding was between ₦1500 and ₦2500/person day and a mean of about ₦1840/person day. When it comes to harvesting, the results presented in Table 5.4 showed that it takes between 1 and 22 person days to harvest a plot of land with mean of about 7 person days. The farmers paid a minimum of ₦1500 and a maximum of ₦2100 /person day for harvest. The mean amount paid for harvesting was ₦1731.58/person day.

When the sources of farm labour are examined, the results showed that the greater proportion of the farming households got their labour from their family members (73.1%). About 66.7% of the farmers used hired labour. Few farmers had voluntary labour (15.7%). These can be friends of the farmer or members of the community, who work for the farmer as help to ailing or bereaved farmers. The voluntary labour was given to the farmers by non-family members whose farm labour were not paid for. A greater proportion of the farmers indicated that farm labourers was often available (45.3%). About 37% of the farmers indicated that farm labour was always available.

When the sources of farm power were explored, the result showed that 52% of the farmers depended on manual labour for their farming. About 26% of the farmers used both tractors and manual labour. Those that used both animal traction and manual labour constituted 17.9% of the respondents. Only 0.8% of the farmers depended mainly on tractors and other farm machine. This result shows that most of the farming activities going on in this area were done manually. Hence, 82% of the farmers indicated that their farming activities were mainly done manually.

The study also explored the households' financial situations (see Table 5. 5). Households annual farm income, average monthly income from farm and off farm jobs, average monthly expenditure and household food expenditure per month data were assessed. The results showed that the households in the study earned between zero and ₦6,800,000/annum from their farms. This was measured by totalling the farm income of the previous season. The average farm income of the households was ₦982,773.6, with a standard deviation of ₦1,393,346.4. The monthly income of the household captured the average total farm and off-farm income of every household member in a month. The household income was calculated by totalling all members' income in a month less the tax paid. This was the disposable income available for the household. The result showed that households earned between zero and ₦570,400/month. The mean average monthly income of the household was ₦149,824.6, with standard deviation of 184,608.3. Household monthly expenditure was calculated by summing all spending of the household excluding investment spending and savings. The household average spending per month was between ₦3,000 and ₦540,000, with a mean of ₦56,236.50. When the food expenditure was assessed, the result showed that households spent a mean of ₦37,746.19/month on food purchase. This includes a minimum monthly food expenditure of ₦1,000/month and maximum food expenditure of ₦340,000/month. Even though some households earned nothing in a month, they still spent at least ₦3,000 for all household expenses including bills and fees, and ₦1,000 on food.

To understand the financial situations of these households, income percentiles were generated from the data to explore the disparities in the earnings and expenditures of the households. For ease of comparison to available national data, per capita income of the household was calculated. Per capita income and expenditure were calculated by dividing the income and expenditure by household size. The results presented in Table 5.5, show that the lowest 25% of the households earned less than ₦180,000/year from their farms and ₦28,000/month average household income per month. The lower 25% of the households spent less than ₦21,000/month and ₦15,000/month on all household expenditure and food, respectively. The upper 25% earned more than ₦1,087,000/year from their farms, ₦290,000/month as their household monthly income, and spent more than ₦50,000/month for the household expenditure and ₦37,250/month on food purchase. The interquartile range for the farm income was 910,250. The results in Table 5.5, shows that the average per capita income from the farm was ₦151,201.4/year. However, the income quantile distribution shows that the lowest 25% of the household earned less than ₦22,857.14/capita a year from their farms, and ₦4,300/capita as monthly income. The upper 25% had more than ₦173,333.3/capita from farms and ₦33,333.3/capita monthly income.

Table 5. 6. Household and Per Capita Income and Expenditures of Surveyed Households

Statistics		Farm income/year (₦)	Farm income per capita (₦)	Household income/month (₦)	Household income per capita (₦)	Household total expenditure/ month (₦)	Per capita household expenditure (₦)	Household Food expenditure /month (₦)	per capita food expenditure (₦)
Mean		1013306.93	151201.40	159717.97	25832.59	56236.56	8763.57	37746.19	5848.03
Std. Dev.		1393346	232702.3	184608.29	42227.43	72445.27	11556.64	45711.04	6919.54
Percentiles	25	180000	22857.14	28000	4300	21000	2653.85	15000	1875
	50	400000	60000	58000	10000	30000	4600	23000	3333.333
	75	1087000	173333.3	290000	33333.33	50000	9000	37250	6666.67

5.3 Household Socioeconomic Characteristics Results Discussion

Food security in Northeast Nigeria is significantly influenced by household socioeconomic characteristics such as gender, age, marital status, education, income and farming experience (Kemi et al., 2014; Omonona et al., 2007; Owoo, 2018). The predominance of male-headed households, which aligned with the national trend (Tsue, 2015), and the large household sizes common in the region, underscore a complex interplay between demographic factors and food provision capabilities. While larger household sizes could theoretically offer more labour for farming, the presence of dependents who contribute minimally to food production or income exacerbates vulnerability to food insecurity.

High unemployment rates compound the food security challenge, leaving many households without a steady income to support basic needs. There is a problem of high unemployment in Nigeria, and this applies to these farming communities also. Many large households in the study area had nobody in the household with a regular job to provide for the family. This lack of support for households without any working members has serious implications for household food and nutrition security. Those with employment also had the burden of taking care of other unemployed members of the households and some are taking care of up to 18 persons as seen in the dependency ratio in the presented results. The results on employed persons, dependency ratio and household size shed light on the high dependency ratio of these households, which might negatively impact the welfare of the households. The results agree with the findings of Ike, et al. (2017b), where 83% of the households in Taraba State had children below 18 years of age, and the average household size was 8.1 person. The results showed that most of the household heads were in the economic and physical active age where they can do physical work like farming and take up more income generating jobs to provide for their households. Though younger household heads are expected to work more and earn more, wealth can be argued to accumulate over a life cycle. So, households with older household heads have been found to be more food secure than the ones with younger heads (Ike, 2017b). The accumulated wealth tends to serve as an insurance against an economic downturn and other eventualities that may affect household food security.

It is important to consider the level of literacy of the household heads as well as the education of other household members as part of the socioeconomic characteristics of the household. Though the literacy of the household heads impacts on the welfare of the household, the education of other household members is also expected to impact on their access to information and other productive resources. Compared to the country adult (15+) literacy average (57.9% in 2010 and 62% in 2018) (Knoema, 2018), both the highest educational qualification of members and the number of years the household head spent in formal education show that the literacy level of people in this area is low. The low literacy level of the people in the study area is reflected in the finding that about 20% of the households have nobody with any form of educational qualification, and a mean year of education of about 10 years.

The agricultural sector, primarily comprising smallholder farming, stands as a critical but strained (unease) source of livelihood. Secondary occupations, and diverse income strategies, emerge as essential for household food security, highlighting the need for policies that support agricultural diversification and access to education (Mgbenka et al., 2015; Sabo et al., 2017). The low literacy levels in the region further limit access to information and opportunities for enhancing agricultural productivity and sustainability.

Land use governance in areas with land conflicts requires careful consideration, especially in the context of agriculture-based communities. The challenges posed by land conflicts, such as those arising from disputes between crop farmers and cattle herders, significantly affect agricultural productivity and sustainability. The governance of land use, therefore, plays a pivotal role in ensuring that agricultural practices are sustainable, conflicts are minimized, and land resources are used efficiently and equitably. This is crucial for maintaining biodiversity, managing grazing practices, and ensuring the security of both crop and livestock production systems against the backdrop of violent conflicts and insurgencies, such as those perpetrated by Boko Haram (Chukwuemeka et al., 2018).

This diversification of farming systems reflects the region's agricultural diversity crucial for mitigating risks associated with monoculture practices (Altieri & Nicholls, 2017). Central to this discussion is the adoption of mixed farming and cropping systems, which is not merely a reflection of traditional values but a strategic approach to enhancing biodiversity, food security, and environmental sustainability. The presence of mixed cropping among crop farms could contribute to dietary diversity and food security by providing a range of food crops throughout the year (M. A. Altieri & Nicholls, 2012) . Pretty et al. (2011) argue that mixed farming systems can enhance biodiversity, improve food security, and reduce environmental impacts. The substantial preference for mixed cropping over monocropping underscores the community's food traditional value and resilience strategy. This practice can reduce pest and disease outbreaks and stabilize yields, offering a buffer against food insecurity (Pretty et al., 2011). Mixed cropping, practiced by crop farmers also highlights an important strategy for optimizing land use and improving crop yields through synergistic plant interactions, a principle supported by (Tscharntke, Clough, et al., 2012) in his study on the ecological basis of intercropping. This diversified approach can enhance soil fertility through the incorporation of manure and reduce dependency on a single source of livelihood, thereby increasing resilience to market and climatic shocks (Herrero et al., 2010).

The reliance on the use of own stored seeds from previous harvests and purchases from local markets or neighbours highlights the importance of community-based seed sharing systems for sustaining agricultural biodiversity, as documented by (McGuire and Sperling, (2016a). The reliance on stored harvest for planting materials underscores the importance of seed sovereignty and traditional knowledge in agriculture, echoing sentiments of some researchers (McGuire & Sperling, 2016b, 2016c; Pautasso, 2015; Pautasso et al., 2013) regarding the role of farmer-managed seed systems in agricultural resilience.

The average landholding and cultivated land area per household in the study indicate that smallholder farming is the dominant practice, supporting the findings of researchers who note that smallholder farms play a critical role in global food security (Lowder et al., 2016; Mailumo et al., 2022; Sabo et al., 2017). The slight variation in the number of plots cultivated over three years suggest limited expansion capacity for farming households. This limitation underscores the importance of sustainable land management practices to enhance productivity without expanding the land under cultivation, as advocated by Pretty et al. (2011). The data on livestock - pigs, cattle, and poultry, reflect the diversity in livestock keeping, which is crucial for household nutrition and income diversification. According to (Herrero - et al. (2013), livestock is a vital asset for rural households, contributing to economic stability and dietary diversity. The significant variability in land and livestock holdings, however, points to disparities in resource access for farmers, which could affect food security outcomes, as argued by Barrett (2008) in discussions on the links between smallholder farming, food security, and the environment.

The reported labour days per plot per year and the associated costs reflect the intensive labour requirements of traditional farming practices. The considerable reliance on family members for farm labour illustrates the critical role of family in small-scale agriculture, a theme explored by Kassie et al., (2014) and Shiferaw et al. (2014)who argue that family labour is a cornerstone of resilience in smallholder farming. The relatively high costs of labour for tilling and harvesting suggest that labour inputs represent a significant expenditure for farmers, affecting their overall profitability and sustainability, as highlighted by Jayne et al. (2010) in their examination of the challenges facing African smallholder farmers.

Seasonal variability in agricultural production notably impacts farm labour intensity in Northeast Nigeria. The cyclical nature of agricultural activities means that labour requirements fluctuate throughout the year, with peak periods demanding increased labour for planting, weeding, and harvesting. This seasonality can exacerbate the challenges of high labour costs and the reliance on family labour, as families may need to hire additional labour during peak times, further straining their finances.

The analysis of household financial situations in this farming community reveals significant insights into income, expenditure, and food security dynamics. The findings illustrate a wide range of annual farm incomes, from zero to ₦6,800,000, with an average farm income of ₦982,773.6. This variability is further highlighted by the standard deviation in farm income of ₦1,393,346.4, suggesting considerable income disparities within the community. Monthly household incomes, incorporating both farm and off-farm sources, ranged from zero to ₦570,400, with an average of ₦149,824.6. Such disparities extend to household expenditures and food spending, reflecting the financial stratification among farming households.

The findings on income percentiles and per capita calculations provide a nuanced understanding of financial well-being among households. The lower 25% of households, for instance, earn less than ₦180,000 annually from farming and have a monthly household income of ₦28,000, spending less than ₦21,000 on household expenses and ₦15,000 on food. Conversely, the upper 25% of households have significantly higher earnings and expenditures, indicating a pronounced financial disparity within the community. This economic disparity is further evidenced by the household and per capita income quantiles which show that the upper 25% of households earn more than six times the farm income, and ten times the average monthly income compared to the lower 25%.

Moreover, the study reveals that a majority of households primarily source their food from their own farming activities, with a significant portion also relying on purchasing, borrowing, bartering, gifts, or aid. This reliance on self-produced food highlights the vulnerability of these households to disruptions in their farming activities, whether due to environmental challenges, security issues such as conflicts with herdsmen, Boko Haram insurgencies, or other factors.

The implications of these results are multifaceted. First, the significant income variability and disparity among households suggest that interventions aimed at improving household income and food security in farming communities must be nuanced and targeted, considering the specific needs of different income groups. Additionally, the reliance on self-produced food for the majority of households underscores the importance of stable and secure farming conditions for food security. Disruptions due to security issues or other external factors could significantly impact these households' ability to meet their food needs, exacerbating food insecurity.

In conclusion, our work reported this Chapter uncovered the intricate relationships between agricultural practices, land management, livestock integration, and labour dynamics, all of which are crucial determinants of food security in Northeast Nigeria. Central to this discourse is the recognition of mixed farming systems' pivotal role in ensuring agricultural adaptability and resilience. By integrating crop and livestock farming, these systems not only mitigate risks associated with monoculture practices but also promote biodiversity, reduce environmental impacts, and secure food supplies through synergistic interactions between plant and animal components. Such practices, deeply embedded in the community's traditions, demonstrate a resilient approach towards sustaining agriculture in the face of fluctuating climatic conditions and economic uncertainties.

The investigation into community-based seed sharing systems reveals a profound reliance on seeds saved from previous harvests or obtained through local exchanges, highlighting the significance of seed sovereignty and the preservation of traditional agricultural knowledge. This reliance not only champions biodiversity, but also stands as a testament to the community's resilience and sustainable agricultural strategies.

Smallholder farms, characterized by small landholdings, embody the region's agricultural backbone, underscoring the pressing need for sustainable land management practices aimed at maximizing productivity within existing constraints. This necessity is further amplified by the intensive labour requirements associated with traditional farming practices, predominantly shouldered by family members. The findings echo the broader discourse on the importance of smallholder farms in global food security, advocating for diversified and sustainable agricultural methods of production.

The analysis also draws attention to the socio-economic dynamics influencing agricultural productivity, emphasizing the critical role of labour management in enhancing farm sustainability. The findings of the study suggest the need for a comprehensive suite of policy interventions aimed at supporting agricultural diversification, sustainable land and labour management, and enhancing resilience against environmental and economic shocks.

The findings of this research advocate for the promotion of integrating crop and livestock farming, capitalizing on the advantages of biodiversity and the synergy between different farming practices to enhance both food security and environmental health. There is a pressing need to enhance local seed systems, improve access to high-quality seeds, and promote practices of community-based seed sharing and preservation. Customized financial solutions designed for smallholder farmers can mitigate the economic challenges linked to labour expenses and investments in sustainable agricultural methods. Additionally, providing education and resources to promote sustainable land management practices is essential for increasing agricultural output while maintaining soil health and ecological balance over the long term. To achieve a sustainable food system there is need for farmers to consider the seasonal nature of farming, with strategies aimed at efficiently managing labour requirements and diminishing the labour-intensive nature of agricultural work. Adopting an approach that honours traditional farming techniques while incorporating modern innovations can significantly boost agricultural productivity and sustainability. Moreover, improving farmers' access to education and extension services is crucial for the adoption of new agricultural practices and technologies, which can lead to enhanced productivity and stronger resilience. This research highlights the intricate array of factors influencing food security in Northeast Nigeria, presenting critical insights into the effective combination of mixed farming, community seed systems, and labour dynamics. Through focused policy interventions and holistic strategies that tackle the diverse challenges encountered by smallholder farmers, sustainable improvements in food security and agricultural resilience can be achieved in the region. This strategy aims not only to protect the livelihoods of farming communities from socio-economic and environmental shifts but also to advance broader objectives of sustainable development and food sovereignty.

Chapter 6: The Food Security Situation of Households in Northeast Nigeria

This Chapter presents results on the food and nutritional security of households. A field survey was carried out to gather primary data as there was little, or no, reliable secondary data on food security in Nigeria. The study estimated the food and nutrition security of households using the DDS module adapted from Kennedy et al. (2011), which looked at the number of food groups the household consumed in the last 24hours before survey. Further analysis of the groups of food consumed was used in estimating the consumption of important macro and micronutrients like iron rich foods, vitamin A rich foods, animal protein, or carbohydrate to determine the existence of hidden hunger. Since the study aimed to identify ways of making household food security sustainable through a sustainable food system, factors important to the food security of the households like household socioeconomic characteristics, household farming activities, forest food harvest, consumption of ultra-processed foods, and farming methods were explored. The main source of food in terms of purchase or own farm production or gift aid were also assessed.

6.1. Dietary Diversity Score of Households in Northeast Nigeria

DDS measure was employed at the household level to capture household access to diversity of food. The frequency of the consumption of these food groups was also captured to understand the pattern of their food consumption. The food groups captured were foods consumed in the household by any or all the members. It did not include foods consumed outside the household. The consumption of food outside the household by members of the household was captured but excluded when calculating the DDS. This is because DDS is designed to capture the diverse foods available and consumed within a household as a unit. Incorporating foods eaten by household members outside the household setting into the DDS could lead to the misinterpretation of the DDS assessment of the household's dietary diversity. Food consumption outside the household setting may misrepresent the typical food access, availability, stability or dietary patterns of the household. This is why, while food consumed outside the household setting is recorded, it is excluded from HDDS which focus is on the household-level food consumption.

The study also assessed the main source of food for the households. This was important to understand how the households got their foods. It is also important in understanding the avenue for improving access to food in this area.

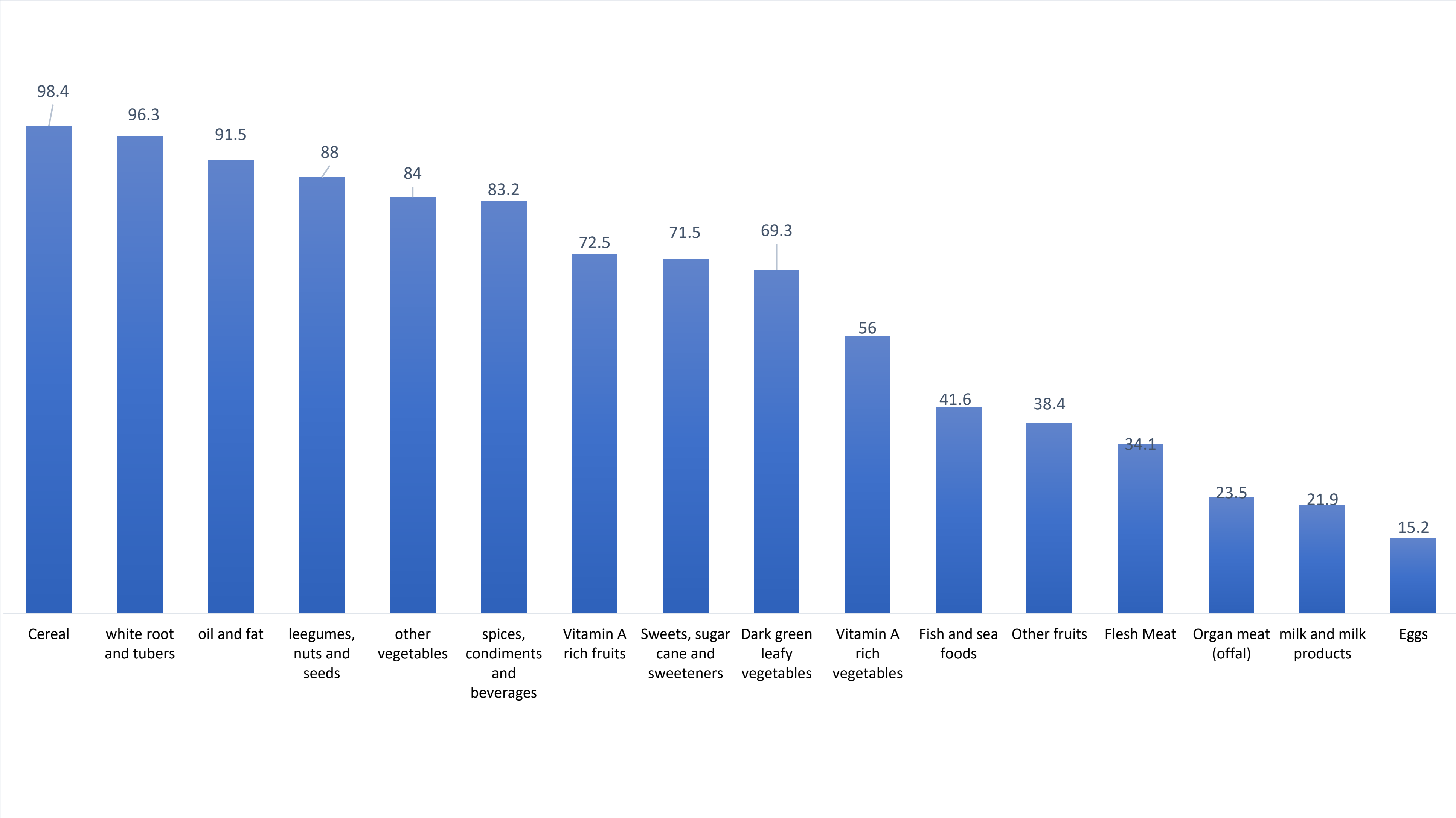


Figure 6. 1. : Distribution of Households that Consumed each of the 16 DDS Food Groups (unit: % of Households)

The results presented in Figure 6.1 show that cereal was the most consumed food by the households (98.4%). This was followed by white root and tuber like yam and cassava (96.3%) and oil and fat (91.5%). The least consumed food groups were eggs consumed by 15.2% of the households, organ meat (23.5%), and flesh meat (34.1%). Only 40.8% of the households consumed animal protein (see Table 6.1).

The 12 groups of food used in calculating HDDS were derived from the 16 DDS food groups (see Kennedy et al. 2011). All vegetable food groups- vitamin A rich vegetables and tuber, dark green leafy vegetables, or other vegetables are designated as vegetables. All fruits- vitamin A rich fruit or other fruits are counted as fruits. In the same way, flesh meat or organ meat is equal to meat in the HDDS. The result presented in Table 6.1 showed that almost all households in the area consumed cereal (98.4%) and white roots and tubers (96.3%) in the last 24 hours prior to the data collection. The food groups that were least consumed were eggs (15.2%) and meat (40.8%). About 52% of the households had members who ate outside their houses in the last 24 hours before the survey.

Table 6. 1. Distribution of Households that Consumed the 12 DDS Food Groups

Food Groups	(%)	Rank
Cereal	98.4	1
White Roots and Tubers	96.3	2
Vegetables	95.7	3
Fruits	78.1	7
Meat	40.8	10
Eggs	15.2	12
Fish and Seafood	41.6	9
Legumes, Nuts, and Seeds	88	5
Milk and Milk Products Milk	21.9	11
Oil and Fat	91.5	4
Sweets, Sugar cane and Sweeteners	71.5	8
Spices, Condiments, Beverages	83.2	6
Household member eating any food outside the home	52	9

The HDDS of the households are between 4 and 12 food groups. The result presented in Figure 6.2, shows that all households in this area ate at least 4 HDDS food groups in the last 24 hours before data collection. A greater proportion of the households ate 8 food groups (24.3%). The households that consumed 4 to 5 food groups constituted 3.2% and those that ate all 12 food groups was 0.5%. The mean HDDS for the households in the Northeast was 8.2. The HDDS showed that the households in this area ate a diverse range of foods. This may be due to the large proportion of household that eat wild food obtained from the forest.

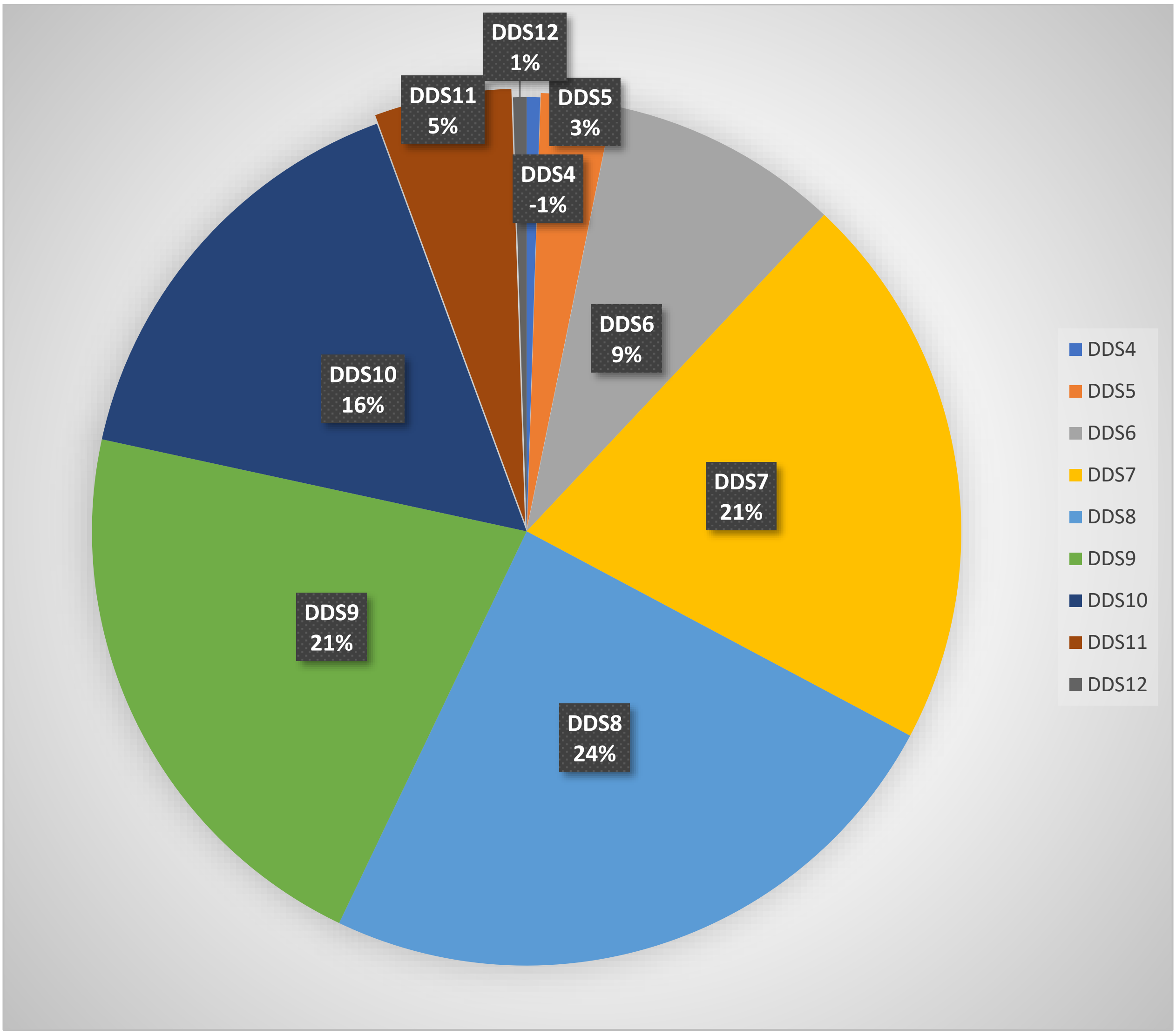


Figure 6. 2. HDDS of Households in Study Area of Northeast Nigeria

The frequency of consumption of the different food groups was assessed by counting the number of days in a week each food group was consumed in the household. The results are presented in Table 6.2 and show that about 30% of the households ate cereal 6 days/week. These cereals were consumed in the form of cooked rice, ground maize or rice prepared as porridge (*kunu*) or thick pudding (*tuwo*), millet (*jero*) and Guinea corn(*dawa*), The mean consumption of cereals was 5.4 days/week.

Table 6. 2. Weekly Frequency of Household Consumption of DDS Food Groups

Food Groups	***0day***	***1day***	***2days***	***3days***	***4days***	***5days***	***6days***	***7days***	**Mean**
Cereals	0.3	1.9	2.9	7.5	6.9	26.1	29.3	25.1	5.4
White roots and tubers	0	7.2	14.7	17.1	17.3	12.8	6.7	24.3	4.3
Vitamin A rich vegetables and tubers	30.1	14.9	29.3	10.9	4.8	5.9	0.3	3.7	1.8
Dark green vegetables	26.1	4.8	7.2	12.3	15.7	16	6.4	11.5	3.2
Other vegetables	5.6	6.9	27.5	17.1	16.3	13.1	6.9	6.1	3.3
Vitamin A rich fruits	13.9	15.5	34.1	20	9.6	4.5	1.1	1.3	2.2
Other fruits	30.4	14.1	31.2	14.9	5.9	2.1	0.5	0.8	1.6
Organ meat	27.5	41.9	30.4	0	0	0	0	0	1
Flesh Meat	9.6	53.3	40.8	0	0	0	0	0	1.3
Eggs	42.9	36.8	20.3	0	0	0	0	0	0.8
Fish and sea foods	12	9.3	22.1	34.9	13.6	7.7	0	0	2.5
Legumes, nuts, and seeds	2.9	9.9	22.9	23.5	10.1	18.7	8	0.3	3.4
Milk and Milk products	22.1	76.8	0	0	0	0	1.1	0	0.8
Oil and Fat	4.3	13.3	30.9	20.8	10.9	10.4	6.4	2.9	2.9
Spices, Condiments, and everages	24.8	4.3	8.3	3.2	5.4	11.7	19.5	22.4	3.9

The number of times each of the food groups was consumed by the household was further assessed. A household is recorded to have consumed cereal for seven days if they had any cereal every day for the last one week prior to the data collection. So, if they had maize porridge in the morning and/or rice in the evening of the same day it was counted as one day cereal consumption. If they have cereal every day for seven days, it was counted as 7 days of cereal consumption for the household.

White roots and tubers consumption had a mean consumption of 4.3 days/week, and most households ate white roots and tubers 4 days/week. Households consumed roots and tubers like yam, cocoyam, white potato, and cassava processed into *garri, fufu, alibo* or tapioca. All households that eat white roots and tuber ate it at least once a week. Vitamin A rich vegetables consumption had a mean of 1.8 days/week and was mostly eaten twice a week. A greater proportion of the households (30.1%) did not eat vitamin A vegetables for a whole week. This might be due to the seasonality of vegetables in this area. About 26% of the households did not consume dark green vegetables in one week and it had a consumption mean of 3.2 days/week. Vitamin A rich fruits had a mean of 2.2 days/week with many of the households eating it 2days/week (34.1%), and about 14 % of the households did not eat it. Organ meat consumption had a mean of once a week. A greater proportion of the households consumed organ meat (41.9%) once a week prior to the survey. About 27.5% of the households did not eat organ meant in a week. No households ate organ meat more than twice a week. Flesh meat consumption had a mean of 1.3days/week. Most of the households had flesh meat (53.3%) in their meals once a week. None of the households had flesh meat more than twice a week. A greater proportion of the households did not eat eggs (42.9%) for a week prior to the survey. Eggs had a mean consumption of 0.8days/week. No households had eggs more than 2 days/week. Fish and other sea food were consumed more than flesh meat and organ meat in this area, and it had a mean of 2.5days/week. Most households ate fish for two days/week (22.1%), and none of the households had fish for more than 5 days/week. Results on the legume consumption pattern of the households show that most households consumed legumes, nuts, and seed for 2 days (22.9%) and 3 days (23.5%) in a week and this food group had a consumption mean of 3.4days/week. The result on the consumption pattern of milk and milk products shows that 22.1% of the households did not have milk in one week. A greater proportion of the households had milk once a week (76.8%), and 1.1% had milk and milk products like yoghurt, locally known as *nunu*, for 6 days a week. Households had a mean milk consumption of 0.8 days/week in this area. The consumption of oil and fat had a mean of 2.9 days/week, and spices, condiments and beverages had a mean of 3.9days/week.

6.2. Consumption of Ultra-processed and Fast Foods

The study also assessed household consumption of ultra-processed and fast foods. These are foods that have gone beyond primary and secondary processing. They are foods that are processed with additional sugar, flavours, and preservatives. It covered foods like soft drinks, energy drinks and bars, breakfast cereals, flavoured chips, flavoured candy, ice cream, indomie (instant noodles), flavoured yoghurt, cake, hot dog and burgers.

Table 6. 3. Household Consumption of Ultra-processed and Fast Foods in the Study Frea of Northeast Nigeria

Ultra-processed and fast-Food Cnsumption	Frequency	percent
More consumption of ultra-processed/fast foods with increased income:		
Yes	287	76.6
No	88	23.4
Reasons for ultra-processed/fast food consumption:		
Always available	151	40
Tastier than traditional home cooked food	65	17.3
Nutritious	65	17.3
Classy	90	24
Convenient	40	10.7
Cheap	41	10.9
*Where household members ate from:		
Street food vendors and hawkers	139	37.1
Restaurant and Bukateria	103	27.5
Food relief and aid	1	0.3
Local food kiosk (food vendors in temporary structures)	112	29.9

*Multiple responses

The results presented in Table 6.3 showed that about 77% of the respondents would like to eat more ultra-processed food if they had more income. The result showed that most of the people indicated that ultra-processed foods were always available (40%). Some of the respondents thought that eating ultra-processed food is classy (24%), and that eating these foods make them look sophisticated and fashionable. It is important to note that about 17% of the respondents think ultra-processed foods are tastier and more nutritious than traditional home cooked foods. Few respondents indicated that it is convenient (10.1%), so fits their plans, need and activities. A greater proportion of the household members that ate outside their homes ate from the street food vendors and food hawkers (37.1%). About 28% of the households ate in restaurants and *bukateria* (casual inexpensive restaurants). Only 0.3% ate from food relief and aid. The main driver behind the preference for ultra-processed foods among the respondents appears to be a combination of increased financial capability and the perceived social status that eating ultra processed foods presents.

6.3. Food contributions of farm crops to household food security

The contribution of farms to household food production and consumption was explored to understand how much influence farms have on food security. The estimation used was from their last farming season's harvests. The proportions of different food groups consumed in the households which they got from their own farms were explored. The food groups covered were vegetables and fruits, grains, and roots and tubers. The results presented in Table 6.4 showed that 26.7% of the households did not grow vegetables and fruit. For those that planted vegetables, about 26% of them got 81 -100% of their household vegetables consumption from their farms, about 25% got 61- 80 % and 81 - 100% of their vegetables from their farms respectively. Only 0.8% got less than 1% of their vegetable consumption from their farms. The results showed that 27.7% of the households did not produce grains, 17.3% of the households got 21-40% of their grain foods from their farms, 16.8% got 81-100% and 16% got 41-60%. Only 0.8% of the households got less than 1% grain for consumption from their farm. Results on the contribution of the farms to roots and tuber consumption of the households showed that greater proportion of households producing roots and tubers (21.1%) got 61-80% of their household consumption from their farms. About 18% got 81-100%, while 0.5% got less than 1% of their roots and tubers from their farms.

Table 6. 4. Percentage Contributions of Farm Produced Goods to household food security

Farm Contribution to Household Food	No of households	Percent of total
Vegetable and Fruits		
Non vegetable producers	100	26.7
>1%	3	0.8
1-20%	18	4.8
21 - 40%	27	7.2
41 - 60%	34	9.1
61 -80%	96	25.6
81 -100%	97	25.9
Grains		
Non grain producers	104	27.7
>1%	3	0.8
1-20%	33	8.8
21 - 40%	65	17.3
41 _60%	60	16
61 -80%	47	12.5
81 -100%	63	16.8
Root and tuber		
Non roots and tuber producers	106	28.3
>1%	2	0.5
1-20%	17	4.5
21 - 40%	36	9.6
41 _60%	66	17.6
61 -80%	79	21.1
81 -100%	69	18.4
What share of all your farm produce do you consume		
All	4	1.1
50% or more	112	29.9
<50%	206	54.9
None	53	14.1
What share of your farm produce do you sell	14	3.7
<20%	57	15.2
20 -50%	121	32.3
51 -80%	181	48.3
81 – 100%	2	0.5

The study further investigated the sales and consumption of farm produce by farmers. The result presented in Table 6.4 showS that about 55% of the households consumed less than half of all their produce. About 30% of the households consumed more than half of their produce. Only 4% of the households consume all their produce. Assessing the proportion of farm produce sold by the household, the result showed that 48.3% of the households sold 51-80%, and 0.5% sold 81-100% of their produce.

6.4. Forest Food Contributions to Household Food Security in Northeast Nigeria

The study investigated activities of the household in the forest and forest harvest contributions to food security. The distance to the nearest forest where the household could source food, the types of forest foods harvested, income from selling harvested forest foods, and the household forest food expenditure were also explored.

Table 6. 5. Forest Food Harvest and Forest Food contribution to household food consumption

Forest food activities	Freq	%	Min	Max	Mean	Std
Distance to the closest accessible forest from home in KM			0	50	13.49	8.23
Number of days in a month spent on forest food searching			0	30	4.55	7.60
Getting food from the forest	179	47.7				
Households that sell forest foods	76	20.3				
Households that buy forest food	367	97.9				
Income realised from the sale of the forest harvests in a year (Naira)			0	400000	13950.45	43948.81
Money spent on buying forest produce in a year (Naira)			0	300000	30413.24	49909.48
Average amount of money made from selling food harvested from the forest/day (Naira)			0	26000	3000.24	5809.78
*Types of forest foods bought						
Bush meat	192	51.2				
Vegetables and fruits	161	42.9				
Mushrooms	14	3.7				

*Multiple response

The results presented in Table 6.5 show that people travelled an average of 13.49km to the closest forest with distance to the closest forest being between zero and 50km. In comparison, the distance to the closest farmland which had the mean of 9.21km (Table 5.3). About 48% of the respondents indicated that they go to the forest in search of food, and 20.3% indicated that they sell forest products. About 98% of the households said they buy forest foods. The results show that an average of 4.55 days were spent in search of forest food. This included those that spent a maximum of 30 days and those that did not go to the forest for food. The implication is that some of the households go to the forest daily to source food.

The respondents were asked how much they got from selling the wild food they harvested, how much they spent buying wild food from the forest, and what percentage of their harvest is sold. When the economic value of forest foods was assessed, the results showed that the mean income from forest food was ₦13,950.45/year with a standard deviation of 43,948.81 and the maximum income was ₦400,000/year. The households that engaged in selling forest foods made a mean income of about ₦3000 from one day's forest food gathering. The mean expenditure on forest food purchase for the households was ₦30,413.24/year with the standard deviation of 49,909.48 and maximum of ₦300,000/year. A greater proportion of the households harvested wild vegetables and fruits (41.9%) from the forest. This was followed by bush meat and wild fish harvested by 37.9% of the households. Only 13% of the households harvested mushrooms from the forest. The forest food harvesters sometimes sell these foods to get income for other household expenses. Most of the forest food harvesters sold bush meat and fish (51.2%). This was followed by those that sold wild vegetables and fruits (42.9%). Very few forest food harvesters sold mushrooms (3.7%).

6.5. Discussion on the Food Security Situation of Households in Northeast Nigeria

This section discusses the results on the food security situation in Northeast Nigeria. This covers the food and nutrition security level of households, the contributions of farm food and forest food harvest to household food security. The roles of the different food production methods in achieving dietary diversity for the households, the role of these food production systems in ensuring employment within the farm to provide income for the households, which in turn improves their ability to access foods, are also discussed.

It is important to note that the DDS, from which the HDDS was derived, captured household access to diversity of food and did not consider intra-household distribution of these foods. This can obscure who within the household benefits from the available food diversity. For example, if a household indicated that they had mango, which is only five in number for a household of 1 or 26 persons. In this case it was recorded for the household as a unit that they ate fruit. So, the result shows that the household as a unit ate fruit. To improve the DDS result, in addition to capturing households' access to diversity of food for food and nutrition security, the study captured the frequency of consumption of these food groups for 7 days prior to the interview. The inclusion of frequency data as an improvement adds to better understand actual consumption patterns over time. It also collected data on consumption of ultra processed foods and food eaten outside the home by members of the households.

The results showed that household food consumption was high for carbohydrate rich food and low for animal protein rich foods. This highlights the findings of Ike, Jacobs, and Kelly, (2017) that the most consumed food groups in this study area were carbohydrate rich food, and the least consumed foods were protein foods, which are a very important nutrient needed for the body, especially for growing children. The result pointing out that less than half of the households consumed meat regularly underscores a significant gap in dietary quality, which can lead to protein-energy malnutrition and micronutrient deficiencies, often referred to as "hidden hunger". The result showed the food groups of special interest which are animal-based proteins and iron rich food were not widely consumed. However, the consumption of vitamin A rich food which comprises of vitamin A rich vegetables and fruit was widely consumed in the study area. This might be because of the habit of adding palm oil to most food consumed in Nigeria. Also, the data collection coincided with the mango season and ripe mango is one of the vitamin A rich fruits. For animal-based protein rich foods, less than half of the households ate meat. It is clear from the results that most of the households do not include meat in their daily meals and ate very little food rich in the micronutrients of interest. This may have negative implications for their health, and the growth and development of the children in the study area. Given the low consumption of protein, micronutrients and vitamin rich food of interest, hidden hunger may constitute a problem in North East. This highlights a critical issue of "hidden hunger" (Burchi et al., 2011)

Cereals, notably maize, millet, and guinea corn, not only form the nutritional backbone of the participants diets, but also hold substantial cultural significance, often featured in traditional dishes and communal rituals like drinking *kunu* and eating *tuwo*. This highlights the role of food as both a cultural identifier, and a social binder, as noted in Hardy et al. (2024); Mayowa, (2020) and Puoane et al. (2006). Similarly, the prevalent consumption of root and tuber crops like yam and cassava, celebrated through various local festivals, reflects their crucial role in ensuring food security, especially during times when other food sources are scarce. These staples are generally favoured for their affordability and storability, which also point to potential issues of limited dietary diversity and food accessibility.

Moreover, the notably low intake of animal proteins- eggs, organ meats, and flesh meats- suggests significant nutritional gaps, potentially leading to micronutrient deficiencies. This pattern, indicative of socio-economic constraints and possibly influenced by cultural dietary preferences, is explored in studies by Headey et al. (2018) and Kennedy et al. (2011), who link low animal protein consumption to higher rates of micronutrient deficiencies, particularly in vulnerable groups.

The consumption of a narrow range of primarily plant-based foods, despite the availability of diverse food groups as indicated by the HDDS, raises concerns about nutritional adequacy. This lack of diversity, compounded by economic, environmental, and social factors, reflects broader systemic issues impacting dietary diversity and food security in dryland regions.

The challenges of climate variability, land degradation, and economic instability call for resilient farming practices and diversified livelihood strategies to enhance food security, as discussed by Morton (2007). Additionally, the need for sustainable agricultural practices and enhanced market access to foster the adoption of diversified diets is emphasized in the literature, including work by Fraval et al. (2019).

The result shows that the households in the study area consumed between 4 and 12 groups of food according to the DDS classification. The gap between 4 and 12 will mean very little if we do not understand what these numbers represent. The fact that the numbers represent nutrients that are vital for human and society development, not consuming one of these food groups sometimes may constitute a nutritional problem. Figure 6.1 (page 140) shows the most consumed food in the study area of which protein rich foods did not make it to the top 10 out of the 16 food groups. For the 12 HDDS food groups derived from the DDS, protein rich foods were fish, meat, milk and milk products at 9th, 10th, 11^{th,} positions respectively, and 12th was eggs which was the least consumed food. The four most consumed HDDS food groups are cereals which were consumed by almost all the households in this area, within 24 hours prior to the data collection, followed by white roots and tubers, vegetables, and oil and fat. The implication of this result is that households that consumed only 4 food groups may have missed protein, iron and vitamin A derived from animal sources. Their food may have been lacking in vital vitamins and minerals needed for their nourishment. Drawing from the result, having the mean of 8 groups of food for this study area, may imply that most of the households in this area, despite having herders and livestock farmers in the sample do not eat protein especially animal protein. This is clearly seen from the number of times meat was included in the household's meals per week. Almost all households ate meat (flesh meat and organ meat) less than twice a week. Carbohydrate rich foods- cereal, and roots and tubers remained the most frequently consumed foods in this area. About a quarter of the respondents had white root and tuber and cereal every day for the 7 days covered in the study. And more than half of the respondents had cereals for at least 6 out of the 7 days. For protein rich foods, no households had eggs, organ meat and flesh meat more than 2 days in a week. Only about 1% of the households had milk or dairy products more than once a week.

Fruit is highly seasonal in Nigeria and, particularly in the Northeast, due to the long dry season. This is reflected in the results of frequency of consumption of fruit in this area. Though the study coincided with the mango fruit season, the households had a mean fruit consumption of about 2 days a week. The households consumed vegetables almost half of the days studied, even though it was in the peak of the dry season. During the dry, and harmattan (hot, dry Northeast trade wind), season, fresh fruit and vegetables are usually scarce. Rain starts in Northeast Nigeria by June and ends in September. So, they have about four months of rain and eight months of dry season and harmattan, which is characterised by no rain, high temperatures, and dusty wind (Adeniyi et al., 2009). The data collection for this study was done during the peak of the dry season between March and April.

The timing of data collection during mango season and the dry season introduces a seasonal bias that may not accurately reflect annual consumption patterns. This temporal limitation affects the generalizability of the findings, particularly for vitamin A intake from mangoes and the availability of fresh vegetables and fruits which are less available during the dry season. This seasonal availability can lead to periodic nutritional improvements but does not guarantee year-round food security (Adeniyi et al., 2009). The reliance on palm oil for vitamin A intake might not adequately compensate for the lack of diversity in other vitamin A sources throughout the year. The research into dietary patterns in the Sahel region's drylands underscores a significant dependence on staples such as cereals and root tubers, highlighting the intersection of agricultural practices and food culture characteristics of this region. These patterns primarily illustrate the constraints imposed by the ecological and agricultural challenges of dryland ecosystems.

The dietary patterns documented in the Sahel region not only reflect the current state of dietary habits but also offer valuable insights for interventions aimed at improving both the diversity and nutritional quality of diets in dry land regions. These findings are pivotal for formulating strategies that address agricultural and nutritional dimensions, thereby enhancing the resilience and sustainability of food systems in the Sahel, aligning with global sustainable development goals. These results shed light on the nature of food and nutrition insecurity in this area. Though these households may worry about their next meal or obtain food using erosive food insecurity coping strategies (Ike, Jacobs, & Kelly, 2017b), their food is still lacking in protein, iron and vitamin A rich foods. The use of food security measures that capture only the consumption of calories will do very little to account for the shortfall in the diversity of their diet especially the vitamins, iron, protein rich foods and other essential nutrients derived from the consumption of a diversified diet. Other household level food security measures like household food insecurity access scale (HFIAS), which is good at clearly classifying the different levels of food insecurity (Coates et al., 2007; Ike et al., 2016), will benefit from DDS results to understand the actual foods consumed, and account for the nutritional security of the households. The DDS and the frequency of food groups consumed by households is important in designing focused improvement plans for household food security in this area. Given that most households in this area have growing children, it is important for households to have protein food that support the growth and development of these children added to their meals.

6.5.1. Consumption of Ultra-processed and Fast Foods Result Discussion

The results on the reason for the consumption of ultra-processed foods may help nutritionists understand the reasons for increasing obesity and other food related problems in our economies. When the respondents were asked if they will eat more ultra-processed food than traditional local food if they become richer, only less than 15% of the respondents did not want to consume more of the ultra-processed foods. About 77% preferred having less traditional foods like yam, cowpeas, fufu, tuwo, meat and milk that has gone through little or no processing. So, most people in the study area are seeing ultra-processed foods as the way to go as their financial condition improves. As a result, increasing incomes in poor regions of the world without proper nutrition education in the face of glamorous advertisements of these ultra-processed foods, may be encouraging its consumption.

When exploring the reasons for the consumption of ultra-processed foods, a large proportion of the respondents said that they eat ultra-processed food because it is always available. This may reflect the availability of these edible products around the year. Ultra-processed foods are unlike the fruits, vegetables and other farm produce which follow seasons, vegetational belts, and a biological life cycle. Ultra-processed foods are also found in all corners of the country even in remote villages and are physically accessible to many. Some of the respondents even thought that eating ultra-processed foods makes them classier than those who do not. It is noteworthy that some people thought that ultra-processed foods contain more nutrition than unprocessed, or less processed home cooked foods. However, literature has shown that most of these ultra-processed foods are not as good as it is presented in adverts. According to Pérez-Escamilla (2017), dietary patterns that are highly dependent on starches and added sugar-sweetener as found in ultra-processed foods, explains the coexistence of obesity, and undernutrition and infectious diseases in middle-income countries. These diets are typically high in calories, but low in essential nutrients, leading to an increase in obesity and related chronic diseases such as diabetes and cardiovascular conditions. At the same time, the lack of essential vitamins and minerals in these diets contributes to undernutrition, particularly in vulnerable populations like children and the elderly, who may not get enough nutrient-rich foods to meet their needs. Furthermore, poor nutritional status weakens the immune system, making individuals more susceptible to infectious diseases. This dual burden of malnutrition- over consumption of unhealthy foods and insufficient intake of nutritious foods create a complex public health challenge in these countries.

The finding that 77% of respondents would increase their consumption of ultra-processed food if they had greater financial resources, highlights significant socio-economic factors influencing dietary choices. This preference underscores the influence of perceptions of convenience, social status, and taste over nutritional considerations among consumers, as outlined by Monteiro et al. (2018). Additionally, the association of ultra-processed foods with classiness and sophistication by 24% of respondents illustrates a critical cultural shift where traditional diets are increasingly replaced by foods perceived as modern or Western, often at the nutritional expense. Kowalczuk et al. (2021) supports this view, suggesting that ultra-processed foods are marketed as symbols of modernity and Western lifestyle, appealing particularly to middle and lower-income populations in developing countries seeking upward social mobility. This marketing effectively influences dietary choices and warrants further exploration. Food choices, as social markers discussed by Cairns et al., (2013) indicate that eating behaviours help construct personal identity and social status, pointing to the potential of public health campaigns to reframe healthy eating as desirable and prestigious.

The study indicates that 40% of respondents views these foods as always available, and this reflects their pervasive presence, especially in urban environments. This accessibility, intensified by global urbanization and market strategies by large food corporations create 'food swamps' where unhealthy options overshadow healthier ones, as argued by Cooksey-Stowers et al. (2017).

Moreover, the misconception by 17% of respondents that ultra-processed foods are tastier and more nutritious than home-cooked meals, highlights a crucial misunderstanding and a vital area for intervention. Public health initiatives could educate on the actual nutritional content of these foods, countering myths and promoting healthier choices, as supported by Gorski and Roberto (2015), and Roberto et al. (2015). Given the high content of unhealthy additives in ultra-processed foods, public health campaigns should address these misconceptions directly.

The convenience factor, noted by 10.1% of respondents, aligns with global trends where fast-paced lifestyles prioritize quick meal solutions, often at a health cost. Studies show frequent consumption of ultra-processed foods is linked to negative health outcomes such as obesity and heart disease (Moodie et al., 2013; Story et al., 2008). This trend underscores the need for initiatives promoting convenient, nutritious food options that cater to busy urban lifestyles (Story et al., 2008).

Significantly, 37.1% of meals consumed outside the home came from street vendors, and 28% from casual restaurants, reflecting a shift in eating habits and food availability. The negligible percentage relying on food aid underscores that consumption choices are influenced more by lifestyle and perceived status than mere availability. This points to the potential impact of policies targeting food vendors and restaurants to offer healthier choices.

These findings call for targeted interventions addressing both the supply and demand for ultra-processed foods. Supporting the availability of healthier options at food vendors and educational programs can reshape perceptions about the nutritional value of ultra-processed versus home-cooked meals. Understanding cultural dynamics will guide effective public health messaging and interventions aimed at promoting nutritional health while respecting consumer autonomy and preferences.

So, this study serves as a call to action for public health officials, policymakers, and community leaders to implement interventions that transform food environments, reshape consumer attitudes, and promote healthier dietary choices, supported by ongoing research into the socio-economic, cultural, and environmental factors that influence dietary behaviour.

6.5.2. Food Contributions of Farms and Forest Foods to Household Food Security Results Discussion

The main source of food for the households in the study is their farms and forests from where they get access to free or low-cost food. There is a difference in the use of forest for food and the use of land for farming in Nigeria. Even with the conflicting land use legislation as of 1978, which put land in Nigeria in the hand of the state Governor to hold in trust for the people even as individuals and communities still used their lands base on their custom, the customary land tenure system is clearly implemented in the Nigerian land tenure system especially in the rural areas (Babalola & Hull, 2019). Unlike the forest with little or no restriction as to its use for food harvesting, users and owners of agricultural land must have statutory or customary right to occupy or use the land (Babalola & Hull, 2019). Hence, forest have served as a food safety net for the poor in Nigeria. The forest can be owned by an individual, community, or the government as in forest reserves, but the poor are free to access the forest for food, thus helping to supplement their diets and improve food security, except for the government reserved forests kept for conservation. For many rural and impoverished communities, these forest foods are crucial in bridging the gap when agricultural harvests are poor, or when market prices for food are too high. Beyond immediate food needs, forests also offer medicinal plants and materials that can be used or sold, providing both health benefits and a supplementary income.

The detailed examination of the contributions of farm produce and forest resources to food security and livelihood in the study area sheds light on the intricate dynamics of subsistence farming and the sustainability of forest resources. The analysis reveals how these elements are essential not only for immediate nutritional needs but also for long-term economic support.

Small-scale farmers are known to engage in farming activities that will help them provide foods for their households. The result on the household food share coming directly from their own farms shows that many of the farming households got a large proportion of their food from their farms. So, it might be inappropriate to use the income or food expenditure methods as a standalone to assess the food security or access to food of farming households. Income based measures of food may underestimate the food security of farming communities since it does not account for foods that are not bought and foods from the wild which may not have market values. This may confirm the reason for developing subjective household measures of food security like Household Food Insecurity Access Scale and DDS which tends to capture the actual consumption in a household (Coates et al., 2007). Thus, there is need to account for the food the households get from their farms and the wild, as it may have a significant influence on their food security.

Though it is believed that most of these small-scale farmers farm for the purpose of directly providing food for their households, it can be seen from the results on farm income and proportion of farm produce sold, that the farmers engage in farming to provide not only food, but income also for their households. The large proportion of farm produce sold by the farmers may be an indication that there are farmers among these smallholder farmers who engage in farming for the main purpose of making money. This behaviour underscores the dual role of farm produce as both a source of food and an essential income stream, which can be crucial for covering other vital expenses such as healthcare and education.

The types of forest foods harvested- bush meat, wild vegetables and fruits, and mushrooms - suggest that these resources contribute essential proteins and micronutrients to the local diet, enhancing dietary diversity which is crucial for nutritional security. The results on forest food show that forest food contributes both food and income to the households. It provides them with meat, vegetables, and fruits, even mushrooms for food. According to the discussions in the policy thrust effectiveness evaluation done by the focus groups (See Chapter 4), many households depend heavily on forests for their livelihood. They get firewood for cooking, honey for household use and income, and foods like vegetables, meat, fish, mushrooms, and fruit. The buying and selling of forest foods contributes heavily to the income of the households in this area and calls for a very conscious management system for the forest. The forest management for this area should focus on the preservation of the forest biodiversity as well as the food sustenance of the people depending on these forests for food and income for sustainable development. In line with the results from the focus group discussion on availability of, and access to diversity of food for the households in Chapter 4, this result shows that these farming households depend heavily on their farms and food from forest for their nutrition and income.

In conclusion, the food and nutrition insecurity in this geopolitical zone may be concentrating toward lack of protein and micronutrients of importance. This is because the household widely reported the consumption of carbohydrate rich food which consist of cereals, and root and tubers. They have access to these foods for about 6 days in a week and some even eat it every day. Given that most of the households in this area have children who are still growing, the consumption of proteins, vitamins and minerals like iron are very important. The low consumption of these vital nutrients, sheds light to the existence of hidden hunger in Northeast Nigeria. Though these households in this farming community get less than the national average living wage, food from their farms and forest plays a very important role in their food and nutrition security. Their involvement in farming gives them access to food that they may find difficult getting if they do not have access to land. By identifying the high dependency on both farm produce and forest resources, the study points to potential risks associated with economic or environmental changes. The analysis of the economic aspects of farm and forest products provides valuable insights into how households balance immediate nutritional needs with economic survival.

So, it is recommended that food security intervention should target covering the gap in the consumption of protein, iron, and vitamin A rich food. A greater proportion of the households in this area depend heavily on their land and labour for food. So, the efforts of the Government in achieving sustainable food security should focus on policies that support poor farmers, especially mixed cropping farmers, to produce their food. Nutritional education is needed to encourage the consumption of less processed food, which is suffering because of enticing ultra-processed food advertisements pushing consumers away from eating traditional foods. The imposition of government restrictions on forest access may lead to the inability of the community depending on this forest to access food, as highlighted by the focus group discussions (See Table 4. 2 result discussions). These restrictions often serve the purposes of protecting environmental resources and regulating their use to prevent over-exploitation. However, limited knowledge of the needs of people living in this area, means that such restrictions can result in illegal activities and increased food security problems given their dependence on the forest. Moreover, the politics surrounding the sale of forest lands often leads to privatization, and so restricted access to such forests for food and as a means of substance for the community.

Chapter 7: A System Dynamic Modelling approach for a sustainable food system

This chapter provides answers to the second objective of this thesis – to explore the linkages between the food system and food security components to understand their interactions and identify the main drivers and the key outcomes of the system. It assesses the linkages and feedback loops within food system; labour, farm practices, agrobiodiversity, household socioeconomic characteristics, and consumption of diverse food.

To achieve a sustainable food system, there is need to focus on ideas, intentions, and institutions to redirect incentives that have perpetuated market externalities that negatively impacted on the environment and human health. To explore the food system feedback/causal loop, a model group as described in the methodology section (Chapter 3) was used to explore the food system: mental model, interrelationship digraph, and finally build a causal loop diagram. The group members contributed their diverse experiences and views on the best practices, problems, exacerbation, and solution to the food system model. The different views were applied and challenged in the model to reach a consensus.

The model investigated and identified the driver and outcome variables, and leverage points for change within food systems. This encompassed identifying:

a) points of intersection with non-food systems that affect the food system within the boundary of the study; climate change, labour, and population;
b) the dynamics interaction and relationships between various elements within the food system; reinforcing and balancing loops and feedback; and
c) the incentives that shape the adaptive behaviours and reactions of those involved in the food system including input subsides.

7.1 Steps in Developing the Food System Causal Loop Diagram of Northeast Nigeria

To build the food system model of Northeast Nigeria, an iterative process was followed. Knowledge, emotion, experience of the food system experts and stakeholders, information from the household survey data and focus group discussions, and existing knowledge from literature were used for the modelling. The iterative process is important for the researcher to challenge her mental model which may not represent reality. Stakeholders' participation in the modelling is very important for building confidence in the system, clearing misunderstanding, and through system thinking, improving the understanding of the participants.

The model development participants aimed to - determine the appropriate boundaries for the food system, identifying which elements are important for the study goal (the context), and identifying which elements are beyond the study scope. To achieve this, the team examined the system, ranging from the food on their plates back to the farm to identify factors that directly impact the study objectives; those with direct influence on the research problem, and those that are significant, but uncontrollable. They also identified critical factors to the research problem over which they have no control and incorporated these into the diagram. This process of filling out the context diagram aided the team in contemplating the broader system and fosters a collective understanding of the system boundary. The context diagram is a valuable reference throughout the model development, assisting in the decision-making processes (Vallance et al., 2022).

The group members followed three steps in developing the CLD. These group activities were coordinated by the researcher.

Step 1 Seeing the bigger Picture

The participants were briefed on the purpose of the research. First, group members were asked to brainstorm individually on the common issues, components, and problems in the food system, looking at what had changed over time. To guide the discussion around the bigger picture of the food system, the participants were made to think about, discuss and answer three questions, (i) how we understand the realities of the food system, (ii) how are we managing the realities of our food system, and (iii) are there challenges of intervening in the food system. A meeting was scheduled online for the group to discuss these big pictures of the food system. In the meeting, everyone presented their thoughts about the food system. Members talked about what has got better, what remained unchanged and what has become worse overtime in the food system.

After presenting their thoughts, participants expressed their views on, the current state of food security in the country, especially the Northeast geopolitical zone that has become a humanitarian emergency case. The group noted that food production is fast moving from mixed cropping to mono-cropping production and becoming more agrochemical-based farming. For this shift in food production practice, the members emphasized that there has been a breakdown in the traditional knowledge of farming, preparation, and use of underutilized local foods, echoing the sentiments of Hernandez Marentes et al. (2022), Kennedy et al. (2022) and Vidal (2019). They also discussed the loss of taste of food produce over the years. It was widely discussed that the meat, vegetable, and other agricultural products have been losing their taste with the increase in scientifically developed varieties dominating the field. Food markets were said to be flooded with locally produced food but having to fight low price due to cheap imported foods. Food consumption was believed to have changed drastically over the past 20 years. The participants believed people consume more noodles and pastries (a foreign food) today than their main local dishes like yam, cassava and beans. They all agreed that food habits and taste of Nigerians have changed dramatically. The consumption of cheap and fast food, the changing population health and changing food culture of the people are in line with changing crop planted in the farm, leading to the call for sustainable and alternative farming (FAO, 2022a).

1) How do we understand the realities of the food system? The highlights from the discussion were that: (i) there is serious hunger in the country. One participant even said, "hunger in the land is too big that even the blind can see it." (ii) Farmers are killed, their lands taken and the remaining few cannot go about their farming business freely. (iii) Farmers are not getting enough support or inputs produce cheap crops. (iv) More foreigners and government officials owning farms are taking over land from local farmers. These large farms are into monocropping of rice, soya bean, benniseed, corn or beans. (v) It is becoming very hard to get food from the farms without using high yielding varieties from seed companies supported by inorganic fertilizers, and agrochemicals to reduce cost of labour. (v) farmers are unlike farm machines. They are human beings with relationships and physiological needs. They are involved in other aspects of lives and make decisions as they deem fit.

2) How are we managing the realities of our food system? The quick fixes employed to manage the food system reality were identified as food aids, money transfer

from the government, going to churches and ceremonies for food, selling of family assets for food and farming, borrowing from formal and informal financial institutions to eat or farm, and planting of high yielding varieties of crop. The anticipation of the people is to achieve high yield, more input subsidies, and security for farmers.

Structurally, the food system has always been handled through agricultural policies which have done very little in achieving food security, let alone, sustainability in the food system. The group noted that there are unwritten rules making farmers to move towards cash crops and avoid mixed cropping even when it helps them to feed their family. This was related to financial and political dynamics of farm inputs and supports.

3) Challenges of intervening in the food system – the group highlighted lack of correct information, ignorance of the impact of our actions, political influence, vested interest of farm input business, the urgency that hunger brings into the system, limited knowledge of the complexity in the food system especially by policy makers.

Step 2 Explicit Expression of Group Mental Pictures

They were asked to draw a rich picture depicting their mental model of the food system. This mental model represents how they see the food system with respect to all the elements that contribute to having food at home in the face of the sustainable development goal of achieving biodiversity, labour and income for the poor farming households and food security. The rich picture gathered was scrutinized by the members (see interrelationship digraph (IRD) of the mental model of each participant in Appendix 4). Conflicts and differences in the elements were discussed and consensus reached for the CLD. From the rich picture, the main elements of the system were selected. To draw an interrelationship digraph, the participants were asked to use a one directional arrow to link variables that have a direct relationship. This enabled the group to have a clearer understanding of the relationship and interactions in the system.

Step 3 Drawing of Feedback/ Causal Loop Diagram

The CLD draws from the IRD and build up on it. This last step was carried out by the researcher and presented to the group for validation. All through the process of the modelling the participants were involved in checking the accuracy of the variables' name, identifying missing variables, and checking the correctness of the arrow polarity.

This detailed mapping and understanding of feedback loops contribute to food security by identifying leverage points. Understanding where small changes could lead to significant impacts, such as improving health and nutrition, improving the knowledge of cultivating diverse crops, investing in sustainable agricultural practices, or enhancing education and training is importance helps recognise the complex interdependencies. As a result, strategies can then be designed to enhance system resilience against shocks like climate change, economic downturns, or pandemics.

7.2 Food System Feedback and Causal Loops

A Northeast Nigerian food system diagram was developed through an interactive and reiterative process. A causal loop diagram (CLD) is a visual representation used in systems thinking to illustrate the feedback loops and causal relationships between variables within a system. These diagrams help researchers to understand how different elements of a system interact with each other and how changes in one element can influence others over time. CLDs are useful for identifying both reinforcing and balancing loops that drive the dynamics of complex systems.

Key Components of a Causal Loop Diagram

Variables: These are the elements or components of the system that influence each other. In the context of a food system, variables might include the food security level, health and nutrition, and household income.

Arrows (Links): Arrows indicate the direction of influence between variables. Each arrow shows that a change in one variable leads to a change in another.

Polarity (+ or -): The arrows can have positive (+) or negative (-) polarity, indicating the type of relationship.

Positive (+) Relationship: An increase in one variable causes an increase in the related variable, or a decrease causes a decrease. For example, increased household income (+) may lead to increased investment in farm input.

Negative (-) Relationship: An increase in one variable causes a decrease in the related variable, or a decrease causes an increase. For example, increased farm labour (-) may lead to reduced available labour force.

Loops: When a series of causal relationships forms a closed path, it creates a loop. Loops can be:

(i) *Reinforcing Loop (R):* Also known as a positive feedback loop, it amplifies change in the system. For instance, increased food security level (+) could improve health and nutrition (+), which further enhances food security level (+). Also, a loop is reinforcing when the polarity of the arrows indicating the direct relationships in the feedback loop are all positive (+) or have an even number of negative arrows (-) like 2, 4, or 6 negative arrows. A reinforcing loop can be positive or negative. A positive reinforcing loop leads to a virtuous cycle, and a negative reinforcing loop leads to a vicious cycle. Reinforcing loops leads to exponential growth or decay, and a balancing loop results in equilibrium, resistance to growth or change, or maintaining stability. Balancing loops can be goal oriented.

(ii) *Balancing Loop (B):* Also known as a negative feedback loop stabilizes the system by counteracting change. For example, higher wages (+) might reduce farm labour availability (-), balancing the system over time. However, a feedback loop is a balancing loop if there are an odd number of negative arrows in the loop.

Example of a Causal Loop Diagram in a Food System

Using the food security and health example to illustrate a causal loop diagram:

Food Security Level (+) ➔ Health and Nutrition: Higher food security improves health and nutrition.

Health and Nutrition (-) ➔ Death: Better health reduces death rates.

Death (-) ➔ Population: Lower death rates increase population.

Population (+) ➔ Available Labour Force: Higher population increases the labour force.

Available Labour Force (+) ➔ Farm Labour: More labour force increases farm labour availability.

Farm Labour (+) ➔ Wage: Increased farm labour can decrease wages (negative relationship can be added if appropriate).

Seed and seedlings from Seed Companies (+) ➔ Agrochemicals and Tractors: More seedlings lead to higher use of agrochemicals and tractors.

Agrochemicals and Tractors (+) ➔ Monocropping System: Increased use promotes monocropping systems.

Monocropping System (+) ➔ Food for Other Use (ethanol, animal feeds): Monocropping supports production for non-food uses.

Understanding the Food System Feedback Loops

Reinforcing Loop (R): Increased food security level improves health, which further reduces deaths, increasing the population and labour force, which leads to higher household income and investments, eventually improving food security even more.

Balancing Loop (B): If increased household size leads to overuse of farm labour, wages might decrease, reducing household income and subsequent investments.

By using causal loop diagrams, stakeholders can better understand complex systems' dynamics, predict outcomes, and identify leverage points for intervention.

From the causal loop diagram developed in this study (Figure 7.1), six system drivers were identified- **agrochemicals and tractors, food harvest, monocropping, mixed cropping, health and nutrition, and land for agriculture**. Four of these drivers can be described as root cause variables in the system. They are drivers, because they have more outgoing arrow than incoming arrows, and root cause variables because they have more outgoing arrows than other elements of the system. The four root cause variables of the system are **food harvest** with 6 outgoing arrows, **monocropping** with 6 outgoing arrows, **mixed cropping** with 6 outgoing arrows, and **agrochemicals and tractors** with 4 outgoing arrows.

These four variables have a great driving force, and determine to a large extent, what happens to the outcome variables of the system. The root cause variables can be considered to shape the current food system of Nigeria and other countries with similar agricultural systems.

Outcome variables are identified by the number of incoming arrows they have. The outcome variables have more incoming arrows than outgoing arrows. The key outcome variables of the system are the outcome variables with the most incoming arrows in the system. About five key outcome variables were identified in the food system causal loop diagram (see Figure 7.1). The key outcome variables were **biodiversity** with 8 incoming arrows and 3 outgoing arrows also making it a driver; **food and nutrition security** with 5 incoming arrows and 1 outgoing arrow; **household income** with 5 incoming arrows and 3 outgoing arrows which also makes it a driver; **farm labour** with 4 incoming arrows and 1 outgoing arrow, and **soil quality** with 4 incoming arrows and 2 outgoing arrows. So, biodiversity and income were also drivers but cannot be identified as a root cause because they did not have as much outgoing arrows as the identified root cause variables of the system.

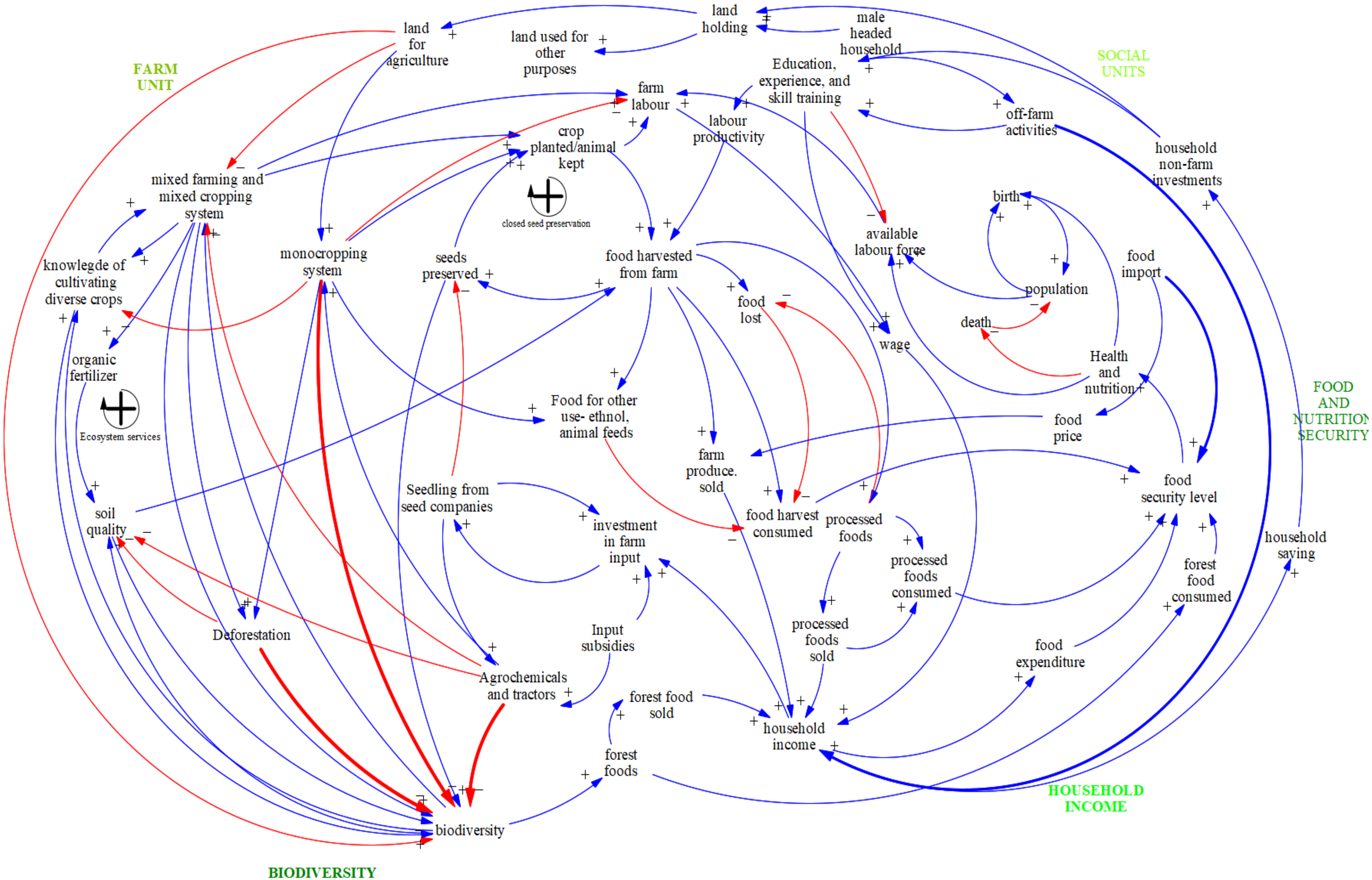


Figure 7.1 Nigerian food system causal/feedback loops diagram (Red arrow = negative relationship. Blue arrow = positive relationship)

From the food system causal loops for achieving food security, there were more balancing loops than reinforcing loops. These balancing loops were either resisting growth, bringing back the system to achieve its goal, or maintaining the stability of the food system. The diagram shows that though seedlings from a breeding company increases investment in the input sector which may improve the economy through income and employment for skilled workers, and the use of agrochemicals that underpins monocropping system of farming. It has a growth resistance effect on food security through its negative impact on seed preservation for next planting. Loops number 3, 8, 22, 23, 28, 30, 35 and 41, show the resistance effect of seed from breeding company on the efforts of other variables in the system to achieve food security (See Appendix 3 for the list of loop numbers). Hence, the effect of farmers sourcing their seeds for planting from the breeder can limit the variables in the system using seed saving to achieve the goal of food security.

It can be seen from the feedback loop diagram that agrochemicals and tractors used in the farms to achieve food security introduces a force of resistance in the system. Although agrochemicals and tractors contributed positively to monocropping, it resisted the growth of food security through its effects on soil quality (loops number 5, 16, 17, 18, and 42), biodiversity (loops number 6, 18, and 40), and mixed cropping (loops number 17, 25, and 27).

Four loops in the casual loop diagram show that food for other uses- animal feeds and ethanol production, introduced a force of resistance to food security. It ended up reducing the long efforts of other food security contributing variables as shown in loops 7, 12, 19 and 29. The dominant loops around income show how income through food expenditure supports food security.

Other variables with growth resisting force in the system were (i) food lost which affected food security through its negative effect on farm food harvest consumed (Loops 20 and 37), (ii) monocropping through reduced biodiversity (loop 26), and (iii) land for agriculture through reduced mixed crop farming (loop 32). Another important variable with dominant force of resistance to food security was deforestation. Deforestation through reduced biodiversity (loop 43) and soil quality (loops 48) have resisting effect to the food security growth efforts of other variables in the system.

There were two goal seeking balancing loops in the food system under study. Loops 44 and 47 show the importance of food processing in the system. In these loops, though seedlings from breeders and agrochemical and tractors were resisting the growth of food security, food processing worked to reduce the effect of food lost and its impact on food consumed.

Dominant Loops in the Food System

Two important feedback loops were identified as particularly dominant within the food system. These loops affected multiple variables across the system. The first highlights how the use of agrochemicals and tractors can unintentionally undermine food security. The second uncovers the implications of food system reliance on outsourced seeds from commercial seed companies for planting, which can also negatively impact the system's resilience and sustainability.

1. ***The Impacts of Outsourcing Seeds for Planting on Food Security-*** The causal loops diagram presented in Figure 2 shows that outsourcing seeds for planting from seed companies can have complex impacts on food security. This can be viewed through the lens of various factors:

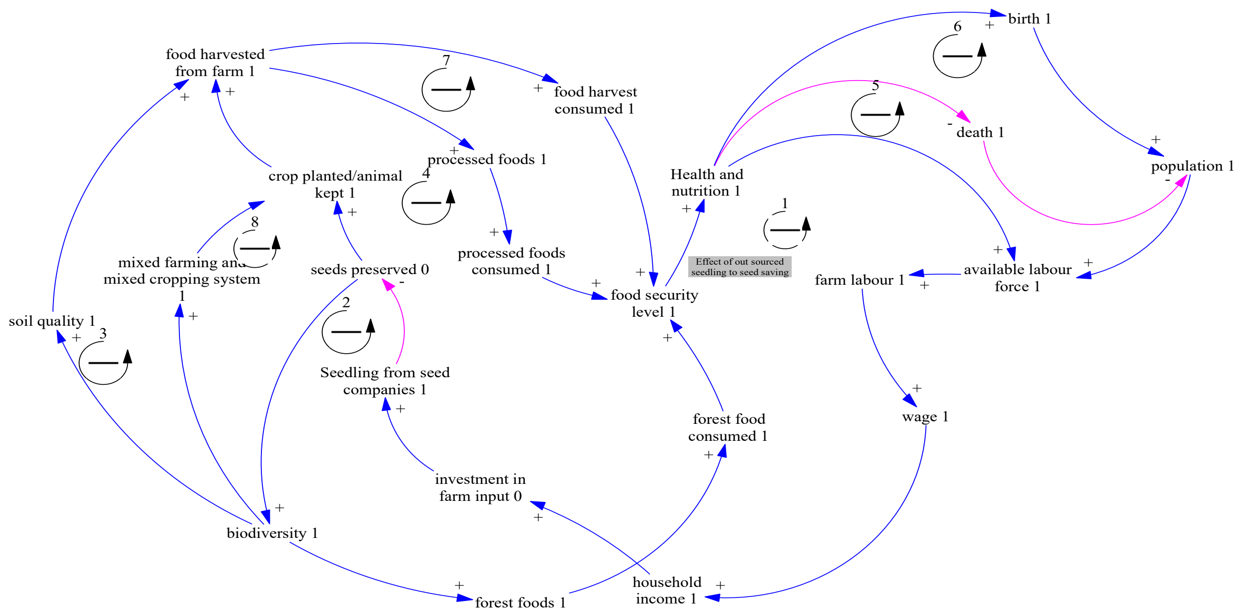


Figure 7. 2 :Outsourcing the Seeds for Planting and the Impact on Food Security

Economic Implications: Increased financial investment in agricultural inputs can lead to greater economic activities in the input sector, enhancing job opportunities and incomes. See the reinforcing loop between investment and seedlings from seed company (Figure 2). However, dependence on purchased seeds may increase operational costs for farmers and impact the cost of food production.

Agricultural Biodiversity: Outsourced seeds often represent a limited variety of crops, which could reduce biodiversity and resilience of food systems. Local seed-saving practices are stifled by the uniformity of commercial seeds, potentially leading to loss of indigenous varieties and knowledge.

Soil Health and Agrochemicals: The focus on high-yield varieties might encourage intensive use of agrochemicals, affecting long-term soil fertility and the environment.

Seed Sovereignty and Security: Farmers who rely on seed companies may face issues of seed sovereignty, losing control over their seed supply and becoming dependent on the fluctuations of the market.

Social and Cultural Impact: Local seeds have cultural significance and tell their stories. So, the loss of local seeds may have economic implication of losing traditional farming practice and knowledge as well as eroding the people's culture. There might be a loss of knowledge associated with local seed varieties and farming practices, which are crucial for the cultural identity of communities. Outsourcing seeds might yield short-term gains in production but can compromise long-term sustainability if not managed properly.

2. *Agrochemicals and Tractors Could Deter Food Security*

Although agrochemicals and tractors contributed positively to monocropping, it brought a force of resistance to the growth of food security through its feedback relationships in the system.

The feedback loop presented in Figure 3 illustrates that the use of agrochemicals and tractors in farming, intended to enhance food security, inadvertently creates resistance within the system. This resistance manifests through its direct impact on soil quality, mixed cropping, and biodiversity, its indirect relationship to monocropping, and the reliance on seedlings from seed companies. The feedback loops suggest that while these agricultural practices contribute to monocropping and short-term economic gains, they pose long-term threats to food security. This is evident in the various pathways from food security to health and nutrition, involving labour, wages, household income, and farm inputs. These pathways show the interconnectedness of agrochemicals and tractors with various aspects of the food system.

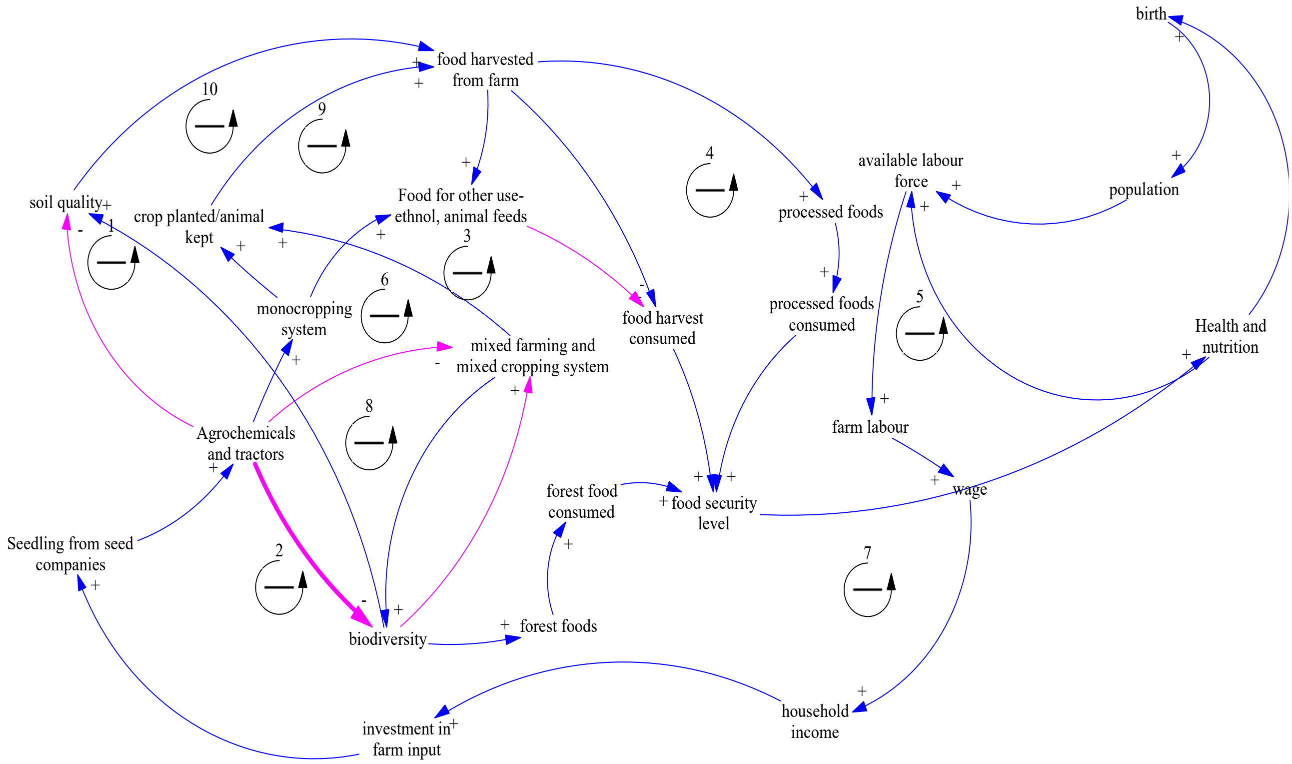


Figure7. 3 linkages between Agrochemicals and Tractors Use and Food security

As one of the main drivers of the food system, the use of agrochemicals and tractors were further explored. The tree diagram makes it easy to trace the direct and indirect contributions of the variables of the system. Figure 7.3, alongside **Error! Reference source not found.** and **Error! Reference source not found.Error! Reference source not found.** (see A5), illustrated that agrochemical and tractor use, supported by subsidies, aligns with the growth of monocropping. While this system can enhance short-term productivity, it undermines long-term sustainability by degrading soil quality, reducing biodiversity, and weakening mixed cropping systems. Furthermore, reliance on industrial seed systems increases farmers' vulnerability to policy shifts, subsidy reductions, and fluctuating input prices- risking the financial and food security of smallholder farmers.

Agrochemical and the use of tractors were identified as a root cause variable of the food system given the number of outgoing arrows it has. The agrochemicals considered in this variable include herbicides, insecticides, inorganic fertilizers, fungicides, and disinfectants. From the tree diagram (Figure 7.8 in Appendix 5), agrochemicals and tractors were very dependent on two variables, seedlings from seed companies and input subsidies. In the use tree diagram presented in Figure 7.9 (see appendix 5), the variable, agrochemicals and tractors, feeds into 4 important elements of the food system. It had a direct relationship with biodiversity, mixed cropping, monocropping and soil quality. For the four variables using agrochemicals and tractors, only monocropping had a positive reinforcing relationship with agrochemicals and tractors. Biodiversity had a direct and dominant negative relationship with monocropping reflected in the bold negative red arrow from agrochemicals and tractors to biodiversity. Agrochemicals and tractors also had an indirect bold negative red arrow link to biodiversity through deforestation. Agrochemicals and tractors also had a negative relationship with the mixed cropping system of farming, and soil quality.

The use tree diagram in Figure 7.9 (see appendix 5) provides insightful details on how agrochemicals and tractors influence various aspects of the agricultural system in Northeast Nigeria. The relationships between these inputs and critical elements like biodiversity, cropping systems, and soil quality highlight the complex interactions that define the sustainability and productivity of agricultural practices. Agrochemicals and tractors facilitate monocropping by providing the necessary tools and inputs to manage large, single-crop fields efficiently. This relationship is reinforced positively as the use of these technologies supports the extensive cultivation of single crops over large areas, maximizing short-term yields and operational efficiency (Tilman et al., 2002; Horlings, & Marsden, 2011). The direct negative impact of agrochemicals and tractors on biodiversity is well documented. Intensive use of agrochemicals often leads to reduced biodiversity, as these chemicals can harm non-target species and disrupt local ecosystems. These tools typically favour large-scale, uniform agricultural practices that reduce habitat diversity and negatively affect soil organisms, plants, and wildlife (Tscharntke et al., 2005). Agrochemicals and tractors typically support more intensive, specialized forms of agriculture, which can be at odds with mixed cropping systems that require different management practices. Mixed cropping relies on the natural synergies between different plant species, which can be disrupted by the uniform application of chemical inputs and mechanical tillage (Altieri, 1999; Lin, 2011).

The role played by Nigerian agricultural extension services and agribusiness companies promoting commercialization of agriculture in Northeast Nigeria is important, but under-represented in food system literature in the local context of chemical inputs and weed killers. Current and successive Nigerian agricultural policies have unequal extension services and incentives toward promoting large-scale, commercial agriculture D'Silva and Raza (1980), and Ecker et al. (2018). This is obvious in the lopsided allocation of extension visits to large farms that receive from 60% of such visits. This unequal allocation of services to large farms, typically encourages the adoption of monocropping and the intensive tractor and agrochemical use. Moreover, the emphasis on input-intensive farming models underscores a wider issue within Nigerian agricultural policy and extension services: the inadequate or lack of support for more sustainable, diverse farming practices that could alleviate the ecological and social needs of the region. These two variables positively reinforced monocropping system of farming in Nigeria. Looking at the diagrams, one of the two variables reinforcing monocropping were also reinforced by investment in farm inputs that is solely supported by income, input subsidy, and seedling from seed companies. So, input subsidies and seedlings from seed companies directly and indirectly reinforce agrochemicals use in the food system. The causal tree diagram highlights the central role of agrochemicals and tractors in the agricultural systems of Northeast Nigeria, identifying these as one of the root cause variables within the food system.

The interdependencies and feedback loops that connect agrochemical and tractor use with other key agricultural variables offer important insights into the dynamics that drive agricultural practices in the region. The heavy reliance on seeds from seed companies and input subsidies underscore a modern agricultural approach that heavily depends on external inputs. The use of commercial seeds, which are often genetically modified or selectively bred for high yields, typically requires specific agrochemical treatments to maximize production. This dependence can create a cycle where the availability of subsidies and commercial seeds directly influences the extent and nature of agrochemical use. Input subsidies make it economically viable for farmers to purchase expensive agrochemicals and use machinery, which is typically necessary for large-scale monocropping. Similarly, the reliance on seeds from seed companies often means these crops are designed to perform well under chemically intensive and mechanized cultivation, thus reinforcing the monocropping system. This cycle is financially underpinned by input subsidies, creating a feedback loop that reinforces itself. The cycle is further reinforced by economic structures that support investment in farm inputs, underpinned by income from agricultural operations, input subsidies, and the availability of commercial seeds. This cycle highlights a systemic push towards intensive, input-driven agriculture. However, dependence on input subsidies and commercial seed systems can make farmers vulnerable to changes in policy, subsidy cuts, and fluctuations in input prices, potentially jeopardizing their financial situation (Horlings & Marsden, 2011). Extensive use of agrochemicals can lead to soil degradation, reduced biodiversity, pollution, and the buildup of chemical residues in the ecosystem, which can have long-term detrimental effects on environmental health and food safety (Tilman et al., 2002).

7.3 Cause and Use Tree Diagram of the Food System

In the causal loop diagram (See 7.1), six system drivers were identified - agrochemicals and tractors use, already discussed, as one of the dominant feedback loop of the system, food harvest, monocropping, mixed cropping, health and nutrition, and land used for agriculture. Among these, four are considered root cause variables due to their significant number of outgoing arrows, which are indicative of their influence within the system. These root cause variables - food harvest, monocropping, mixed cropping, and agrochemicals and tractors, each respectively featured six, six, six, and four outgoing arrows. These elements are instrumental in determining the outcomes of the food system.

The factors contributing to these growth and resistance were explored further by looking at the use and cause tree diagrams of the key outcomes and root causes in the system generated from the CLD (Figure 7.1). The root cause or main driver variables identified in the causal/feedback loops diagram of the food system were food harvested, mixed cropping, monocropping, and agrochemicals and tractors. The results will present the cause tree and use tree diagrams of these root cause variables in the system to explore their relationship with other variables in the system. Note, variables in brackets in the diagram are variables that have a feedback loop with the key variable under consideration.

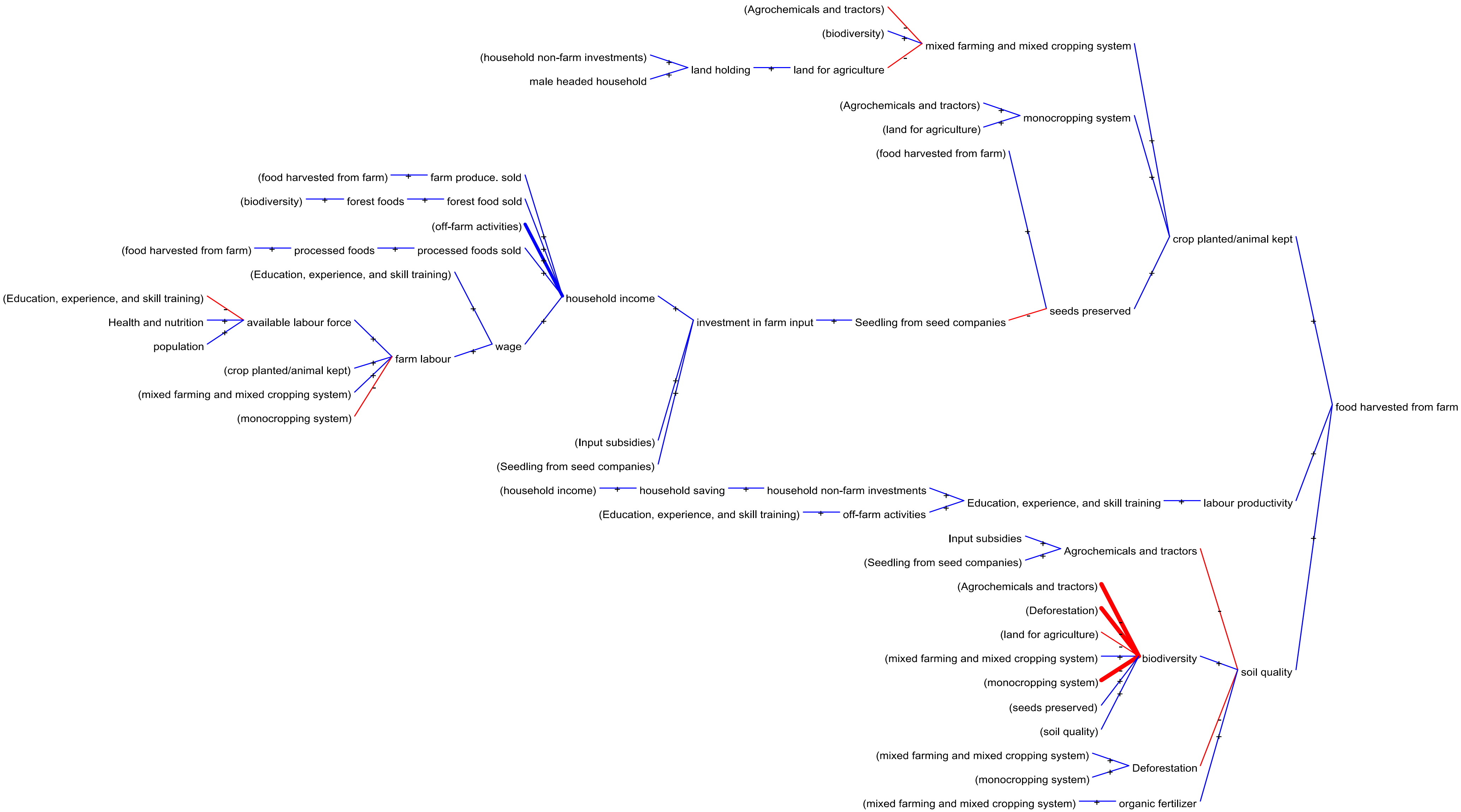


Figure 7. 4 Food harvested causes tree (Blue link= positive arrow. Red Links = negative arrow)

Figure 7. 5 Farm food harvested uses tree (Blue link= positive arrow. Red Links = negative arrow)

Food harvested from the farm which represents both the quantity of food, and the diversity of food farmers get from their farms is one of the root cause variables of the food system. The cause tree diagram presented in Figure 7.4, shows 9 relationship depths of variable that feeds into food harvested from the farm. Area of crop planted/number of animals kept, labour productivity and soil quality were the variables with direct contribution to food harvested from the farms.

Area of Crop Planted/Number of Animals Kept is a direct indicator of potential agricultural output. The extent of land use and animal husbandry directly impacts the volume and diversity of food produced (Pretty et al., 2011). Highly productive labour can significantly enhance agricultural output. Education, training, and experience are crucial in improving labour productivity, as they equip farmers with better techniques and strategies for managing crops and livestock (Feder et al., 2004). Enhancements in labour productivity directly affect food harvest quantities. Training, health, and better working conditions can significantly improve labour efficiency, leading to increased productivity (FAO, 2017). The health of the soil is fundamental for agricultural productivity. Soil quality affects plant growth and yield directly, influencing how well plants can uptake nutrients and how they resist pests and diseases (Lal, 2006). These three variables have a positive reinforcing relationship with food harvest.

At the second depth of the dynamic relationship are the variables that contributed to the first depth variables. Mixed cropping, monocropping, and seed preserved by the farmers for next season planting had reinforcing relationship with crop planted and animal kept. Mixed cropping and monocropping farming practices influence the area of crop planted. Mixed cropping can enhance soil fertility and reduce pest outbreaks, thereby supporting more sustainable agricultural output (Lin, 2011). Monocropping, while sometimes efficient, can lead to soil degradation and increased vulnerability to pests if not managed carefully (Altieri, 1999). The practice of seed saving is essential for maintaining biodiversity and ensuring that farmers have access to seeds that are well-adapted to local conditions, hence contributing positively to crop yields (Kloppenburg, 2010).

Education, experience, and skill training had a positive relationship with labour productivity. For soil health, there were four contributory variables: agrochemicals and tractors, biodiversity, deforestation, and organic fertilizer. Two of these four contributing variables, agrochemicals and tractors, and deforestation had negative relationships with soil health. At a distance depth of the relationship, agrochemicals and land for agriculture had a direct negative relationship with mixed cropping. Seedlings from breeding companies had a direct negative relationship with seed preservation. While agrochemical and tractor use can improve soil productivity in the short term, they can still lead to negative impacts such as soil compaction and reduction in soil biodiversity, ultimately degrading soil health (Montgomery, 2007). The use of agrochemicals can negatively impact the sustainability of mixed cropping systems by degrading soil quality and reducing crop diversity (Wezel et al., 2014). Deforestation has a clear negative impact on soil quality, as it leads to erosion and loss of nutrients, which are critical for sustainable farming practices (FAO, 2015). Using organic fertilizers is a positive practice that enhances soil fertility and structure, promoting better crop yields (Mäder et al., 2002). Increasing access to agricultural education and training can enhance labour productivity and encourage the adoption of sustainable farming practices (Feder et al., 2004).

Assessing the variables that use harvested food as an input (see Figure 7.5). Food harvested from the farm has a positive relationship with farm produce sold, food for other uses such as grain production for animal feed and sugarcane for ethanol production, food harvest consumed, food lost, processed foods, and seeds preserved. This means that an increase (decrease) in food harvested from the farm will lead to an increase (decrease) in these 6 direct use variables.

Tracing the connections from food harvest provides clear illustrations of how harvested food functions as a crucial input within the agricultural and economic systems of Northeast Nigeria. This is key to understanding the flow of food from fields to various endpoints, each of which plays a significant role in shaping food security and economic stability in the region.

Selling farm produce directly influences household and community economic stability. A larger food harvest leads to more produce available for sale, which can enhance farmers' income. This increased income is vital for improving living standards and enabling investment back into the farm, which in turn can lead to a virtuous cycle of productivity and profitability (World Bank, 2007).

Greater availability of food for sale can also affect market prices and supply dynamics, potentially making food more affordable locally if supply outstrips demand (Pinstrup-Andersen, 2014). It is important to note that while utilizing harvested food for purposes like animal feed and ethanol can diversify income sources. It may also divert essential food resources away from direct human consumption (Charles et al., 2010). This diversion needs to be managed carefully to avoid undermining food security. Hence, the use of crops for ethanol production raises questions about the sustainability of biofuels and their impact on food prices and land use (Searchinger et al., 2008).

The most straightforward impact of increased food harvest is more food available for consumption. This can directly improve food security by increasing the quantity and potentially the diversity of food available to local populations (FAO, 2019). Increases in food harvested can lead to increased food loss if not managed properly especially in areas like Northeast Nigeria with poor storage and transportation systems. Strategies to reduce post-harvest losses are crucial for ensuring that the maximum possible amount of harvested food reaches consumers (Gustavsson et al., 2011a).

Processing food can add value and increase the profitability of agricultural produce. It can also help in preserving food, extending its shelf life, and making food available year-round (Aiking, 2011). Processed foods can vary in nutritional quality. Enhancing processing techniques to retain nutritional value while reducing additives is essential for health outcomes (Monteiro et al., 2018).

Preserving seeds from one harvest to the next is critical for maintaining agricultural biodiversity and resilience. Seed preservation allows farmers to be less dependent on seed companies and can ensure that planting materials are well-adapted to local conditions (Kloppenburg, 2010).

The use tree analysis highlights the multifaceted impacts of how food harvested from farms is utilized in Northeast Nigeria. Each pathway from harvest to end-use has implications for economic stability, sustainability, and food security. Strategies to optimize these pathways should focus on enhancing efficiency, reducing waste, and ensuring that food production contributes positively to both economic and nutritional outcomes. Balancing the use of harvested food between direct consumption, sale, and other uses is crucial for sustainable development in the region. This balance requires integrated policies that address market access, storage and processing infrastructure, and the promotion of sustainable agricultural practices.

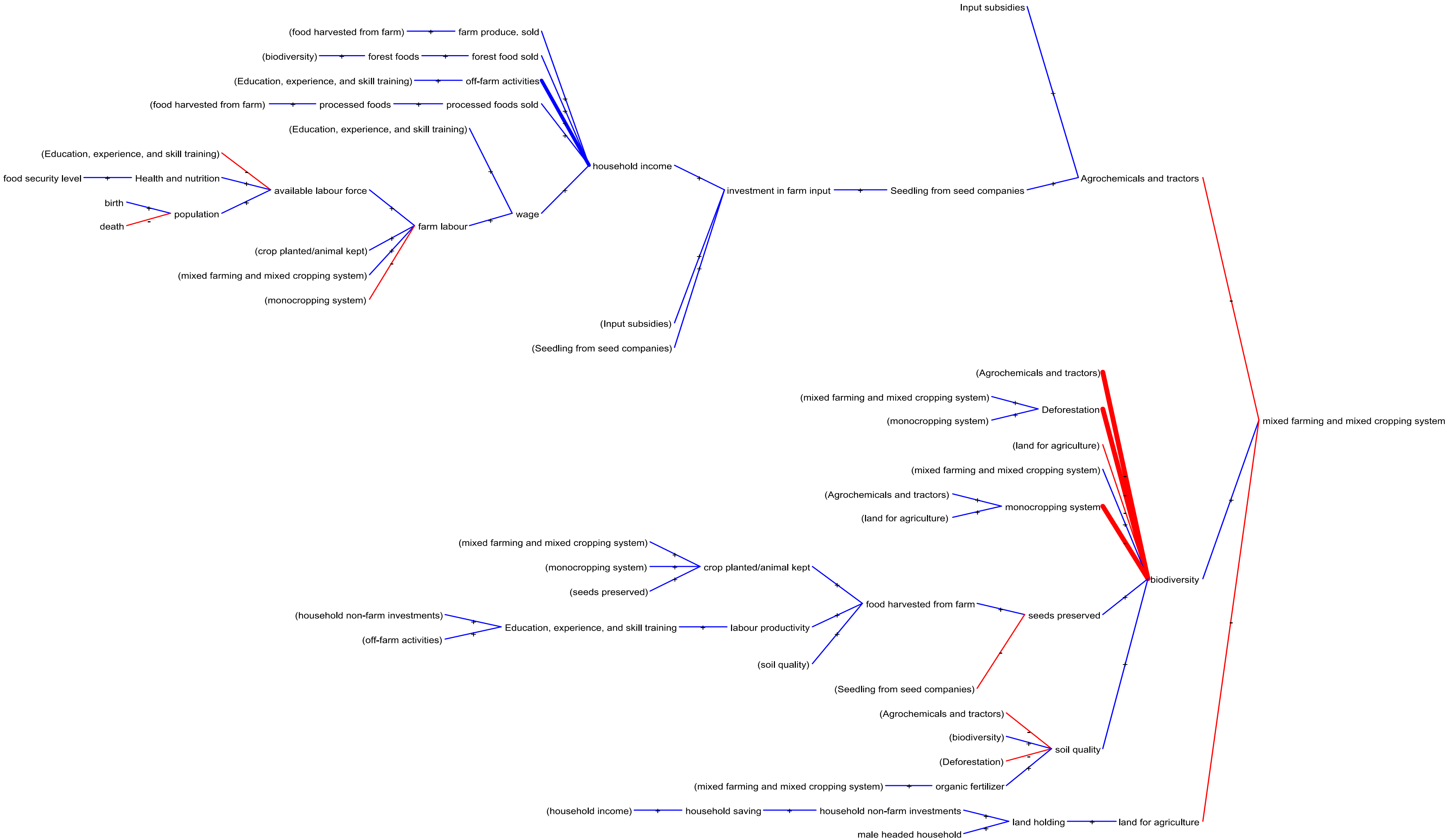


Figure7. 6 Mixed cropping causes tree (Blue link= positive arrow. Red Links = negative arrow)

The mixed cropping practice cause tree diagram in Figure 7.6 shows that Mixed cropping has three variables with direct cause relationship. Out of these three, agrochemicals and tractors, biodiversity, and land for agriculture, only one variable, biodiversity, had a positive relationship with mixed cropping. So, increase (decrease) in biodiversity leads to an increase (decrease) in mixed cropping. Agrochemicals and tractors, and land for agriculture had negative relationships with mixed cropping. Even with two out of three variables limiting mixed cropping, the only positive contributing variable, biodiversity, had many variables in the system resisting its growth. Hence, the variables limiting the growth of biodiversity indirectly limits the growth of mixed cropping. So, there is an overwhelming limitation in the system for mixed cropping practice.

The analysis of the mixed cropping practice cause tree diagram (Figure 7.6) highlights the intricate dynamics influencing the viability and success of mixed cropping systems in Northeast Nigeria. These interactions underscore the complexity of agricultural practices and their dependence on environmental and socio-economic factors.

Biodiversity enhances mixed cropping by supporting ecosystem services such as pest control, pollination, and nutrient cycling- essential for sustaining multiple crops within a single system (Tscharntke et al., 2005, 2012). Strengthening biodiversity fosters ecological balance and agricultural diversity, promoting resilience and sustainability in food production (Lin, 2011).

Despite its benefits, biodiversity is constrained by factors such as land use changes, deforestation, and the dominance of monoculture which reduce habitat diversity essential for a robust ecosystem (Altieri, 1999).

Agrochemical use and mechanization, common in intensive monoculture, negatively affect mixed cropping by disrupting soil structure, depleting organic matter, and diminishing biodiversity (Horlings & Marsden, 2011). While these practices may initially boost agricultural output, long-term effects include soil degradation, reduced microbial diversity, and impaired natural pest control, making mixed cropping less viable (Horlings & Marsden, 2011). Mechanization, particularly tractor use, often favours large-scale monoculture due to its reliance on uniformity and simplified management (Wezel et al., 2014).

Large-scale land use, driven by management efficiency and short-term economic gains, can discourage mixed cropping despite its long-term sustainability (Altieri, 1999). Additionally, land allocation policies that prioritize monoculture restrict the availability of land for mixed cropping, which, though labour-intensive, yields greater environmental benefits (Wezel et al., 2014).

The cause tree diagram indicates that mixed cropping in Northeast Nigeria faces systemic barriers largely due to agricultural policies and practices that do not support biodiversity. The negative impacts of agrochemicals and the allocation of land for agriculture suggest a policy environment and agricultural practice that may prioritize short-term yields over long-term sustainability and ecological health. The cause tree analysis reveals that while biodiversity promotes mixed cropping, the negative impacts of agrochemicals, tractors, and land management practices for agriculture pose significant barriers. Furthermore, the factors that limit the growth of biodiversity also indirectly constrain the expansion of mixed cropping. This constraint includes resistance to biodiversity growth and overwhelming system limitations.

Factors such as deforestation, urbanization, and intensive agricultural practices reduce natural habitats, decrease species diversity, and thus limit the ecological benefits that support mixed cropping (Tscharntke, Clough, et al., 2012; Tscharntke, Tylianakis, et al., 2012). The predominance of factors that inhibit biodiversity, coupled with agricultural practices that favour monoculture, creates a challenging environment for implementing mixed cropping despite its benefits for sustainability and resilience.

Despite the overwhelming limitations for mixed cropping indicated by the cause tree diagram, the positive impact of biodiversity presents a valuable leverage point. Enhancing biodiversity not only supports mixed cropping but also contributes to a more resilient and sustainable agricultural system. Addressing the negative impacts of agrochemicals and inappropriate land use is crucial for enabling mixed cropping practices that can lead to improved food security and sustainable agricultural development in Northeast Nigeria

To encourage mixed cropping, policies should focus on promoting agricultural biodiversity. This could involve supporting seed banks, local seed systems, and farming practices that encourage crop and varietal diversity (Kloppenburg, 2010). Adjusting the regulation and use of agrochemicals to support more sustainable practices could help mitigate their negative impact on mixed cropping systems. Encouraging the use of organic fertilizers and integrated pest management could be beneficial (Pretty, 2008). There is need to also reform land use policies to support small-scale farming, and mixed cropping can help maintain the viability of diverse agricultural practices that are crucial for long-term sustainability. Developing land use policies that support mixed cropping can help ensure that adequate land is available for these practices. This might include zoning regulations that promote diverse cropping systems or providing incentives for farmers who adopt sustainable practices.

Figure 7. 7 Mixed cropping uses tree (Blue link= positive arrow. Red Links = negative arrow)

Figure 7.7 shows that mixed cropping feeds into five variables in the system. Mixed cropping had positive direct relationships with biodiversity, crop planted/animal kept, deforestation, farm labour, and organic fertilizer. The tree diagram also shows that mixed farming had two different relationships with biodiversity. One is direct positive reinforcing feedback between mixed cropping and biodiversity, and the second is an indirect negative balancing loop through deforestation. So, mixed cropping is an important driving force in the achievement of biodiversity.

Figure 7.7 underscores the complex and dualistic role of mixed cropping in the food system of Northeast Nigeria, particularly regarding its impact on biodiversity and sustainable agricultural practices. Figure 7.7 illustrates the multifaceted interactions mixed cropping has within the agricultural system: contributing both positively and negatively to different variables, which are essential for understanding the overall dynamics of food security and ecological sustainability. Mixed cropping, a practice where multiple crop species are planted together in the same area, has significant implications for biodiversity, farm productivity, and environmental sustainability.

Mixed cropping inherently promotes biodiversity by cultivating a variety of plants in the same space. This diversity helps to mimic natural ecosystems, which can lead to more resilient agricultural systems. The direct positive relationship between mixed cropping and biodiversity enhances the ecological resilience and sustainability of agricultural practices.

Mixed cropping can increase the efficiency of land use, as different plants can complement each other's growth needs. For instance, leguminous plants can fix atmospheric nitrogen, making it available in the soil for other plants that require high nitrogen levels to grow well. This synergy can lead to higher overall productivity, and support more diverse livestock by providing a variety of forage options (Pretty, 2008, Lin, 2011).

The practice of mixed cropping often goes hand in hand with the use of organic fertilizers. Organic matter from diverse plants contributes to soil fertility when it decomposes. This enhances soil structure and fertility, leading to better water retention and nutrient availability, which benefits all crops in the mix (Pimentel et al., 2004).

Despite its benefits, mixed cropping can have unintended negative consequences, particularly through the mechanism of deforestation. To implement mixed cropping on a larger scale, farmers might clear more land, including forested areas. This deforestation negatively impacts biodiversity, contradicting the biodiversity gains made within the cropped area. The loss of forest cover not only reduces habitat for wildlife but also affects the functionality of entire ecosystems, such as water cycling and carbon storage (Foley et al., 2005).

There is a need for agricultural policies that encourage sustainable land management practices that integrate mixed cropping without expanding the area of agricultural land at the expense of forests. Incentives for agroforestry, where trees and crops are combined, could be one such strategy. Farmers should be educated on the benefits of mixed cropping not only for their crop yields but also for maintaining local biodiversity. Training on sustainable farming techniques that minimize land clearing can also be beneficial.

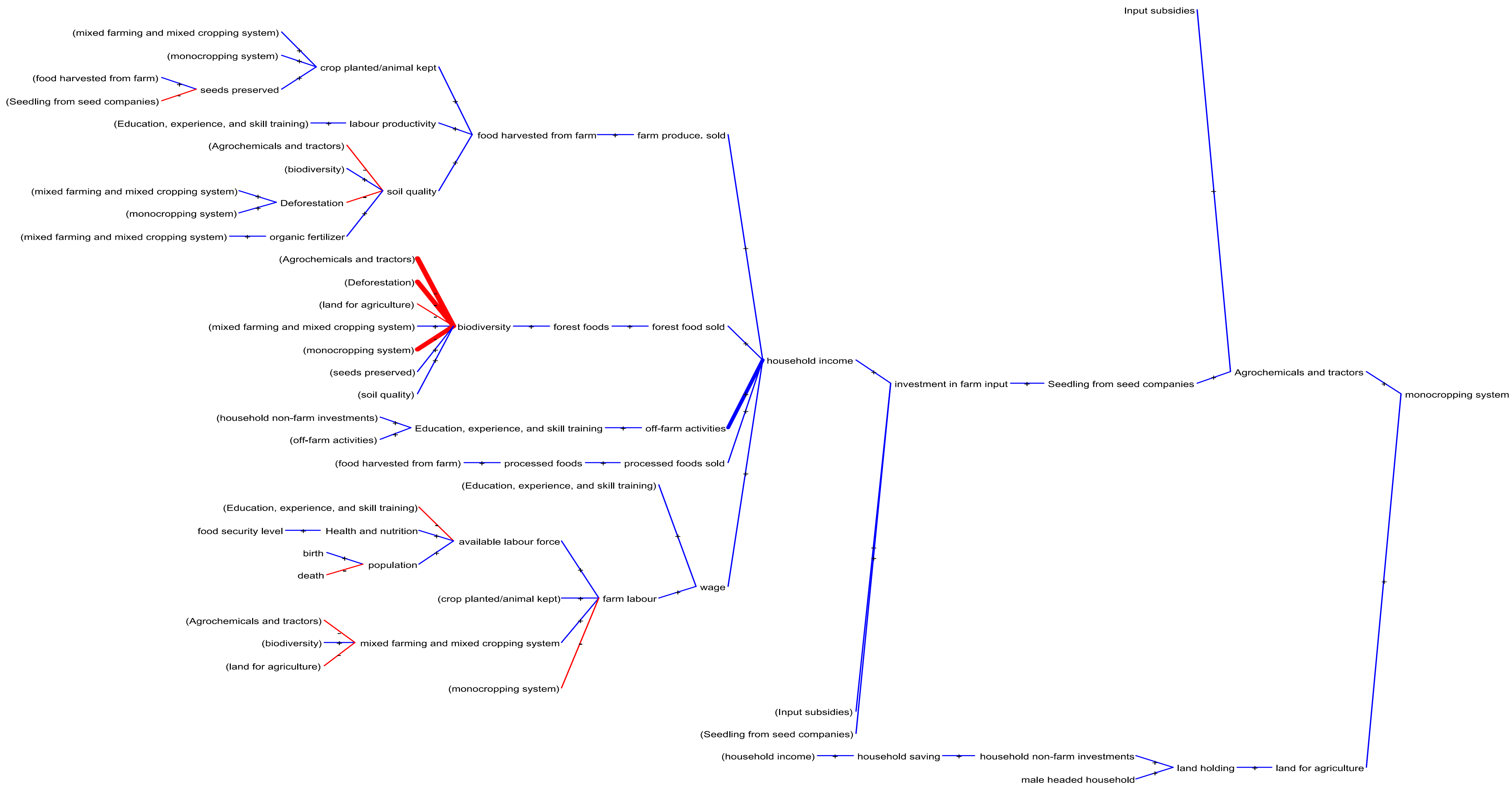


Figure7. 8. Monocropping causes tree (Blue link=positive arrow. Red links= negative arrow)

Monocropping practice currently dominating developed countries' farming is seen to be sustained by two contributing variables- agrochemicals and tractors, and land for agriculture. Unlike mixed farming with two negative relationships and one positive relationship, monocropping had its two positive contributing relationships. Monocropping started showing resistance at the 6th depth of its relationship, where it reduced farm labour in a feedback loop, affecting wages. Figure 7.10 (See Appendix 5) shows that at the second depth of the relationships, input subsidies and seedling from seed breeder are the leading factors to agrochemical and tractor usage. So, the more (less) the input subsidies and seedling from seedling companies, the more (less) the use of agrochemicals by farmers. The amount of land held by households has direct relationship with the amount of land they allocate to farming, and the system of farming practiced. The third depth of relationship in Figure 7.10 shows that the two second depth relations are supported by investment in farm inputs and non-farm inputs, and the socioeconomic factor- gender in the case of land holding. These investments came from household income. The result from the causal loop diagram reflects the dynamics of monocropping practices, and how various factors support or resist this agricultural system. Monocropping, characterized by the cultivation of a single crop species over a large area and over successive seasons, relies heavily on specific agricultural inputs and practices.

Monocropping relies heavily on the input of agrochemicals and the use of tractors, which enhance the efficiency of farming large single-crop fields. These tools allow for extensive cultivation of a single crop over a large area by reducing labour costs and increasing land productivity. The relationship is sustained by subsidies and the availability of commercial seedlings, which make these inputs more accessible and economically viable for farmers (Tilman et al., 2002). Input subsidies and the availability of seedlings from breeding companies significantly influence the use of agrochemicals and tractors. These inputs are critical for maintaining the high productivity demanded by monocropping systems. Subsidies make these inputs more affordable, encouraging their widespread use, which is essential for managing large areas of a single crop effectively (Horlings & Marsden, 2011).

The amount of land a household holds directly influences their ability to engage in monocropping. Larger land holdings are more conducive to monocropping due to economies of scale, where the cost per unit of production can be reduced, making it a more viable option (FAO, 2017). Gender and other socioeconomic factors influence land holding patterns, which in turn affect the farming system practiced. Men typically have access to more land and resources, which supports more extensive monocropping practices.

At the 6th depth of relationships, monocropping begins to show resistance through its impact on farm labour. By reducing the need for labour, monocropping can suppress wage growth, which in turn affects the local economy and can feed back negatively into the monocropping system itself by reducing the available income for reinvestment in agricultural inputs. This reduction in labour demand can subsequently affect wage levels and employment opportunities in farming communities, potentially feeding back into reduced community support for monocropping if alternative employment is not available. Investment in farm inputs is influenced by household income, which is itself a product of the economic success of farming practices. Non-farm income and investments also play a role, diversifying the economic base of rural households and affecting their farming decisions.

While monocropping can enhance short-term productivity and economic returns, its long-term sustainability is questionable due to its reliance on chemical inputs, susceptibility to pest outbreaks, and the negative impacts on soil health and biodiversity (Altieri, 1999). Sustainable practices such as crop rotation, integrated pest management, and organic farming could mitigate some of the negative impacts of monocropping. Economically, reliance on a single crop can also pose risks if market prices fluctuate or if the crop fails due to disease or adverse weather conditions (Altieri & Nicholls, 2004).

Understanding the complex interactions between agricultural practices, economic policies, and socioeconomic factors is crucial for developing sustainable farming strategies that balance productivity with environmental and social health. The dynamics described in the causal loop diagram offer insights into how changes in policy or practice might ripple through the agricultural system, affecting everything from soil health to household income and labour dynamics. These insights are essential for policymakers aiming to enhance the sustainability and resilience of agricultural systems.

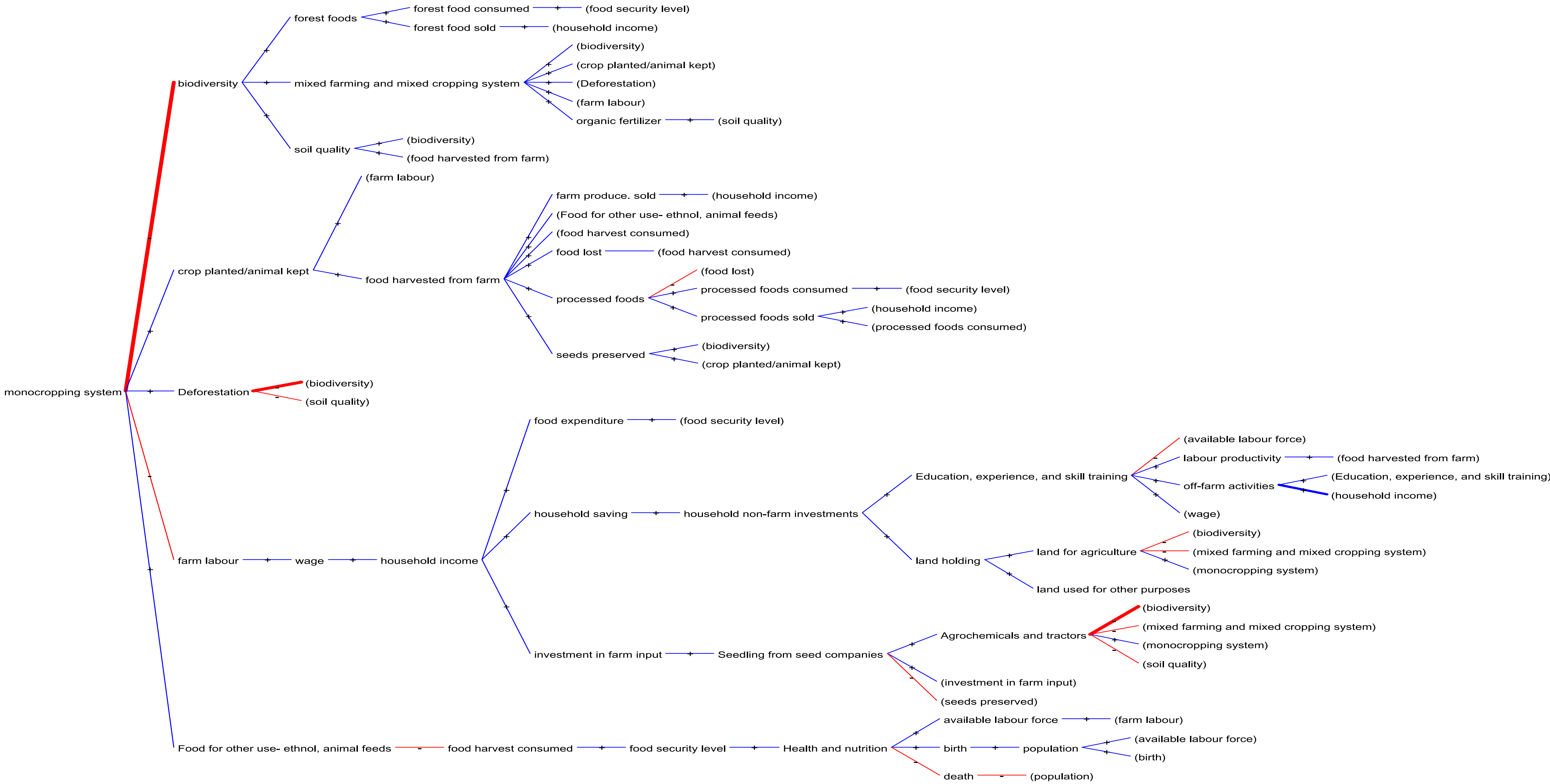


Figure 7. 9 Monocropping Use tree (Blue link=positive arrow. Red links= negative arrow)

Like mixed cropping, monocropping also drives five important variables in the food system. Figure 7.11 shows that monocropping has direct relationships with biodiversity, crop planted, deforestation, farm labour, and food for other purposes. There are 3 positive and 2 negative direct relationships in the monocropping use tree. Monocropping had a positive direct relationship with crop planted deforestation and food for other uses. Biodiversity and farm labour had a negative relationship with monocropping. Hence, monocropping has two negative relationships with biodiversity. One is a direct negative relationship that shows that increase (decrease) in monocropping practice leads to decrease (increase) in biodiversity. The second negative relationship is an indirect relationship through deforestation to biodiversity and soil health. There is a negative relationship between mono cropping and farm labour. So, the adoption of monocropping leads to reduction in the need for farm labourers.

The results regarding monocropping and its impact on various variables within the food system of Northeast Nigeria provide insightful observations on the dynamic interactions between agricultural practices and their wider environmental and economic effects. Monocropping, the agricultural practice of cultivating a single crop species over a wide area and over successive seasons, plays a significant role in shaping the food system's structure and sustainability.

Monocropping has a direct positive relationship with the area of crop planted. Typically, monocropping involves extensive cultivation of a single crop, which simplifies planting and harvesting processes, potentially resulting in an increased area under cultivation. Without considering the consequence of this system of farming, it can enhance short-term agricultural productivity and food availability (Tilman et al., 2002).

The expansion of monocropping can lead to deforestation as more land is cleared to accommodate large-scale single crop farming. This relationship is particularly evident in places like Nigeria where large tracts of land are converted into agricultural land to meet the demands of these growing high-yield crops (Mongabay, 2020; Ogunwale, 2015; World Resources Institute, 2021).

Monocropping is often associated with the production of crops for industrial uses, such as biofuels and animal feed. Crops like sugarcane, corn, and soy, often grown in monocultures, are used extensively in these sectors, linking monocropping positively with the production of non-food items. This can be economically beneficial but may divert essential resources away from food production (Searchinger et al., 2008).

Monocropping negatively impacts biodiversity both directly and indirectly. Directly, it reduces the variety of species planted in a given area, which can diminish agro-biodiversity and lead to a reduction in ecosystem services such as pest control and pollination. Indirectly, by promoting deforestation, monocropping can lead to the loss of diet diversity and natural habitats, further reducing biodiversity at the landscape level (Tscharntke et al., 2012).

Monocropping can reduce the need for farm labour due to the mechanization and simplification of agricultural practices associated with growing only one type of crop. While this might reduce labour costs and increase land productivity, it can also lead to job losses and less diverse agricultural knowledge and skills among the local workforce (Daum et al., 2023).

Deforestation resulting from monocropping indirectly impacts biodiversity and soil health. Clearing forests for monoculture may compromises soil health by increasing erosion, reducing organic matter, and disrupting nutrient cycles. The reduction in biodiversity due to habitat loss further impacts ecological functions essential for sustainable agriculture (Laurance et al., 2014).

The dynamics shown in Figure 7.11 suggest that while monocropping might offer short-term economic benefits through specialized production, its long-term implications can undermine sustainability and food security. The reduction in biodiversity and the negative impact on soil health can decrease agricultural resilience, making food systems more vulnerable to pests, diseases, and climate variability. Moreover, the reduction in farm labour demand due to monocropping can have socio-economic repercussions, potentially leading to rural depopulation and loss of agricultural knowledge.

Key Outcome Variables of the Food System

In the system feedback loop analysis, the consequence or output elements of a complex system are identified by their number of incoming arrows. Biodiversity, food and nutrition security, household income, farm labour, and soil quality emerged as key outcome variables. Biodiversity and household income also act as system drivers but are not classified as root causes due to their lesser number of outgoing arrows compared to the identified root cause variables.

These key outcome variables are fundamental to understanding the overall dynamics of the system because they are the endpoints that are most affected by the changes within the system. Biodiversity with six incoming arrows and three outgoing ones stands out, showing its two-fold role as both an outcome and a driver in the system, although not a root cause. Food and nutrition security, with five incoming and one outgoing arrow, shows the main goal of the food system, reflecting the impact of various drivers on the well-being of the population.

Similarly, household income, with its five incoming arrows and three outgoing, not only is impacted by the system but also influences it, revealing the interplay between economic factors and agricultural practices. Farm labour and soil quality, each with more incoming than outgoing arrows, are critical to the functionality and sustainability of the system, indicating how labour availability and soil health are influenced by other variables.

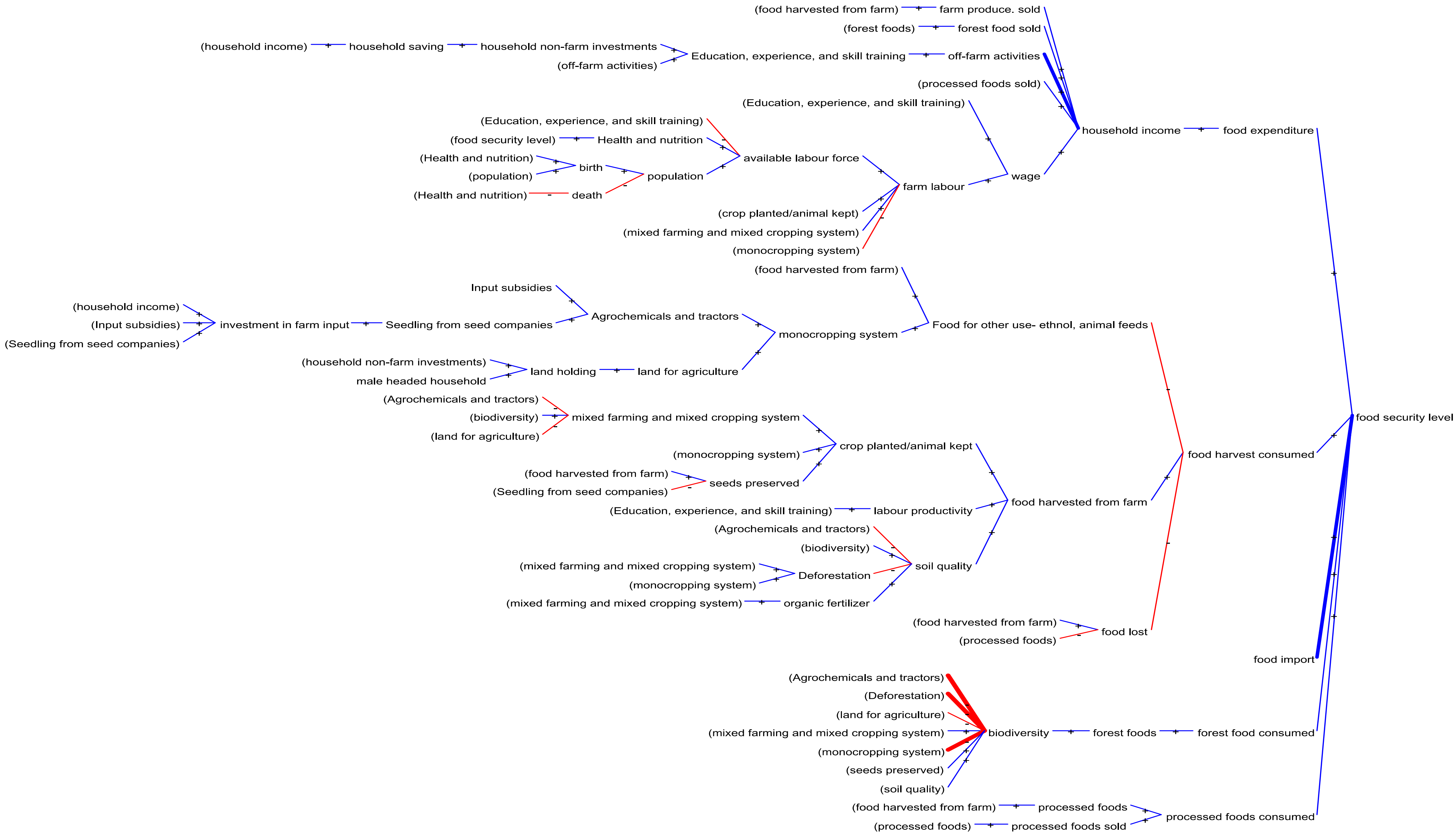


Figure 7. 10 Food security cause tree (Blue link= positive arrow. Red Links = negative arrow)

Figure 7.12 presents a cause tree diagram of one end goal of the food system - Food security. Food security can be seen to be a result of food expenditure, food harvest consumed, food import, forest food consumed, and processed foods consumed. These five causal variables positively reinforced food security level. This means that the more (less) these variables, the more (less) the food security level. Income contributed to food security through enabling food expenditure and there are many variables reinforcing household income in the system.

Food harvested from the farm which had a positive direct relationship with food security, had two variables (food for other uses and food lost) in the system which directly limited its growth.

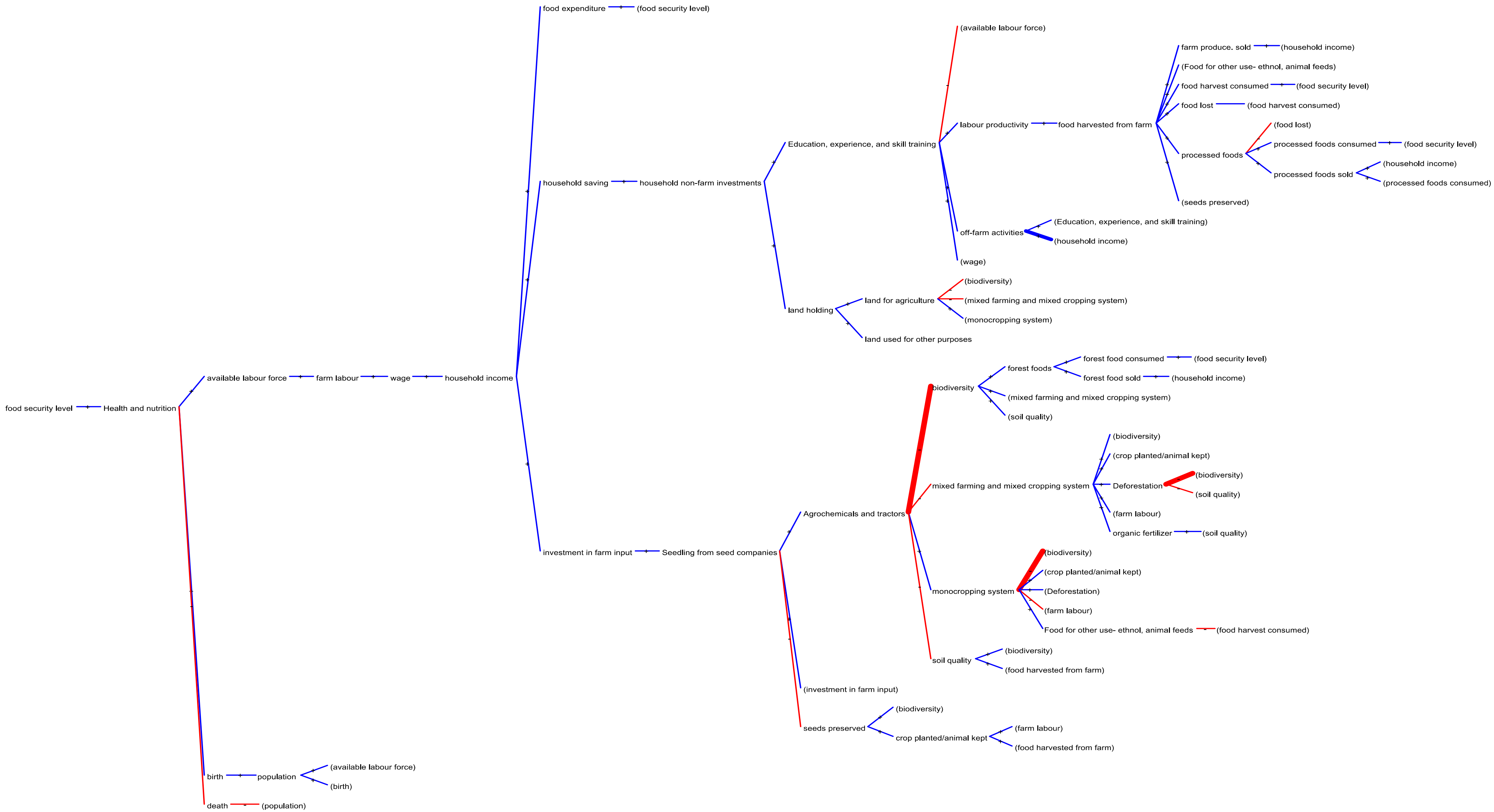


Figure 7. 11 Food security use tree (Blue link= positive arrow. Red Links = negative arrow)

Food security is a key outcome variable that drives one important variable of the system, health and nutrition level. So, other important elements of the food system that results in food security and other desirable outcomes of the system indirectly use food security through health and nutrition. Variables like available labour force, income, food expenditure, and birth and death in the population loops indirectly through health and nutrition level which has a dynamic feedback relationship with food security. Figure 7.13 shows that income is a very important variable of the food system, and it has a reinforcing relationship with food security up to the 5^{th} depth of relationships.

The tree diagram analysis of food security in the food system delves into the complexities of how harvested food directly affects food security and how certain factors within the system can either limit or enhance this effect.

As the primary source of food, the quantity and quality of food harvested directly impacts food security. The direct positive relationship between food harvested from farms and food security is intuitive-more food produced leads to greater availability for consumption, which enhances food security. This direct link underscores the primary role of agricultural productivity in the broader context of food security. However, this relationship is complicated by two variables, food for other uses and food lost, which can potentially reduce food availability for human consumption (Charles et al., 2010).

Food losses can occur due to several reasons, including inadequate storage, poor handling, and inefficiencies in the food supply chain. These losses can occur at various stages, from post-harvest losses during storage and transport to spoilage. Food loss reduces the effective output from agriculture, directly impacting the food availability for consumption, thus limiting food security (Gustavsson et al., 2011b).

Food security significantly drives health and nutrition levels, establishing a foundational role in promoting a healthy and productive labour force. Improved nutrition enhances individual health, which in turn can lead to increased productivity and an ability to engage in more labour-intensive tasks, thereby influencing agricultural output and economic activities positively.

Improved health and nutrition increase the available labour force, enhancing productivity and potentially leading to higher income. Increased income allows for better food access and diversity, further reinforcing food security (Black et al., 2013). As income resulting from higher productivity increases, households can spend more on food, improving their food security through access to a variety of nutritious foods. This expenditure is critical in ensuring that their diets are not only calorie-sufficient but also nutritionally adequate (Smith & Haddad, 2015). Health and nutrition have a profound impact on demographic dynamics. Better nutrition reduces mortality rates and can influence birth rates through improved health conditions. These demographic factors indirectly affect the labour force and productive capacity, influencing food security (Martorell & Zongrone, 2012).

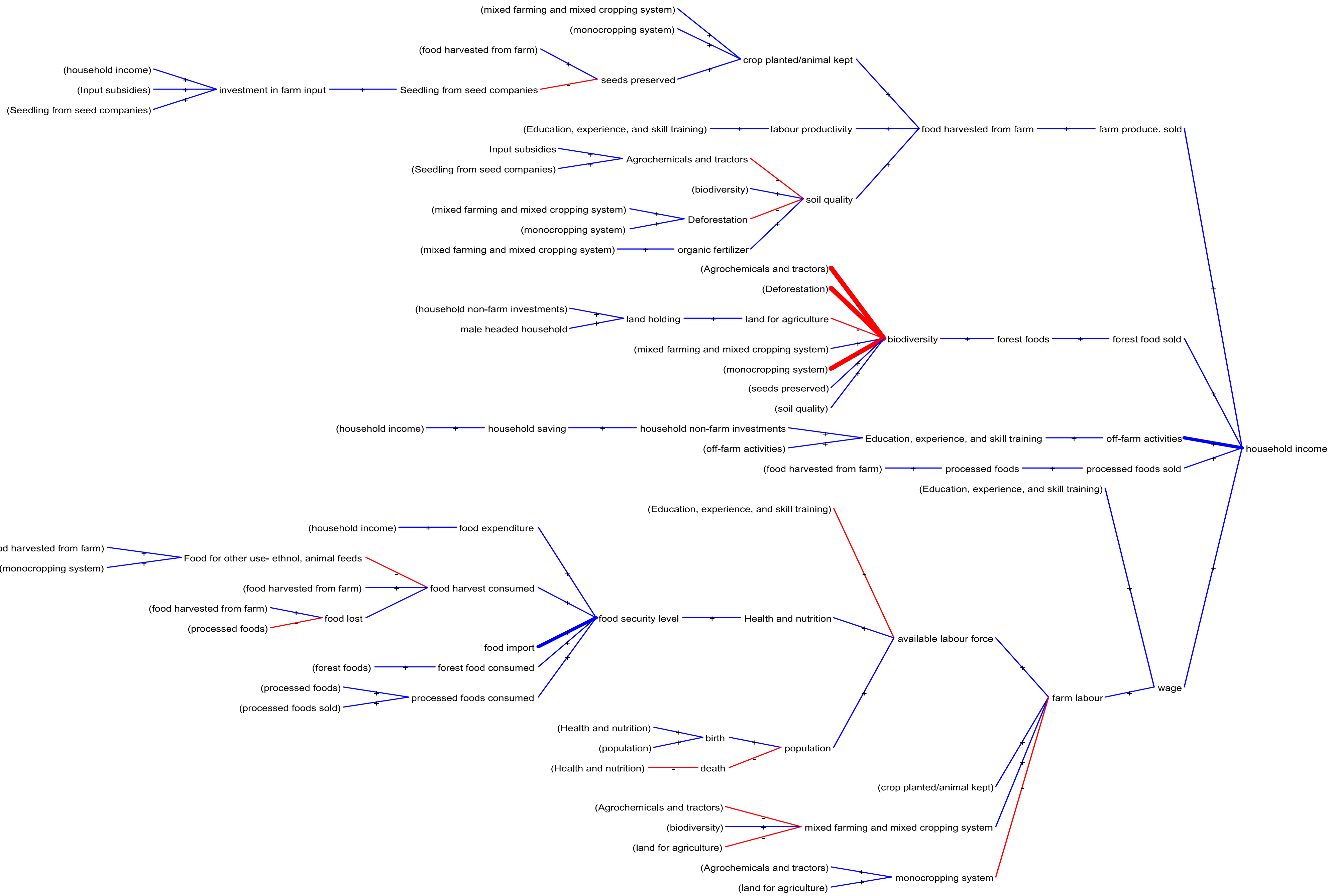


Figure7. 12 Household income causes tree

Another important key outcome variable in the system is household income. Household income in the food system is the direct result of five elements of the system. Households get their income from farm produce sold, forest food sold, off-farm activities which is a major source of income flow for most farming households, processed foods sold, and wages (see Figure 7.14). At the second stage of the cause tree diagram, food harvest from the farm, forest food, processed foods, farm labour, and education, experience and skill training had a positive relationship with the variables that directly reinforce household income. The variable with the closest relationship to household income that had a negative relationship was monocropping and its relationship with farm labour need at the 3rd depth of the tree diagram.

The income cause tree diagram derived from the causal loop diagram illustrates how household income in Northeast Nigeria is intricately tied to various components of the food system. This detailed exploration shows both the direct sources of income and the underlying factors that influence these income streams, painting a comprehensive picture of the socioeconomic interactions within the agricultural sector of Northeast Nigeria. The study effectively identifies several primary and secondary sources contributing to household income, as well as the dynamics influencing these income streams.

Selling farm produce is a primary source of income for many households. The ability to generate income from this channel heavily depends on the quantity and quality of the food harvested, which is influenced by factors such as soil health, farm labour productivity, and the types of crops planted. This aligns with the findings of Lentz, Barrett et al. (2013), who discuss the significance of agricultural productivity in boosting rural incomes.

Similar to farm produce, forest foods provide a significant source of income for households engaged in gathering and selling these wild foods. The sustainability of this income source is linked to the health of local forests and biodiversity, which are impacted by agricultural practices and land use changes. Also, for many farming households, off-farm income is crucial. This can include small businesses, labour in nearby towns, or seasonal work elsewhere. The ability to engage in off-farm activities often correlates with the level of education, skills, and the overall economic health of the region.

The success of this income stream from processed foods is tied to factors such as the availability of raw materials (farm and forest food harvests) and the level of technological and educational advancement in processing techniques. This reflects value addition to agricultural products, which can significantly increase household income. Processing food adds market value and can open new markets.

Income from wages, whether from farm labour or other employment, is a direct contributor to household income. The availability and quality of such jobs are influenced by broader economic conditions, educational opportunities, and labour demands.

Figure 7. 13 Household food security uses tree (Blue link= positive arrow. Red Links = negative arrow)

When the use tree diagram of the household income was extracted, Figure 7.15 shows that income as well as a being a key outcome variable in the system also drives three other variables that have dynamic relationships to outcome and driver variables in the food system. Income had a positive relationship that drives food and nutritional security directly through food expenditure. Household non-farm investments in education, training, and acquisition of land come from household income through household savings. Income had a direct positive relationship with investment in farm inputs. The use of agrochemicals and tractors, investment in farm inputs, and seed preservation by farms for next season planting had direct relationships with seedling from seed companies that gets its source from investment in farm inputs. However, at this 3rd relationship depth in the tree diagram, seeds preservation had a negative relationship with seedling from the seed companies.

The analysis of the use tree diagram in Figure 7.15, provides insightful details about how income functions both as a driver and an outcome within the food system of Northeast Nigeria. This dual role underscores the pivotal position of income in influencing various aspects of agricultural and non-agricultural investments, and consequently, on food and nutritional security.

Income has a direct positive relationship with food and nutritional security, primarily mediated through its linkages with food expenditure. This relationship underscores the basic economic principle that higher household income allows for greater spending on diverse and nutritious foods, thus directly enhancing food security and people's nutritional status (Smith & Haddad, 2015). The ability to purchase sufficient and nutritious food directly affects the health and well-being of households. Research has shown that increased household income leads to better quality diets and improved nutritional outcomes (Drewnowski, 2022).

Income influences non-farm investments such as education, training, and land acquisition through household savings. This pathway highlights the role of income in enabling households to invest in assets and capabilities that can increase their economic resilience and potential for income generation (Lentz & Barrett, 2013). Investments in education and training are particularly significant as they equip individuals with skills and knowledge that enhance labour productivity, potentially leading to higher income. Furthermore, land acquisition can expand agricultural opportunities, thus contributing to increased food production and security.

The positive impact of income on investment in farm inputs such as seedlings, fertilizers, and machinery directly contribute to agricultural productivity. More resources dedicated to farm inputs can lead to higher yields and more stable food supplies.

While investment in modern farm inputs generally supports agricultural productivity, it can negatively impact traditional practices such as seed preservation. The commercialization of seed supply (buying seedlings from companies) may discourage farmers from preserving their seeds, which can affect biodiversity and farmers' independence from commercial seed suppliers (Kloppenburg, 2010). This negative relationship raises sustainability concerns, as reliance on commercial seeds might increase vulnerability to market fluctuations and reduce agrobiodiversity, which is crucial for resilience against pests, diseases, and climate change (M. Altieri & Nicholls, 2004).

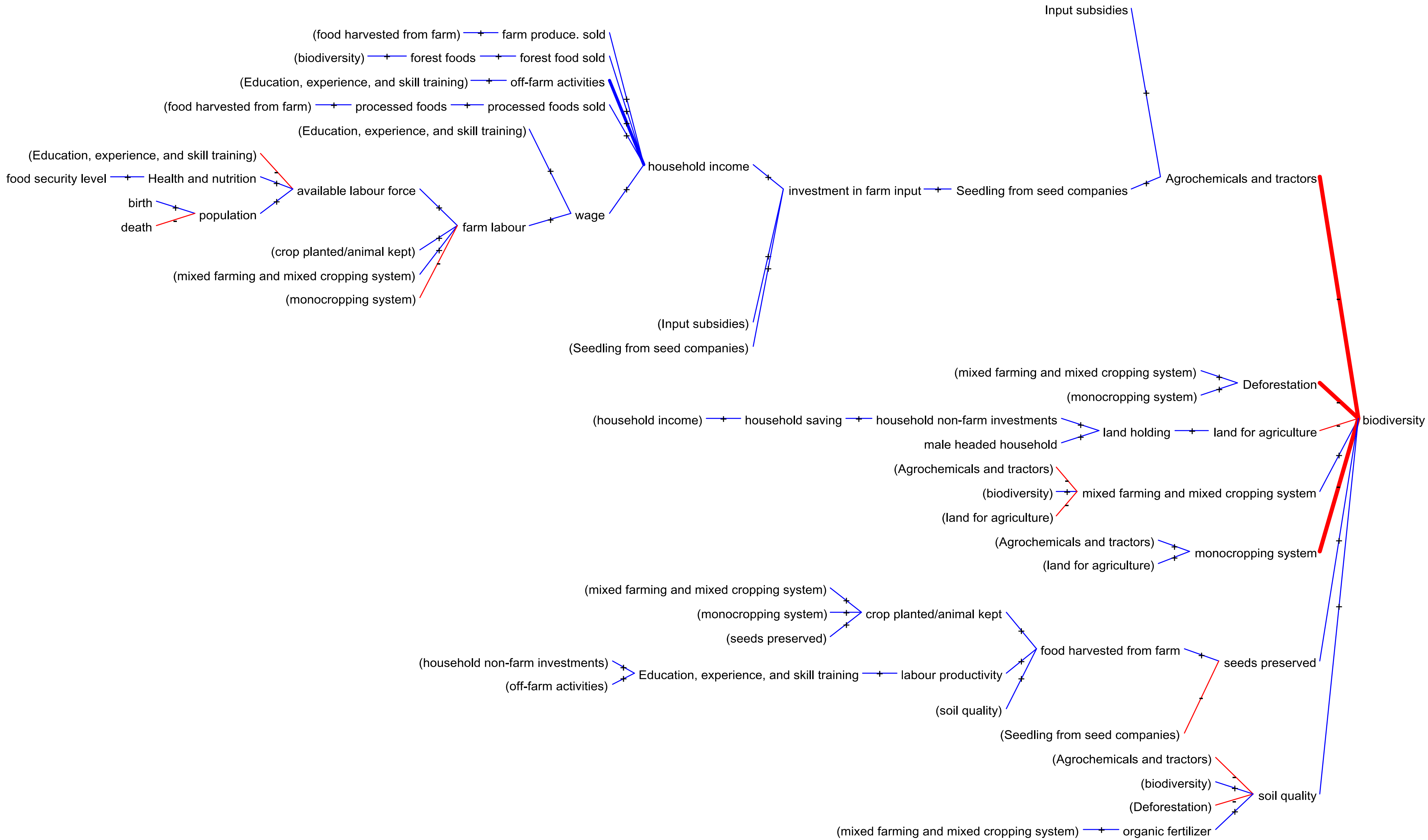


Figure 7. 14 Biodiversity causes tree (Blue link= positive arrow. Red Links = negative arrow)

In the food system, biodiversity is the single element of the system with the highest number of direct relationships with other variables. Figure 7.16 shows that seven elements of the system have direct impact on biodiversity. Among these 7 elements, 4 have negative relationships and 3 have positive relationships with biodiversity. The four variables-agrochemical use and tractors, deforestation, monoculture, and land for agriculture had negative relationship with biodiversity, with the first three having a dominant negative impact as indicated using thick red arrows. These variables with the negative relationship with biodiversity all have a positive relationship with their direct cause variables. The biodiversity direct cause variable with the longest depth of relationship was agrochemicals and tractor use, through its relationship with income.

The result highlighting biodiversity as a critical element in the food system of Northeast Nigeria, with extensive interactions affecting its status, underscores its importance and vulnerability within agricultural practices. The analysis of these interactions offers crucial insights into how different agricultural practices influence biodiversity and, consequently, the sustainability of food systems.

The extensive use of agrochemicals and heavy machinery like tractors often leads to degradation of natural habitats, reduction in soil biodiversity, and contamination of water sources which negatively affects overall biodiversity (Tilman et al., 2001; Tscharntke et al., 2005).

The direct cause relationship between income and the use of agrochemicals suggests that economic considerations often drive their use. Agrochemicals and tractors are typically associated with higher immediate agricultural yields, which translate to increased income for farmers. However, this short-term gain can lead to long-term ecological damage, underscoring the need for sustainable practices that balance economic benefits with environmental health.

Clearing forested land for agriculture is one of the most direct and significant threats to biodiversity. Deforestation leads to habitat loss for numerous species and disrupts ecosystems, resulting in biodiversity loss (Gibson et al., 2011 Foley et al., 2005). Often driven by the demand for more agricultural land or for the sale of timber, deforestation is economically motivated, but ecologically detrimental.

Monocultural practice reduces the diversity of plant species and, by extension, affects the diversity of other organisms including pollinators, soil microbes, and other beneficial fauna (Altieri & Nicholls, 2004). This practice simplifies ecosystems, making them more vulnerable to pests and diseases, which can have catastrophic effects on crop yields and local biodiversity.

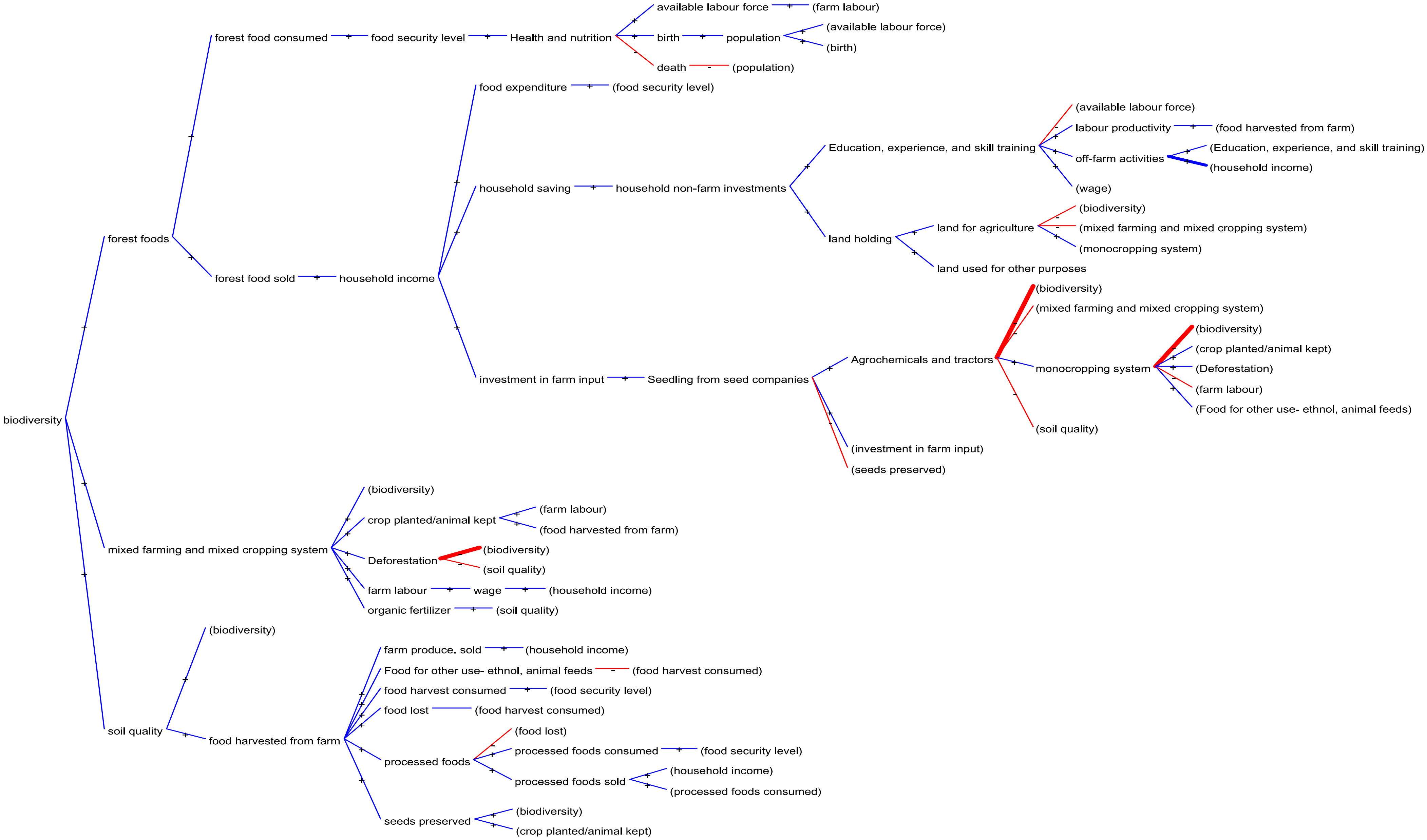


Figure 7. 15 Biodiversity uses tree (Blue link= positive arrow. Red Links = negative arrow)

Biodiversity had positive relationship with three direct cause variables – soil quality, traditional seeds preservation for next the planting season, and mixed cropping system. These positive and direct cause variables of biodiversity had contributing variables that limits their growth. Biodiversity had direct positive use relationship with forest foods, mixed cropping (root cause variable) and soil quality (outcome variable). Apart from soil quality and mixed cropping, biodiversity contributes to two key outcome variables- food security and income through forest foods.

The analysis of the role of biodiversity in the food system of Northeast Nigeria demonstrates its central importance in promoting sustainable agricultural practices and enhancing food and nutritional security. It also provides crucial insights into how various elements of the ecosystem interact with the environment to affect food security and economic outcomes. Through the provision of forest foods and support for mixed cropping, biodiversity directly contributes to food security. These systems are more resilient to environmental stressors and can produce stable yields under a variety of conditions. Healthy biodiversity contributes to a robust ecosystem, which is foundational for productive agriculture (Tscharntke et al., 2012). The use of agrochemicals and heavy machinery (tractors) can compact the soil and reduce its biological activity, porosity and aerobic condition thereby negatively impacting soil quality.

Biodiversity supports the preservation of traditional seeds by maintaining a variety of genetic resources that can adapt to local conditions and resist pests and diseases. It ensures a wide gene pool necessary for the resilience of crops to varying conditions. Diverse genetic resources enable farmers to select seeds that are best adapted to local conditions (Kloppenburg, 2010). The introduction of seedlings from seed companies often focuses on high-yielding varieties that may displace traditional varieties, thus reducing genetic diversity and the resilience of the system (Kloppenburg, 2010; FAO, 2014).

Concerning the direct use relationships, biodiversity supports a variety of forest foods, which contribute significantly to food security and dietary diversity in rural communities. Biodiversity directly contributes to the availability and variety of forest foods, which are vital for food security and nutritional diversity. Forest ecosystems rich in biodiversity tend to have a higher abundance and variety of edible plants and animals, offering crucial nutritional resources to local communities (Bhagwat et al., 2008). Forest foods also provide an important source of income for local communities, as they can be collected and sold with minimal investment (Sunderland et al., 2015).

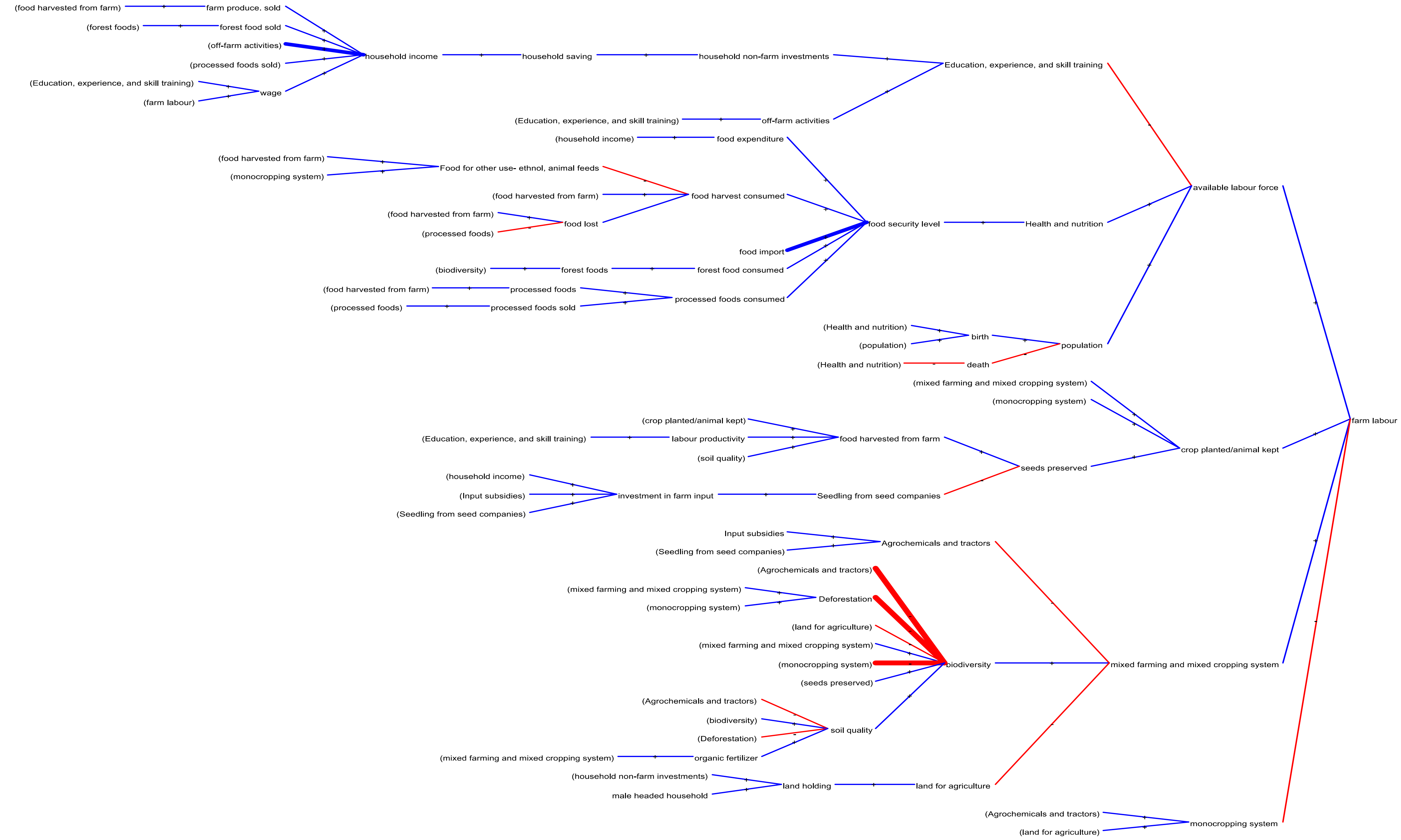


Figure7. 1816 Farm labour cause tree (Blue link= positive arrow. Red Links = negative arrow)

Figure 7.18 shows that farm labour has a direct cause relationship with four variables of the food system- monocropping, mixed cropping, area of crop planted and number of animals, and available labour force. Three of these variables: mixed cropping and mixed farming, crop area planted, and animals kept, and available labour force had a positive relationship with farm labour. Their increase or decrease leads to the increase or decrease in the need for farm labour. Monocropping is seen to have a negative relationship with farm labour. The more the farmlands is used for monocropping, the less the need for farm labour, and vice versa. Figure 7.18 shows that available farm labour has a negative relationship with education, experience, and skill training, and has a positive relationship with population, and health and nutrition. Farm labour and crop area planted, and number of animals kept had a positive relationship. Mixed cropping and mixed farming require more manual labour than monocropping which substitutes for manual labour with machines and chemicals.

Figure 7.18 clearly outlines the various interactions between farm labour and other significant agricultural system variables in Northeast Nigeria. This interaction plays a crucial role in shaping labour dynamics and, ultimately, agricultural productivity and sustainability in the region.

The direct cause relationship for farm labour shows that an increase in mixed cropping and mixed farming leads to a higher demand for farm labour. Mixed cropping systems often require more diverse management practices, which are labour-intensive but beneficial for soil health and ecological balance (Horlings & Marsden, 2011).

Encouraging mixed cropping can enhance biodiversity and soil fertility but requires supporting policies that address the increased labour needs, possibly through labour incentives or mechanization support where appropriate. In contrast, monocropping often involves repetitive tasks that can be mechanized, reducing the labour requirements per unit area. This can lead to a reduction in employment opportunities for those in local communities (Altieri & Nicholls, 2005). Hence, while monocropping might improve efficiency and reduce costs, it can also lead to social challenges, such as unemployment and reduced soil health due to decreased crop diversity.

Expanding the area of crops planted, or the number of animals raised, naturally increases the demand for labour, especially in situations where agricultural practices are relatively low labour-intensive.

As for the second depth relationships, higher levels of education and training might reduce the dependency on traditional farm labour as more educated workers may seek employment outside of traditional farming, or they may implement more efficient farming techniques that require less labour. This highlights the importance of education and training in implementing agricultural innovation. However, it also suggests the need for job creation in other sectors, or for advanced roles within agriculture that can accommodate a more skilled workforce. Good health and proper nutrition are crucial for a productive labour force. Healthy workers are more efficient and can significantly contribute to higher agricultural output (FAO, 2017).

Figure 7. 17 Farm labour uses tree (Blue link= positive arrow. Red Links = negative arrow)

Exploring the farm labour use tree (Figure 7.19) shows that only one variable in the system makes direct use of farm labour to contribute to food security. Farm labour contributes to food security through the wages the labourers earn from working in the farm. This link is especially important in understanding how the position of agricultural labour impacts the broader economic and nutritional well-being of households in Northeast Nigeria.

Farm labourers earn wages by working on farms, which directly translates into household income. These wages are a crucial source of income for many rural families. This income is vital as it enables households to meet various financial needs, including investment in more productive farm inputs and technologies, and consumption expenditure on nutritious foods or education, which indirectly influences nutritional outcomes and general well-being. Part of the wages earned from farm labour may be reinvested into their own farm itself, purchasing better quality seeds, farm equipment, or even by expanding the land under cultivation. This reinvestment can lead to increased agricultural productivity, which is critical for sustained food security.

The economic model demonstrated by the farm labour use tree (Figure 7.19) highlights how integral labour wages are used to maintain, not just individual household stability, but also community-wide food security. This economic input is particularly crucial in rural areas where alternative employment opportunities might be scarce, and agriculture represents a significant portion of local economic activity. The dependency on farm labour for household income also suggests vulnerability in relation to FEE theory. Any factors that disrupt agricultural labour- such as health pandemics, extreme weather events, or economic downturns- can have direct negative effects on food security.

The last key outcome variable of the food system is soil fertility with four variables directly feeding into it. Organic fertilizer and biodiversity have positive relationships with soil quality as seen in Figure 7.20. However, deforestation and agrochemical use have negative and direct relationships with soil quality. The direct cause variable with the longest tree branches in the diagram is agrochemical use, which has a negative relationship with soil quality. The tree diagram shows that the variable that exerts the strongest influence on soil quality were deforestation, and agrochemical use and tractor use. These two variables had first and second depth negative relationship with soil quality, with agrochemical use and tractors having up to a third depth negative relationship with soil quality.

The results highlighting the impact of various factors on soil fertility in Northeast Nigeria present crucial insights into the interactions that either support or undermine soil health. The discussion of these results is framed within the context of sustainable agricultural practices, revealing the conflicting impacts of organic inputs and conventional farming practices on soil quality.

Organic fertilizers contribute to soil fertility by enhancing the organic matter content and microbial activity within the soil. This results in better nutrient cycling and improved soil structure. Biodiversity, especially when it comes to cover crops, crop rotations, and the presence of beneficial insects and microorganisms, plays a crucial role in maintaining soil health by enhancing nutrient availability and reducing soil erosion (Tscharntke et al., 2012). Deforestation disrupts the soil structure and reduces its organic content. The removal of vegetation cover exposes soil to the elements, leading to nutrient losses and reduced fertility (Montgomery, 2007).

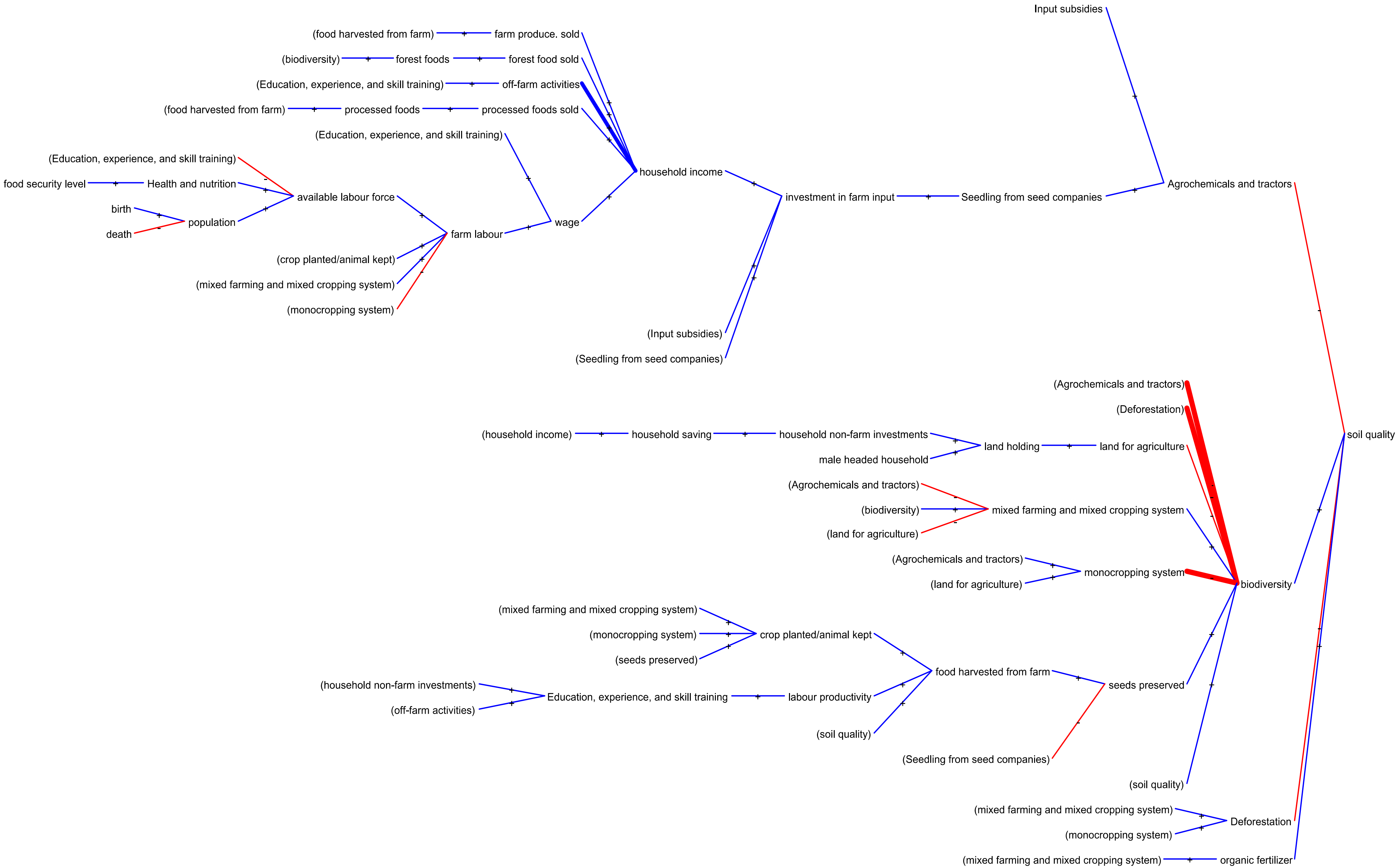


Figure 7. 18 Soil Health causes tree (Blue link= positive arrow. Red Links = negative arrow)

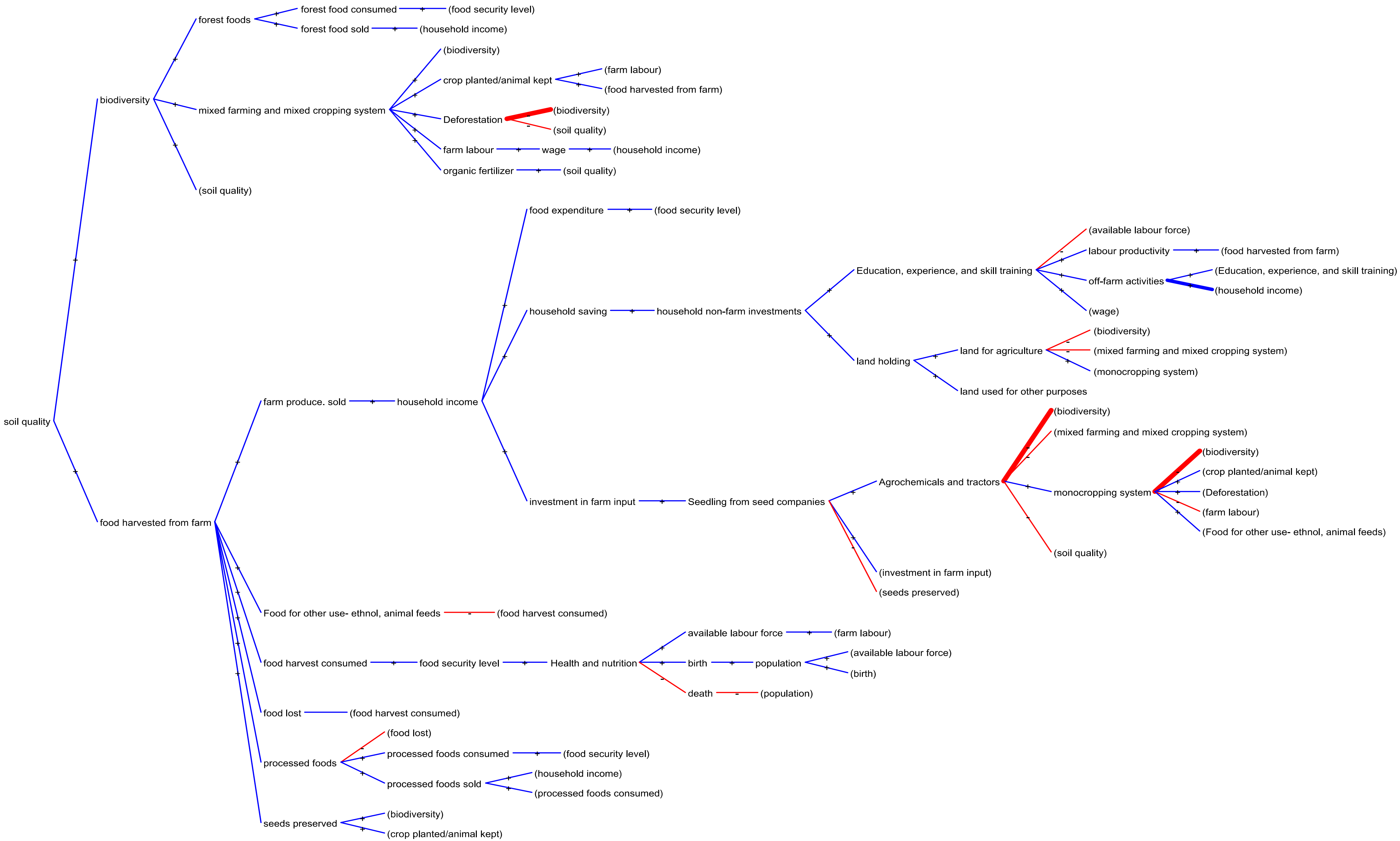


Figure 7. 19 Soil health use tree (Blue link= positive arrow. Red Links = negative arrow)

Soil quality feeds into two important outcome variables of the food system: food harvested from the farm and biodiversity (Figure 7.21). There is a positive relationship between soil quality and its direct use variables. A good soil quality leads to a good harvest. Hence, soil quality, through these two key outcome variables lead to food security. Soil quality is vital for farm foods, household income, and forest foods.

The relationship between soil quality and its impact on various components of the food system, as depicted in Figure 7.21, provides a critical insight into the mechanisms through which sustainable agriculture can be promoted to enhance food security. Good soil quality is fundamental to achieving high agricultural yields. Healthy soil provides essential nutrients to crops, supports root growth, and enhances water retention, all of which are vital for optimal plant health and productivity (Lal, 2004). This relationship is directly observable from the yield level and quality of the food harvested from farms.

Soil quality also affects biodiversity within agricultural systems. Healthy soils support a wide range of life forms, including micro-organisms, insects, and plants. This biodiversity is crucial for ecosystem services such as pest control, pollination, and nutrient cycling which, in turn benefits crop production and stability (Tscharntke et al., 2012). Diverse ecosystems are more resilient to diseases, pests, and environmental stresses, thereby ensuring more stable food outputs.

In the causal loop diagram (Figure 7.20), soil quality is shown as a driver that affects both farm food outputs and biodiversity. The enhancement of soil quality can lead to a virtuous cycle where improved harvests and biodiversity reinforce each other. For instance, better harvests can provide more resources for soil improvement practices, and increased biodiversity can lead to better soil health through natural processes like nitrogen fixation and organic matter decomposition. The productivity of soil can significantly affect household income. Farms with better soil quality typically produce higher yields, which can be sold for profit, thereby enhancing the economic situation of the farmer.

7.4 Feedback and Causal Loop Discussions

This study explored the complex dynamic relationships and interactions of elements between the food system. Important to this study are the relationships shared between these variables. Relationships are very important in the functioning of every system be it mechanical, biological, or social. However, human society operates a very rich and dynamic relationship. Humans share rich relationships between themselves, and elements of other systems as seen in the food system. The food system brings together human society, farms, and forests. It encompasses a multitude of subsystems that interact dynamically to fulfil multiple essential functions -providing food for human consumption, maintaining environmental health, and offering services that support societal well-being. Through a highly iterative process of gathering knowledge about the food system, rich pictures and individual mental models were created for each member of the modelling group, which ultimately led to the development of a causal and feedback loop diagram of the food system. Additionally, knowledge drawn from the reviewed literature, food system household survey, and focus group discussions held in Northeast Nigeria were applied in the development and discussion of the causal/feedback loop diagrams. This complex system diagram of the food system represents the relationships and interactions that created the present food system in Nigeria. The study, through utilizing a system thinking approach, identified four main root cause variables in the system, the main drivers of the food system. The feedback diagram shows that Nigerian food system produced 5 key outcome variables. These outcome variables are the consequences of the relationships in the system. These outcome variables- biodiversity, food security, household income, farm labour and soil quality, form the target of sustainable food system.

The tree diagrams present a simplified picture of relationships driven by the root cause variables, and the relationships driving the key outcome variables. The cause tree diagrams show the variables in the system that contribute to the key variables of the system, and the kind of relationships shared. Environmental sustainability, economic viability and social justice are important components of sustainable development. Although there are several definitions of sustainable development, there is consensus on the importance of biodiversity and natural environment preservation, poverty, and hunger eradication to the extent of having zero hunger in the world, and a just system to ensure social justice. These variables are very important in that they are the focus of much research. However, efforts to achieve them have yielded very little result, especially in Nigeria. Nigeria records the highest level of deforestation in the world (Ogundel, Oladipo and Adebisi, 2016; World Resources Institute, 2021). In 2021, Nigeria recorded an increase in unemployment with many more employed people losing their jobs (Olurounbi, 2021).

Hunger and food insecurity are on the rise in Nigeria, with the NorthEast being a humanitarian emergency case (FAO-ILO-IUF et al., 2005; Integrated Food Security Phase Classification, 2021). Loss of soil fertility is a problem in Nigeria with so many soils being dependent on inorganic fertilizers for food production and subsequent soil pollution and acidification (The Guardian, 2020; Yusuf & Yusuf, 2008). The continuous fall in the real value of the Naira over the years has left so many households poorer (Onyekakeyah, 2021; Ubah Jeremiah Ifeanyi, 2021).

The feedback loops tell stories about the interactions of the elements in the system with limiting or escalating effects on the key outcome variables. Elements like income and biodiversity have a major influence in the food system as both key outcome and driver variables, given the rich and lengthy relationship shared with other variables. They have strong impact on food and nutrition security and the health of the society. Income and biodiversity cause tree diagrams highlighted the variables in the system that will lead to more biodiversity and more income for the household, which will invariably improve the living conditions of both humans and non-human living components of our world.

The causal and feedback loop diagrams highlight the importance of seed in the farm and food system. The causal and feedback loop diagram underscores a critical aspect of agricultural systems, the role of seed within the food systems. The choice of seed source and seed variety influences not only the yield and quality of the harvest but also the resilience of the crop to pests, diseases, and changing climate conditions. Moreover, seeds are at the heart of agricultural biodiversity, which is crucial for food security, ecosystem sustainability, and the resilience of farming systems to environmental changes. Sourcing seed locally from farmers encourages the preservation and propagation of indigenous crop varieties that are often well-adapted to the local climate and soil conditions. These local varieties can be more resistant to local pests and diseases and may require fewer inputs such as fertilizers and pesticides to produce a good crop. Moreover, local seed systems support the cultural heritage of communities, preserving traditional knowledge and practices related to agriculture. Local seed sourcing also promotes genetic diversity which is a key component of agricultural resilience. Diverse crops can better withstand diseases, pest infestations, and extreme weather conditions, reducing the risk of total crop failure and enhancing food security. Hence, sourcing seeds from industrial seed companies often means relying on a narrow selection of scientifically improved or genetically modified varieties (Tschersich et al., 2023). While these seeds can lead to an increased food harvest and are designed for high productivity, they can also have unintended consequences like a reduction in crop diversity.

Negative feedback loops resulting from sourcing seeds from seedling companies could represent the diminishing diversity and increased dependency on industrial seeds. Being able to source seeds from seed companies has given farmers access to high performing seeds, and undermined seed biodiversity and increased farmers' input cost. This is because farmers now care little about their native seeds, are losing knowledge of their traditional seed preservation techniques, and must keep buying seeds and its accompanying chemicals to keep producing (Schapiro, 2018). It also showed how some root cause activities like monocropping and the use of agrochemicals and tractors in the system currently promoted in agricultural policies like APP and NATIP is working against the desired outcome variable (biodiversity, and labour in developing economy). The diagram shows that we can explore this cause and use variables further to minimise undesirable outcomes in the system, like diminishing biodiversity, monotonous non-diverse diets that do little to improve nutrition security, and loss of source of livelihood for the poor farm labourers who depend solely on their wage from working on farms.

The food security feedback loops in line with Thrupp (2000) and Majeed (2018) show that agrochemicals and tractors limit the efforts in achieving food security through four different dominant loops affecting biodiversity, soil quality, mixed cropping, and labour. Though agrochemicals support food production through monocropping, the diagram shows that agrochemicals, through 4 different paths resist the achievement of food security through its negative relationship with soil health. There is a direct negative relationship between agrochemicals and tractor use and soil health, and a direct negative relationship between agrochemical use and biodiversity that shares a positive relationship with soil health. Agrochemicals and tractor use are very important cause variable for monocropping, and it has a positive relationship with deforestation and a negative relationship with biodiversity. With increasing agrochemical and tractor use on farms, soil fertility becomes dependent on inorganic fertilizer for production, and on pesticides and herbicides for the ever- changing bad weeds and resistant pests and diseases. Chemicals have been used on the farms for centuries and is considered a very important component of the system for achieving food security. Agrochemicals and tractors which have encouraged and sustained monocropping have contributed to feeding the growing population. The use of chemicals and machines in farming have contributed to yield increase over the past 40 years through soil fertility and pest and weed control (Majeed, 2018). However, there are concerns on the negative effects of agrochemicals and tractors on the environment and human health (Fritz, 2011; Majeed, 2018), biodiversity (Thrupp, 2000), soil organisms (Gunstone et al., 2021), and labour for poor farm owners and farm labourers (Baltensperger & Tensperger, 1987).

As rightly pointed out in Princy (2020) and Thrupp (2000), agrochemicals are used to improve soil nutrition and kill weeds and pest in the farm and may not consider the other components of the ecosystem an important part of the food system. Agrochemicals also might be considered a very important food increasing factor. So, agrochemicals affect both the intended and unintended targets (Thrupp, 2000). Pesticides can have a devastating effect on a wide array of susceptible components of the system, thereby affecting the system structure and system knowledge of the ecosystem. Causal/feedback loop group model members think the chemicals have subtle but great effects on wild foods like edible weeds and insects. They also thought the chemicals used for farming are changing the type of weeds found on farms. According to Harris and Mohammed (2003) about 33 wild food varieties are found in the farm. These wild foods contribute greatly to the food of household, and can be destroyed with the use of agrochemicals. The effects of agrochemicals in the food system to a large extend hinders the achievement of sustainable development than it contributes to yield. This can be seen in the large number of feedback loops coming from agrochemicals and tractor use and the negative relationship it shares directly, and indirectly, with biodiversity, mixed cropping, and soil health. Agrochemical use encourages monocropping which contributes to food yield and so food security.

However, its impact on the three key variables of the system brings out the need for caution in its promotion and use.

APP policy and subsequent Nigeria agricultural policies aimed at achieving commercial scale agriculture to increase exports have made mixed cropping unpopular. Mixed cropping which is widely practiced in Nigeria is threatened by high labour costs, and agrochemical and tractor use which receive input subsidy support from the Government. Most farmers practicing mixed cropping have very small farm sizes that make it unreasonable economically to use tractors. Due to the nature of mixed crop farms, farmers use little or no pesticide and herbicides on the farm. These smallholder mixed crop farmers plant more than two crops on a piece of land at the same time, use farm labourers for their activities, and store seeds from previous harvests for next season planting. So, the use of agrochemicals may be difficult. Thus, monocropping with its cheap agrochemicals and tractors which reduces the cost of labour, and diseases, and pest attacks is an attractive alternative, especially for large scale farming. The cheaper the agrochemicals, and so the more the use of agrochemicals, the less farmers will practice mixed cropping. The feedback loop diagram highlights the importance of farm labour for the poor farm labourers who depend on their wage for almost all their needs. If they are pushed out of the system by agrochemicals and tractors, and without an alternative source of income, they will become a humanitarian crisis.

The use of tractors in farming removes the drudgery of farming, cultivate more lands, and makes farm commercialization easier. However, tractors usage can only be profitable where farmers have large portion of land, and this is not common in Nigeria where the average land holding size of the farm households is about 0.5ha. Policy supports and many campaigns for industrialized farming and commercialized foods will work in favour of the rich who have money to purchase more land from the poor landowners and access tractors. Knowing there are fixed areas of land, the consolidation of land by the rich will end up depriving the poor landowners the only resource they depend on for food, leading to failure of exchange entitlement.

Unlike manual labour managed farms with tree shade left on the farms, tractor farming leaves the farm bare and exposed to weather elements. The trees which shield the soil, hold the soils together and serve as habitat and sleeping place for small animals are uprooted and removed in tractor farming. With the heavy rainfall in Nigeria, total tree clearing leads to nutrient leaching and soil erosion.

Monocropping like mixed cropping are methods employed by farmers to produce food. However, monocropping makes for the large production of very few selected crops, while mixed cropping supplies a large variety of foods including wild ones. This study found, through focus group discussions and household survey, that farmers practicing monocropping plant an average of 1.2 crops on a piece of land for a year and mixed crop farmers plants a mean of 5 crops on a piece of land in a year. The focus crops of the monocrop farmers were soya beans, sugar cane, sesame or beniseed, maize, millet, and guinea corn. However, over generations, mixed crop farmers have maintained the wild diversity of domesticated crops and wild plants in Nigeria. According to Sarumi et al., (1996), Nigeria has over 4,600 identified plant species, and 205 of these plants are endemic. The northern zone is home to 39 endemic species, Western Zone has 38, and the eastern zone is home to 128 endemic species. With the growing interest in the production of more food through monocropping and its packaged system of industrial seeds, and agrochemicals, these endemic plants may be negatively affected. These endemic plants receive little or no attention from the Government and policy makers who promote a simplified farming system that undoubtably push these endemic plants to extinction.

Declining agrobiodiversity in farms is fuelled by the food security policies of Nigeria (like other countries with input subsidy programme) and focus on commercialization of agriculture for food export. Mixed cropping is very much discouraged by the many policies in agriculture. The ageing population of mixed crop farmers are going out of farming without passing on their knowledge and skills. The depleting knowledge economy going on unnoticed in the food system will be a problem for food system resilience. In the soils, trees, microorganisms, birds, bees, and humans lay the undocumented and very much incomprehensible knowledge bank that has fed the people and kept the balance in the system. These knowledge gaps have been created by polices and top-down support for simplified farming systems can be difficult to identify and address the longer it lasts. Advances in computer technology is very important in solving the problems of much organisational knowledge lost (DeLong, 2005), but this will do very little in solving the problems of the complex food system that is shrouded in biodiversity complexity. This is because the large proportion of the knowledge and skill are undocumented and stored in soft copies in human minds and system component memories. Because food system elements are interdependent, delays in recognising the problem can be costly. The longer the problem stays unrecognised the more the system suffers. Food system stakeholders cannot afford to lose system knowledge. The knowledge of keeping diverse plants and animals is currently being replaced by an in-depth knowledge of a few crops and how to increase them with increasing science of chemical use and creating a microclimate for these few crops. The most subtle erosion extinction happening in the food system is the fast but subtle depletion of the traditional and indigenous knowledge of the food system which has preserved biodiversity over generations (Berkes et al., 2000; Cilliers, 2000a; Convention on Biological Diversity, 2010; Daniel et al., 2022; Kennedy et al., 2022; Mistry, 2009; Thomas et al., 2019).

Traditional and indigenous knowledge in the food system are skills, knowledge, understanding, practice, ideology, and experiences learned, developed, sustained through a long history of interactions with the environment and passed on through generations within the community (Mistry, 2009; Vidal, 2019. This knowledge forms part of their spiritual and cultural identity (Mistry, 2009), this type of knowledge is important for preserving global biodiversity, and survival of our future generations.

In conclusion, the food system feedback loop diagram (Figure 7.1) had 4 root cause variables and 5 key outcome variables addressing the third objective of the study - explore the linkages between the food system components and food security pillars to understand their interactions and identify the main drivers and the key outcomes of the food system. The linkages and feedback loops within food system policy interventions, labour, farm practices, agrobiodiversity, household socioeconomic characteristics, and consumptions of diverse food were explored. The diagram shows the dynamics in the sources of seed for planting, use of agrochemicals and tractors, two different farming practices -mixed and mono cropping and farming, food harvested from farm, off farm activities, and their reinforcing and balancing effects through biodiversity, soil health, labour, food security, health, and other outcomes in the system. It is clear from the food system feedback loops diagram and the tree diagrams of the root cause variables, that the use of agrochemicals and tractors, food harvest, monocropping system of farming, and mixed cropping system, to a large extent, control what happens in the food system. Mixed cropping through its dynamic and complex relationships in achieving food security, is an important factor in creating more labour especially farm labour for the poor in an economy like Nigeria where the unemployment rate is very high. Their wage is all they must live on and anything taking their places in the farms is indirectly impoverishing them and making them more vulnerable. Mixed cropping plays an important role providing the household with varieties of different foods, and the soil with organic manure. This feedback system will help us understand that the variables supporting the use of agrochemicals and tractors are indirectly working against soil health and biodiversity. A good soil quality will result in a good harvest. It will support the activities and growth of soil living organisms to achieve a sustainable food security in Nigeria. The 5 outcome variables and 4 root cause variables driving the system should be the focus of policies. The action plan of the Government and people should involve treating these components of the system as a package. So, the root drivers and, importantly their cause variables, should be explored to reduce or limit the variables with limiting impact on the desired variable and improve the ones with positive impact on the desired variable. This is important for improving biodiversity, income for the poor farmers, food security for the health of the population, and soil health to produce healthy food and society. It is also important for creating jobs, especially in countries with high unemployment rates, for the teeming population of unemployed labourers who depend on their labour for sustenance.

Policies on food security should be improved by applying system thinking to enable practical and more informed food security policies that consider food security as a part of the food system. The use tree of these outcome variables also enlightened us on the importance of biodiversity and income to other components of the system. Though population increase and the ever-increasing gap in resource distribution encourage agrochemical use, policy makers and farmers should look beyond the food produced by using agrochemicals. If food and nutrition security entails always having enough quantity of food and diversity of diet from different plant and animal sources, then there is need to rethink the monocropping ideology being promoted for food security as it can only supply very few foods at the expense of biodiversity and the health of the system. The study of the dynamic relationships of the root causes variables, and their feedback mechanisms from the causal loop diagram shed light on elements of the system that sustains or escalates the current situation. This is important in solving the current situation of the food system. To avoid problems such as protecting the trees by using plastic bags and ending up in suffocating the earth through this good intension, there a is need for the adoption of the system thinking approach to problem solving.

Chapter 8: Conclusion, and Recommendations

8.1 Conclusion

This study investigated the complex challenges of achieving food and nutritional security in Northeast Nigeria, due to various social, economic, and environmental constraints. In Nigeria, there are significant food security issues, with millions of people experiencing hunger and living under the poverty line. The Northeast geopolitical zone of the country faces severe food crises exacerbated by high levels of malnutrition among children. The country's deforestation rate also impacts food security negatively. Malnutrition is prevalent in Nigeria, with one in three people suffering from malnourishment and 4 in 5 food insecure. The Northeast region faces severe challenges, with millions of children in urgent need of humanitarian assistance. The study shed light on the need to explore and understand the linkage between income, labour, biodiversity, agrobiodiversity, and food security to understand the root causes of the situation. It found that sustainable agricultural practices and the promotion of biodiversity can lead to an increased food system resilience and better food security outcomes.

The broad objective of the thesis was to explore the relationship between food systems and food security of Northeast Nigeria, applying the system thinking approach, with the aim of achieving sustainable development. To achieve this broad objective, household level data on food security situation were collected, and focus group discussions on agricultural policy were conducted. A system causal and feedback loop diagram was developed and analysed to understand the relationships and the interdependence of the components of the food system. Exploring whether encouraging farmers and poor households with access to land to produce their own food, using farming methods that give them access to a range of crops and animals for consumption, will help combat food insecurity. The quantitative and qualitative data collected on food production and policy interventions in the food system, enabled the causal and feedback loop diagram to identify interventions needed to achieve a sustainable food system.

The specific research objectives of the study were achieved as follows:

Objective 1. What policy interventions are needed to encourage crop and animal diversity, employment, increase biodiversity, income, and food security? Through Likert-type scale ratings and rankings, potential policy interventions aimed at promoting the cultivation of diverse crops and livestock, generating employment, and enhancing food security were identified and evaluated. This analysis underscored the importance of targeted policy measures in achieving sustainable food systems and biodiversity, with a particular focus on their potential to improve employment and income for vulnerable populations.

The study achieved the research question using a mixed-method approach that included both qualitative and quantitative methods to gather comprehensive data on the effectiveness of policy interventions aimed at achieving sustainable food system. It looked at the focus group participants’ perceptions of the effectiveness of the policy interventions in enhancing crop and animal diversity, employment, biodiversity, income, and food security. Thus, the research provided robust evidence to guide targeted policy action.

Here is how the study specifically addressed the research question:

Methodology Used was Focus Group Discussions (FGDs). Qualitative primary data was collected through structured FGDs. FGDs explored perceptions about the effectiveness of the Nigerian Agricultural Promotion Policy (APP) interventions in achieving sustainable food system goals. Participants discussed and evaluated 11 distinct policy interventions, rating their effectiveness on a Likert-type scale from very ineffective (1) to very effective (5).

Effectiveness ratings using the **Likert-type Scale Ratings** were systematically collected and analysed. A clear mean scoring method was employed:

- A Scores <2.45 is described as "ineffective".
- Scores between 2.45 and 2.55 indicated "moderately effective".
- Scores >2.55 indicated "effective".

Achievement of Research Question through Evaluated Outcomes:

1. **Food Price Stability**: Strategic national food reserves, use of agrochemicals and tractors, organic farming, and supporting large-scale specialized farming were identified as effective strategies for stabilizing food prices.
2. **Access and Availability of Diverse Foods**: Creating balanced diet awareness, organic farming, forest conservation, and labour subsidies to small-scale farmers significantly enhanced access to diverse foods, addressing nutrition security.

3. **Biodiversity and Environmental Benefits**: Organic farming, forest conservation, supporting small-scale farmers, strategic national reserves, and dietary diversity awareness were effective for biodiversity conservation and environmental benefits.

4. **Employment Generation**: Promoting organic farming and supporting small-scale farmers through labour subsidies were rated as highly effective for employment generation among vulnerable populations.

5. **Income Support**: Encouraging organic farming, providing labour subsidies, and forest conservation were highly effective for providing income support to poor households.

6. **Soil Health Improvement**: Organic farming, labour subsidies for small-scale farming, and forest conservation strategies were rated to be highly effective for improving soil health and sustainability.

Validation through Participant Feedback:

- Qualitative insights from participants were integrated into quantitative evaluations to contextualize and support the ratings.
- Participants highlighted real life challenges and emphasized interventions that were closely aligned with local socio-economic realities and ecological conditions, thus ensuring the relevance and applicability of policy recommendations.

Integration of Socioeconomic and Ecological Factors:

- The study considered broader socioeconomic impacts of the interventions, such as employment displacement risks due to large-scale farming initiatives, reflecting sensitivity to Sen's entitlement theory and the concept of food sovereignty.
- Environmental sustainability was prioritized alongside socioeconomic benefits, showing an integrated approach to sustainable food system policy development.

The findings clearly identified effective and ineffective policy interventions across multiple sustainable food system goals, guiding targeted and context-specific policy recommendations.

The study provided recommendations that emphasized holistic, agroecological approaches and small-scale farmer support, highlighting their broad effectiveness in achieving multiple sustainability and food security outcomes.

In summary, the study systematically and comprehensively answered its research question by combining qualitative insights from participants with quantitative thematic coding and Likert-scale evaluations, resulting in nuanced, practical, and contextually grounded policy recommendations aimed at promoting sustainable food systems, biodiversity, employment, and food security.

The analysis highlighted that interventions such as encouraging organic farming, supporting small-scale farmers with credit and labour subsidies, forest conservation, and dietary diversity awareness were highly effective across multiple sustainable food system goals, including food security, employment generation, biodiversity conservation, income support, and soil health improvement. These approaches were closely aligned with local socio-economic and ecological realities, offering viable pathways to enhance the resilience and sustainability of local food systems.

Conversely, policies promoting commercial seeds and allocating 10% of total arable land for cattle grazing were deemed largely ineffective by stakeholders, reflecting broader concerns about their environmental and social sustainability, particularly in relation to smallholder livelihoods and biodiversity conservation.

Notably, the findings underscored the importance of context-specific policy implementation, emphasizing community-based forest management and agroecological approaches that integrate traditional knowledge and practices. Participants expressed significant concerns about displacement risks associated with large-scale farming initiatives and highlighted the importance of inclusive and equitable policy measures that safeguard the rights and entitlements of small-scale farmers. The results showed that most of the farmers in this area were still involved in a closed farming system where the inputs for their farms are sourced from their own farm. The dependence of the farmers on their saved seedlings may save them some costs while preserving the indigenous biodiversity. Sustainable agriculture requires the protection of local biodiversity. So, it is good for the environment that most of the farmers studied still source their planting materials from their saved farm produce, and other farmers in their local markets.

Objective 2. The study ascertained the food and nutritional security situations of households in Northeast Nigeria. It employed a comprehensive approach, collecting primary data on various aspects of the food system, including production systems, food sources, and dietary diversity. The findings shed light on several critical aspects of food and nutrition security in the region.

The thesis highlighted the prevalent consumption of carbohydrate-rich foods, primarily consisting of cereals and roots and tubers, in the diets of households (See Chapter 6, Table 6.1). These staples were consumed frequently, often on a daily basis. While these foods provide energy, the study revealed a concerning trend of low consumption of essential nutrients such as from animal protein, iodine, and iron rich-foods, which are crucial for the growth and well-being of household members, particularly children. This observation points to the existence of hidden hunger in Northeast Nigeria, emphasizing the need for a more diverse and nutrient-rich diet.

Furthermore, the research illuminated the impact of income levels on dietary choices, with rising incomes leading to greater consumption of ultra-processed foods (see Table 6.2). Despite earning less than the national average living wage, households in this farming community heavily relied on food from their farms and the forest for their food and nutrition security. Access to land, and the ability to rely on indigenous knowledge, saved seeds, forests, and labour were paramount for the survival of smallholder farmers in the region.

The study also raised concerns about Government agricultural policies that promote the commercialization of farms and the commoditization of food. Such policies that support monocropping through the use of commercial seeds, agrochemicals and tractors, may not be favourable for the majority of Nigerian farmers, particularly those in Northeast Nigeria. The risk of losing their small plots of land which they depend on for subsistence farming, in favour of larger commercial farms is high. This loss of entitlement could exacerbate food insecurity in the region, and lead to competition with wealthier farmers, increased unemployment, and deforestation, which would deprive the people of wild food resources from the forest.

The study also revealed that most farmers in the region predominantly focus on food crop production, utilizing small-scale mixed cropping systems (See Table 5.2 in Chapter 5). This implies that support and policies that prioritize monoculture and cash crop farming may inadvertently exclude the majority of farmers in this area.

This research underscores the complex interplay of factors influencing food and nutrition security in Northeast Nigeria. It emphasizes the importance of diversifying diets to address hidden hunger, preserving biodiversity, protecting smallholder farmers' access to land and traditional knowledge, and carefully considering the implications of Government policies on food security in the region.

Objective 3. To study the linkages between, and within, the food system a food system causal/feedback loop diagram was developed. This objective aimed to examine the food system, activities, practices, components of the food system, and the relationships between and within these elements of the food system for food security. The study explored the linkages and feedback loops between and within labour, agrobiodiversity, household socioeconomic characteristics, and consumptions of diverse food groups necessary for adequate DDS. This study provided valuable insights into the intricate dynamics of the food system, shedding light on the critical factors that drive its functioning, and the outcomes it produces. Four main drivers emerged as key to shaping the food system: mixed cropping, monocropping, the use of agrochemicals and tractors, and the harvested food from farms. These drivers influence various aspects of the food system, exerting a significant impact on the overall performance of the system.

The study also Identified five key outcome variables of the food system – biodiversity, income, and food security, and two other outcome variables- soil quality and farm labour. It highlighted the paramount importance of key outcome variables in evaluating the effectiveness and sustainability of the food system. Biodiversity, as a measure of ecological health and resilience is crucial for maintaining the long-term viability of agricultural practices. Food security, ensuring that communities have access to adequate quantities of, and nutritious, food is a fundamental sustainable development goal. Income generation represents economic well-being, while soil quality and farm labour underscore the sustainability of farming practices. These outcome variables collectively define the success and sustainability of the food system.

Furthermore, the study recognized the role of system knowledge as a lever within the food system. It identified that system accumulation of knowledge of the complex interactions between the key drivers and outcome variables is essential for effective decision-making and policy formulation. System knowledge serves as the foundation for informed actions aimed at achieving desired outcomes while mitigating unintended consequences.

In essence, this study underscored the intricate web of interconnections within the food system, emphasizing the need for a system thinking approach that considers both the drivers and outcome variables in order to achieve a sustainable, resilient, and equitable food system. By comprehensively addressing these factors, policymakers, researchers, and stakeholders can work together to develop strategies that promote food security, biodiversity, income generation, soil health, and farm labour, ultimately leading to a more sustainable and prosperous food future.

8.2 Policy Recommendations

Overall, the study's findings provide valuable insights for policymakers, researchers, and communities in Nigeria, helping them develop evidence-based strategies to ensure food security and address the underlying causes of food insecurity. It emphasizes the importance of addressing food insecurity through sustainable agricultural practices, improved access to employment, and promoting biodiversity to enhance food system resilience. This study advocates seeing food insecurity as a transdisciplinary issue and, studying food security through system thinking to enable research evidence that takes into consideration the very important relationships and interdependence aspects of a complex system.

The study recommends that:

1. Food and nutrition security intervention should target covering the gap in the consumption of protein, iron, zinc, iodine, and vitamin A rich food identified in the

study (see Chapter 6.). The study highlighted the food and nutrition insecurity situation in Northeast Nigeria, with particular focus on the lack of protein and essential micronutrients, which is an indication of hidden hunger. Micronutrient deficiencies pose a significant public health challenge, affecting the well-being and development of individuals and communities. To effectively combat these deficiencies, it is imperative to adopt a multi-sectoral approach involving government agencies, healthcare providers, educational institutions, community organizations, and individuals. This policy recommendation outlines key actions that different sectors of government should take to address micronutrient deficiencies comprehensively and sustainably.

Government agencies, particularly the Federal Ministry of Health, should collaborate with researchers working on food security to conduct continuous monitoring and evaluation of the nutritional status of the population. This data will inform evidence-based interventions and track and measure progress over time.

The Ministry of Education should take a lead role in designing and implementing awareness campaigns and workshops in schools, health centres, and communities. These campaigns should emphasize the importance of consuming foods rich in micronutrients and protein, in addition to carbohydrate-rich foods, for overall health. Also, the Ministry of Education should integrate nutrition education into the national school curriculum. This will ensure that students receive comprehensive education on the importance of a balanced diet and the role of micronutrients in health.

School feeding programs, under the purview of the Ministry of Education, should prioritize the inclusion of essential micronutrient-rich foods. This will not only improve the nutritional status of students but will also set a positive example for healthy eating for the rest of the population.

The Ministry of Agriculture and Natural Resources should provide comprehensive support to farmers, including training, resources, and incentives, to encourage the cultivation of diverse crops. This will help bridge the nutritional gap in the population and promote dietary diversity.

The Federal Ministry of Health should develop and implement training programs for healthcare providers to equip them with the knowledge and skills to identify and address micronutrient deficiencies in patients. This will enhance early diagnosis and intervention.

All relevant ministries, including Health, Agriculture, and Education, should allocate resources and support research initiatives focused on sustainable food security. This research will provide evidence-based solutions and inform policies and interventions. Addressing micronutrient deficiencies requires a concerted effort from multiple sectors of government. By implementing these recommendations, government agencies can work collaboratively to improve the nutritional status and overall health of the population. It is essential to recognize that this is a long-term endeavour that demands sustained commitment and coordination among stakeholders to achieve meaningful and lasting impact.

2. To effectively tackle the challenges related to food security, environmental sustainability and poverty reduction, there should be a policy shift. This shift should prioritize support for small-scale farmers, with a particular emphasis on those engaged in mixed cropping. This policy proposal underscores the importance of ensuring fair employment opportunities, especially for small-scale farmers and a sustainable food system in agriculture. To achieve this, the study suggests that the Federal Ministry of Agriculture and Natural Resources should work closely with the Federal Ministry of Labour and Productivity to ensure that agricultural labour is decently and adequately compensated. These ministries should establish a comprehensive system for collecting and monitoring data. This system will be instrumental in assessing the impact of their policies on small-scale mixed cropping farmers, as well as their contributions to food security and poverty reduction.

   The Federal Ministry of Agriculture and Natural Resources should take the initiative to develop and implement targeted assistance programs tailored to the needs of mixed cropping farmers. This recognition is based on their role in diversifying agricultural production, which is vital for ensuring food and nutrition security, increasing income, and promoting environmental sustainability. To facilitate this, the government should provide financial support for land and labour, as well as offer training to enable mixed cropping farmers to maximize their yields and enhance their livelihoods. Furthermore, there is a pressing need for the Ministry of Agriculture to partner with the Federal Ministry of Environment. This collaboration should aim to promote sustainable agricultural practices among mixed cropping farmers. Encouraging the adoption of organic farming techniques can help improve soil fertility and mitigate environmental degradation.

3. The study has brought to light a troubling trend characterized by a growing consumption of ultra-processed foods, which often lack essential nutrients and contribute to a range of health issues (see Table 6.3). Most of the respondents expressed their intention to consume more ultra-processed foods as their income increases.

   The study recommends that the Federal and State Ministries of Education, Agriculture, and Health collaborate to establish a nationwide program dedicated to nutritional education which emphasizes the benefits of consuming minimally processed foods and highlight the risks associated with excessive consumption of highly processed foods. It is imperative to launch public education and awareness campaigns using diverse communication channels, including television, radio, social media, and community events, to effectively reach a broad audience. Also, there is a need for stricter regulations governing media and advertising, especially concerning the promotion of highly processed foods. Additionally, NAFDAC (National Agency for Food and Drug Administration and Control) should take steps to implement transparent and easily comprehensible labelling systems that clearly indicate the level of processing in food products. This will enable consumers to readily distinguish between highly processed and less processed food options.

   Promoting the consumption of minimally processed foods through nutritional education represents a pivotal measure in advancing public health and alleviating the burden of diet-related diseases. This policy recommendation underscores the significance of equipping individuals with the knowledge and tools required to make informed dietary choices. By implementing these strategies, we can empower consumers to prioritize healthier, traditional foods over highly processed alternatives, ultimately contributing to enhanced overall health and well-being.

4. The Ministries of Agriculture and of Land and Urban Development should prioritize policies that support sustainable farming, and forest conservation that not only focuses on wildlife protection but also the livelihood of the community dependent on it. This can be achieved through training, technical assistance, and facilitating access to organic resources. In line with the outcomes of the FGDs, forest conservation policies should not only focus on safeguarding wildlife but should also consider the well-being of communities reliant on these forests.

   Promoting community-based forest management that empowers local communities to actively participate in, and benefit from, efforts to preserve forests, and equitable revenue-sharing mechanisms should also be established to create economic incentives for communities to engage in forest protection. For effective implementation of sustainable forest management policies, the Ministry of Agriculture should foster collaboration among relevant government departments, local communities, environmental organizations, and agricultural associations.

   The findings from FGD emphasize the importance of the Federal Ministry of Environment, in collaboration with state environmental protection agencies, establishing platforms for ongoing dialogue and knowledge exchange. These platforms should address emerging challenges and opportunities in organic farming and forest conservation. Furthermore, the Ministry of Environment should design tailored training programs for farmers, forest communities, and government officials to enhance their capacity in organic farming techniques and forest conservation practices. By implementing these policies and measures, policymakers can significantly contribute to a more sustainable and resilient agricultural sector, the preservation of invaluable natural resources, and the improvement of the livelihoods of forest-dependent communities. This will ultimately create a healthier environment that benefits everyone.

5. There is need for caution in promoting monocropping and agrochemical use, and the importance of preserving traditional knowledge to ensure food system resilience and sustainability. Preserving traditional knowledge is vital to ensuring the resilience and sustainability of the food system. Taking a system thinking approach, which considers the interconnectedness of environmental sustainability, economic viability, and social equity in interventions, is essential when addressing the challenges faced by the Nigerian food system. This is especially crucial in addressing concerns related to the potential negative impacts of monocultural practices resulting from commercial seed programs and the widespread use of chemicals (see Figures 7.3, 7.8 and 7.9). As such, it is imperative for the Ministry of Agriculture and researchers involved in food system interventions to conduct comprehensive assessments of the policy effects on the food system's sustainability.

6. The action plan of the government, communities and people should involve treating the components of the food system as a package. Thus, the root drivers and importantly their cause variables derived from the CLD in Chapter 7, should be explored to reduce or limit the variables with limiting impact on the desired variable and improve the ones with positive impact on the desired variable.

8.3 Community-Led System Change Recommendations for a Sustainable Food System

These recommendations are not policy recommendations which needs the intervention of government bodies, but actionable practices and changes that communities, local groups, and stakeholders can use to improve biodiversity, food security, local knowledge, and build resilience in the food system based on the outcome of this study.

1. Farmers should be encouraged to adopt mixed cropping systems to improve soil health and biodiversity, employment, income, and dietary diversity through production of diverse food types. To do this, communities can offer local field schools, host local seed fairs, or demonstration plots to share knowledge and best practices on mixed cropping.

2. To strengthen local seed systems and sovereignty, there is ned to promote seed saving, seed banks, and farmer-to-farmer seed exchanges within and between local communities. This can be done be enacting and reviving traditional seed planting festivals and storytelling

rituals that is focused on preserving seed knowledge. Celebrating traditional rites that pays tribute to different planting seasons or ancestral seed spirits or guardians in educational platforms can be used to strengthen the seed systems.

3. Implementing training programs and farmer field schools on composting, natural pest control, and low-input techniques is needed to support organic and agroecological farming. Local demonstration plots to model agroecological practice that mix learning with cultural celebration through seasonal agricultural festivals or community-wide workshops can be implemented to boost agroecological practices.

4. To preserve and transmit indigenous knowledge, local communities and stakeholders should be encouraged to collect and document oral histories, indigenous recipes, farming calendars, and herbal uses of crops. Intergenerational knowledge transfer can be promoted through establishing school gardens, and youth mentorship programs with elders,

5. Community-based Forest and biodiversity should be supported to foster stewardship. This can be achieved by encouraging sustainable use of forest resources through community-managed forest programs, reviving sacred groves, and traditional forest management rites and conservation rituals.

6. Farmer can be encouraged to establish and use cooperatives and labour groups to provide credit for labour-intensive sustainable practices like mixed cropping.

7. Community nutrition weeks can be organized to include cooking demonstrations with traditional foods to promote nutrition awareness. This can be done in partnership with schools, women and youth groups, churches, and mosques for awareness workshops on the importance of balanced diets and hidden hunger.

8. Households can be supported to improve food preservation through training on preservation techniques like drying, fermentation, and construction of local silos. This can also encourage value-added processing that can increase their income while reducing food waste.

8.4 Limitation of the study

The focus of this study is on the food security of households in Northeast Nigeria considering the food system of this area. This study did not focus on the nutritional content of food consumed or planted in this area.

The study investigated the food security situation of households using the DDS. Although there are many indicators of food security, the study used DDS as it focused was on the consumption of adequate quantity and quality of diverse foods.

One significant limitation of this study pertains to the extended duration of data collection, which deviated from the initially proposed timeframe of three months. The unanticipated disruption caused by the COVID-19 pandemic restrictions resulted in a prolonged data collection period of approximately one year. The pandemic necessitated the employment of additional enumerators, which incurred extra costs encompassing wages, accommodation, mobile data, and phones to facilitate electronic data collection.

Furthermore, the intended training of enumerators for conducting focus group discussions had not commenced prior to the pandemic's onset. The prohibition of gatherings during the pandemic rendered face-to-face training impossible. So, the author had to opt for online training while awaiting the pandemic's resolution. Only one refresher training session was conducted in person with enumerators once pandemic restrictions eased. The online training expedited the process, thereby reducing the training time that could have further increased the data collection duration.

Additionally, the necessity to complete the study on schedule required the researcher to return to the University of Reading after the long COVID 19 restriction, interrupting fieldwork, to initiate the analysis of the previously collected household data. During this period, stakeholder consultations were also conducted online to finalize the data collection process.

Furthermore, the successful completion of this research relied heavily on the use of specialized analytical software, VENSIM, and the development of expertise in its use.

Initially, the study planned to utilize the student version of VENSIM. However, it soon became apparent that the student version was inadequate for the required level of analysis. Unfortunately, these resources were not readily accessible within the university. To overcome this limitation, the researcher sought funding from the School to purchase the full version of the software and to enrol in a three-month advanced VENSIM online course. This strategic move greatly contributed to the successful completion of the thesis.

8.5 Contribution to knowledge

The goal of this study was to get researchers, policy makers, communities and the people thinking about food and food related issues in a different way. It has always been bounded under different disciplines and thought as - food production problems for the farmers, crop, and animal scientists; nutritional and food related health problems for the dieticians and food nutritionists; food preservation and food safety problem for the food scientists; and a problem of food access, distribution, production efficiency, value chain, and profitability of down and upstream food business for the food marketers and economists. However, this study wants us to start thinking about food as a system with subsystems and elements working together to create what we see. This study underscores the complexity of addressing global food security and sustainability challenges and the need for a system thinking approach to food system studies (Matchaya & Guthiga, 2023). The relationships between the elements of the system are very important and determine the outcome of the system. It starts us thinking about the very important thing about this system, that is the nature of connections, relationships, interdependence of the element of the system and then the emergence of the whole complex system.

In this study, the system thinking approach employed embraces a perspective that considers food systems as intricate and interlinked networks consisting of various actors, processes, and feedback loops as described in Cilliers (2000c). It placed a high priority on understanding the dynamic relationships and interdependencies among components within and between food production, consumption, and environmental factors. In contrast, conventional reductionist methods often used in food security literature focus on isolated elements or variables within the food system, such as specific food production practices, yields, or consumption patterns, often neglecting the crucial relationships that underpin the system.

This study recognizes that activities and elements within the food system are interconnected rather than isolated occurrences. Consequently, it delves into understanding the causes and consequences of actions throughout the entire system, highlighting the significance of understanding unintended consequences that can arise from both direct and indirect relationships, as well as long-term impacts as described in (Cilliers, 2002). In contrast, typical discipline-bound approaches used by most researchers working on food security, although statistically robust, tend to concentrate on identifying correlations and static relationships between variables without delving deeply into the underlying causal mechanisms or feedback loops, potentially overlooking the nuanced dynamics driving food system behaviour.

As highlighted in chapter 1, background to the study, this system thinking study promotes interdisciplinary and transdisciplinary research, harnessing insights from diverse fields and consulting individuals from agronomy, food science, system dynamics modelling, agricultural economics, agricultural extension, and farmers outside the traditional academic disciplines. It acknowledges that food systems are influenced by a multitude of factors and necessitates collaboration among experts from various disciplines. In contrast, existing literature reveals that many researchers working on food security and food systems tend to be confined to their respective disciplines, thus limiting their understanding of the intricate nature of food systems.

To capture the diverse perspectives and experiences embedded within food systems, this research incorporated qualitative techniques, such as focus group discussions, mental models, interrelationship diagraph, and stakeholder engagement. This qualitative understanding complements the quantitative data used in this study, marking a departure from the predominant reliance on quantitative data and statistical analysis seen in most food security studies, which often neglect the human and social dimensions of food systems.

In essence, this study provides a more comprehensive and integrated framework for studying food systems. The system thinking approach underscores the interconnectedness of food system components and the critical role of causality and feedback. By embracing system thinking, this research offers a holistic and more effective means of addressing the complex and interdependent challenges of food security in our complex modern world.

Removal and Separate Publication of the food system simulation model:
Following the External and internal examiner's advice, Chapter 8 was be removed from the thesis. It was developed into a separate manuscript which has been presented in the International System Dynamics Conference (ISDC) 2025 and already sent out for publication in an academic journal.

8.6 Suggestions for further study

- Adopting and applying this model to food systems research in various regions around the world would be beneficial.
- Examine how system knowledge contributes to the preservation of biodiversity, including the development of a standardized measure for assessing social and natural system history/knowledge.
- Assess the significance of both food quantity and food quality in the context of food security. This will require an interdisciplinary or transdisciplinary approach to weight, quantify, or rank the importance of food quantity compared to food quality in achieving food security.
- Develop a simulation dynamic food system model that incorporates animal production and consumption. This expansion should involve incorporating various species of animals from the wild and farms into the diversity of foods already considered in the study. It is essential to determine whether different animal varieties have nutritional impact compared to crop varieties.
- Investigate food systems for food security, specifically comparing monocropping, mixed or intercropping, and various sustainable farming systems such as biodynamics or permaculture. These sustainable farming systems differ from the mixed cropping method described in this study.
- Explore household preferences for forest-derived foods versus farm-produced foods. Participants in the Focus Group Discussions (FGD) and stakeholders involved in the modelling have indicated that wild foods, crops, and animals have superior taste

compared to their farmed counterparts, especially the improved and hybrid varieties. Conducting a detailed research study on these preferences will be valuable for planning interventions in the food system.

References

Adeniyi, M., Ogunsola, O., Nymphas, E., & Oladiran, E. (2009). Food security measures during uncertain climatic conditions in Nigeria. *African Journal of Food, Agriculture, Nutrition and Development*, *9*(2).

Adeola, M. (1992). Importance of Wild Animals and their Parts in the Culture, Religious Festivals, and Traditional Medicine, of Nigeria. *Environmental Conservation*, *19*(2), 125-134. https://doi.org/10.1017/S0376892900030605

Adewumi, M. O., & Animashaun, J. O. (2013). Dietary Diversity , Farm Income and Technical Efficiency Correlates : Empirical Evidence from Small-scale Farming Households in Nigeria Key words. *Agris On-Line Papers in Economics and Informatics Households '*, *V*(4), 3–11.

Ahungwa, G. . T., Umeh, J. C., & Muktar, B. G. (2013). Empirical Analysis of Food Security Status of Farming Households in Benue State , Nigeria . *Journal of Agriculture and Veterinary Science*, *6*(1), 57–62.

Ajayeoba, A. (2010). Concerning Food Security in Nigeria. *West African Insight*, *December*. http://westafricainsight.org/articles/PDF/81

Akinbobola, T. O., & Saibu, M. O. O. (2004). Income inequality, unemployment, and Poverty in Nigeria: a Vector Autoregressive Approach. *The Journal of Policy Reform*, *7*(3), 175–183. https://doi.org/10.1080/1384128042000261800

Akinyele, I. O. (2009). Ensuring Food and Nutrition Security in Rural Nigeria : An Assessment of the Challenges , Information Needs , and Analytical Capacity. In *Nigerian Strategy Suppoort Program* (NSSP 007; 7, Vol. 7, Issue NSSP Background Paper).

Altieri, M. A. (1999). The Ecological Role of Biodiversity in Agroecosystems. *Agriculture, Ecosystems & Environment*, *74*(1–3), 19–31. https://doi.org/10.1016/S0167-8809(99)00028-6

Altieri, M. A. (2002). Agroecology: the Science of Natural Resource Management for Poor Farmers in Marginal Environments. *Agriculture, Ecosystems & Environment*, *93*(1–3), 1–24. https://doi.org/10.1016/S0167-8809(02)00085-3

Altieri, M. A. (2018). Agroecology: The Science of Sustainable Agriculture. *Agroecology: The Science of Sustainable Agriculture, Second Edition*, 1–433. https://doi.org/10.1201/9780429495465

Altieri, M. A., & Nicholls, C. I. (2012). *Agroecology Scaling Up for Food Sovereignty and Resiliency* (pp. 1–29). https://doi.org/10.1007/978-94-007-5449-2_1

Altieri, M. A., & Toledo, V. M. (2011). The Agroecological Revolution in Latin America: Rescuing Nature, Ensuring Food Sovereignty and Empowering Peasants. *Journal of Peasant Studies*, *38*(3), 587–612. https://doi.org/10.1080/03066150.2011.582947

Altieri, M., & Nicholls, C. (2004). Biodiversity and Pest Management in Agroecosystems. *Biodiversity and Pest Management in Agroecosystems*. https://doi.org/10.1201/9781482277937

Atkinson, J.-A., Wells, R., Page, A., Dominello, A., Haines, M., & Wilson, A. (2015). Applications of System Dynamics Modelling to Support Health Policy. *Public Health Research & Practice*, *25*(3), e2531531. https://doi.org/10.17061/phrp2531531

Ayanlade, A., & Drake, N. (2016). Forest Loss in Different Ecological Zones of the Niger Delta, Nigeria: Evidence from Remote Sensing. *GeoJournal*, *81*(5), 717–735. https://doi.org/10.1007/S10708-015-9658-Y/METRICS

Babalola, K., & Hull, S. (2019). Examining the Land Use Act of 1978 and Its Effects on Tenure Security in Nigeria: A Case Study of Ekiti State, Nigeria. *Potchefstroom Electronic Law Journal (PELJ)*, *22*(1), 1–34. https://doi.org/10.17159/1727-3781/2019/V22I0A5803

Bagnall, A.-M., Radley, D., Jones, R., Gately, P., Nobles, J., Van Dijk, M., Blackshaw, J., Montel, S., & Sahota, P. (2019). Whole Systems Approaches to Obesity and other Complex Public

Health Challenges: a Systematic Review. *BMC Public Health*, *19*(1), 8. https://doi.org/10.1186/s12889-018-6274-z

Baker, E. F. I. (1978). *Mixed Cropping in Northern Nigeria :Cereals and Groundnuts*. *14*, 893–298. https://doi.org/10.1017/S0014479700008917

Ball, B. C., Hargreaves, P. R., & Watson, C. A. (2018). A Framework of Connections between Soil and People Can Help Improve Sustainability of the Food System and Soil Functions. *Ambio*, *47*(3), 269–283. https://doi.org/10.1007/s13280-017-0965-z

Baltensperger, B. H., & Tensperger, B. H. B. A. L. (1987). Farm Consolidation in the Northern and Central States of the Great Plains. *Great Plains Quarterly.*, 349.

Baquedano, F., Christensen, C., Ajewole, K., & Beckman, J. (2020). *International Food Security Assessment, 2020-2030*.

Barrett, C. B. (2002). Chapter 40 Food Security and Food Assistance Programs. *Handbook of Agricultural Economics*, *2*(PART B), 2103–2190. https://doi.org/10.1016/S1574-0072(02)10027-2

Barrett, C. B., Reardon, T., & Webb, P. (2001). Nonfarm Income Diversification and Household Livelihood Strategies in Rural Africa: Concepts, Dynamics, and Policy Implications. *Food Policy*, *26*(4), 315–331. https://doi.org/10.1016/S0306-9192(01)00014-8

Barrios, E., Gemmill-Herren, B., Bicksler, A., Siliprandi, E., Brathwaite, R., Moller, S., Batello, C., & Tittonell, P. (2020). The 10 Elements of Agroecology: Enabling Transitions towards Sustainable Agriculture and Food sSstems Through Visual Narratives. *Ecosystems and People*, *16*(1), 230–247. https://doi.org/10.1080/26395916.2020.1808705

Barwise, J. (2019, July 16). *Biodiversity Loss and the Threat to Food Production | Croner-i*. Environment-Inform. https://app.croneri.co.uk/feature-articles/biodiversity-loss-and-threat-food-production

Becquey, E., Martin-Prevel, Y., Traissac, P., Dembele, B., Bambara, A., Delpeuch, F., & Dembélé, B. (2010). The Household Food Insecurity Access Scale and an Index-Member Dietary Diversity Score Contribute Valid and Complementary Information on Household Food Insecurity in an Urban West-African setting. *The Journal of Nutrition*, *140*(12), 2233–2240. https://doi.org/10.3945/jn.110.125716 [doi]

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications*, *10*(5), 1251–1262.

Beuchelt, T. D., & Badstue, L. (2013). Gender, Nutrition- and Climate-Smart Food Production: Opportunities and Trade-offs. *Food Security*, *5*(5), 709–721. https://doi.org/10.1007/S12571-013-0290-8/FIGURES/2

Bharucha, Z., & Pretty, J. (2010). The Roles and Values of Wild Foods in Agricultural Systems. . *Philosophical Transactions of the Royal Society: Biological Sciences*, *365*(1554), 2913–2926.

Bjornlund, V., Bjornlund, H., & Van Rooyen, A. F. (2020b). Why Agricultural Production in sub-Saharan Africa remains low compared to the rest of the world–a historical perspective. *International Journal of Water Resources Development*, *sup1*, 1–34. https://doi.org/10.1080/07900627.2020.1739512

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., De Onis, M., Ezzati, M., Grantham-Mcgregor, S., Katz, J., Martorell, R., & Uauy, R. (2013). Maternal and Child Undernutrition and Overweight in Low-Income and Middle-Income Countries. *The Lancet*, *382*(9890), 427–451. https://doi.org/10.1016/S0140-6736(13)60937-X

Braun, J. von. (1991). *Labor-Intensive Public Works for Food Security Experience in Africa - Very Good Nigerian Overview-Older than sp Paper-seepg52.pdf ?* (6; Food Subsides). https://ageconsearch.umn.edu/record/45871/files/Labor-intensive public works for food security Experience in Africa.pdf

Bulman, M. (2017). 90,000 children are expected to die in Nigeria over the next 12 Months, Unicef Warns. The Independent. In *Independent*. Independent Newspaper. https://www.independent.co.uk/news/world/africa/nigerian-children-starve-to-death-2017-nigeria-africa-help-unicef-international-community-aid-a7546176.html

Bundy, D. A., Gentilini, U., Schultz, L., Bedasso, B., Singh, S., Okamura, Y., TMM Iyengar, H., & Monique Blakstad, M. (2024). *School Meals, Social Protection and Human Development: Revisiting Trends, Evidence, and Practices in South Asia and Beyond*. www.worldbank.org

Burchi, F., Fanzo, J., & Frison, E. (2011). The Role of Food and Nutrition System Approaches in Tackling Hidden Hunger. *International Journal of Environmental Research and Public Health*, *8*(2), 358–373. https://doi.org/10.3390/IJERPH8020358

Butler, R. (2005, November 17). *Nigeria Has Worst DeforestationRrate, FAO Revises Figures*. Mongabay. https://news.mongabay.com/2005/11/nigeria-has-worst-deforestation-rate-fao-revises-figures/

Cairns, K., Johnston, J., & Mackendrick, N. (2013). Feeding the 'Organic Child': Mothering through Ethical Consumption. *Http://Dx.Doi.Org/10.1177/1469540513480162*, *13*(2), 97–118. https://doi.org/10.1177/1469540513480162

Cairns, K., & Johnston Josée. (2015). *Food and Femininity - - Google Books*. https://books.google.co.uk/books?hl=en&lr=&id=1YYvCgAAQBAJ&oi=fnd&pg=PP1&dq=Cairns+et+al.+(2013),+indicates+that+eating+behaviours+help+construct+personal+identity+and+social+status&ots=DarSfemrTm&sig=KmSgMvxn2auybLODdGmVh2nOPfI#v=onepage&q&f=false

Capone, R., El Bilali, H., Debs, P., Cardone, G., & Driouech, N. (2014). Food System Sustainability and Food Security: Connecting the Dots. *Journal of Food Security*, *2*(1), 13–22. https://doi.org/10.12691/JFS-2-1-2

Care. (2023). *State of Emergency Declaration on Food Security: A Policy Brief*.

Carey, G., Malbon, E., Carey, N., Joyce, A., Crammond, B., & Carey, A. (2015). Systems Science and Systems Thinking for Public Health: A Systematic Review of the Field. *BMJ Open*, *5*(12), e009002. https://doi.org/10.1136/bmjopen-2015-009002

Cavana, R. Y., & Clifford, L. V. (2006). Demonstrating the Utility of System Dynamics for Public Policy Analysis in New Zealand: the Case of Excise Tax Policy on Tobacco. *System Dynamics Review*, *321*(4), 321–348. https://doi.org/10.1002/sdr

Chappell, M. J., & LaValle, L. A. (2011). Food Security and Biodiversity: Can we Have Both? An Agroecological Analysis. *Agriculture and Human Values*, *28*(1), 3–26. https://doi.org/10.1007/s10460-009-9251-4

Charalabidis, Y., Loukis, E., & Androutsopoulou, A. (2012). A System Dynamics Approach for Complex Government Policies Design . Application in ICT Diffusion. In *International Conference on Modeling, Simulation and Visualization Methods 2012 (MSV'12)* (Vol. 2012). https://www.academia.edu/2852463/A_System_Dynamics_Approach_for_Complex_Government_Policies_Design._Application_in_ICT_Diffusion

Charles, H., Godfray, J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food security: The Challenge of Feeding 9 billion People. *Science*, *327*, 812–818. http://science.sciencemag.org/

Chaudhary, V. (2019, July 1). The Indian State where Farmers Sow the Seeds of Death | Food Security | The Guardian. *The Guardian*. https://www.theguardian.com/global-development/2019/jul/01/the-indian-state-where-farmers-sow-the-seeds-of-death

Chazdon, R. L., Brancalion, P. H. S., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., Moll-Rocek, J., Vieira, I. C. G., & Wilson, S. J. (2016). When is a Forest a Forest? Forest Concepts and Definitions in the Era of Forest and Landscape Restoration. *Ambio*, *45*(5), 538–550. https://doi.org/10.1007/S13280-016-0772-Y/FIGURES/3

Chikaire, J. U., Orusha, J. O., Irebuisi, D. C., Amanze, P. C., & Asonye, N. C. (2016). *Communal Clashes / Conflicts : Bane of Achieving Food Production and Security among Farming Households*. *3*(2), 65–72.

Child, B. (1996). The Practice and Principles of Community-Based Wildlife Management in Zimbabwe : The CAMPFIRE Programme. *Biodiversity and Conservation*, *5*, 369–398.

Chukwuemeka, E. E. O., Aloysius, A., & Eneh, I. M. (2018). The Logic of Open Grazing in Nigeria: Interrogating The Effect on Sustainable Development. *International Journal of Family Business and Management*, *2*(1), 1–17. https://doi.org/10.15226/2577-7815/2/1/00114

Cilliers, P. (2000a). Knowledge, Complexity, and Understanding. *Emergence*, *2*(4), 7–13. https://doi.org/10.1207/S15327000EM0204_03

Cilliers, P. (2000b). What Can we Learn From a Theory of Complexity? *Emergence*, *2*(1), 23–33. https://doi.org/10.1207/S15327000EM0201_03

Cilliers, P. (2000c). What Can we Learn from a Theory of Complexity? *Emergence*, *2*(1), 23–33. https://doi.org/10.1207/S15327000EM0201_03

Cilliers, P. (2002). Why we Cannot Know Complex Things Completely. *Emergence*, *4*(1–2), 77–84.

Coates, J., Swindale, A., & Bilinsky, P. (2007). Household Food Insecurity Access Scale (HFIAS) for Measurement of Food Access: Indicator Guide. In a Food and Nutrition Technical Assistance Project, Academy for Educational Development (Ed.), *FHI 360/FANTA.* (Version 3, Issue August). Food and Nutrition Technical Assistance III Project (FANTA).

Convention on Biological Diversity. (2010). Linking Biodiversity Conservation and Poverty Alleviation: A State of Knowledge Review. In *Pubsiiedorg* (Vol. 55, Issue 55). https://www.cbd.int/doc/publications/cbd-ts-55-en.pdf

Cooksey-Stowers, K., Schwartz, M. B., & Brownell, K. D. (2017). Food Swamps Predict Obesity Rates Better Than Food Deserts in the United States. *International Journal of Environmental Research and Public Health*, *14*(11). https://doi.org/10.3390/IJERPH14111366

Coomes, D., & Lines, E. (2020). *Coomes Group: Passive Rewilding the Woodlands in the Southern Alps of New Zealand | Department of Plant Sciences*. https://www.plantsci.cam.ac.uk/postgraduate/projects/coomes-group-passive-rewilding-woodlands-southern-alps-new-zealand

Cramer, W., Egea, E., Fischer, J., Lux, A., Salles, J.-M., Settele, J., & Tichit, M. (2017). Biodiversity and Food Security: from Trade-offs to Synergies. *Regional Environmental Change*, *17*(5), 1257–1259. https://doi.org/10.1007/s10113-017-1147-z

Currie, D. J., Smith, C., & Jagals, P. (2018). The Application of System Dynamics Modelling to Environmental Health Decision-Making and Policy - A Scoping Review. *BMC Public Health*, *18*(1), 402. https://doi.org/10.1186/s12889-018-5318-8

Daniel, R. A., Wilhelm, T. 'Aulani, Case-Scott, H., Case-Scott, H., Goldman, G., & Hinzman, L. (2022, December 2). *What is "Indigenous Knowledge" And Why Does It Matter? Integrating Ancestral Wisdom and Approaches into Federal Decision-Making*. Guidance for Federal Departments and Agencies on Indigenous Knowledge.

Daum, T., Baudron, F., Birner, R., Qaim, M., & Grass, I. (2023). Addressing Agricultural Labour Issues is Key to Biodiversity-Smart Farming. In *Biological Conservation* (Vol. 284). Elsevier Ltd. https://doi.org/10.1016/j.biocon.2023.110165.

de Mello, F. P. (1991). Boiler Models For System Dynamic Performance Studies. *IEEE Transactions on Power Systems*, *6*(1), 66–74. https://doi.org/10.1109/59.131048

de Oliveira Otto, M. C., Anderson, C. A. M., Dearborn, J. L., Ferranti, E. P., Mozaffarian, D., Rao, G., Wylie-Rosett, J., & Lichtenstein, A. H. (2018). Dietary Diversity: Implications for Obesity Prevention in Adult Populations: A Science Advisory From the American Heart Association. *Circulation*, *138*(11), e160. https://doi.org/10.1161/CIR.0000000000000595

De Schutter, O. (2010). *Report Submitted by the Special Rapporteur on the Right to Food, United Nations*. https://www.scirp.org/reference/referencespapers?referenceid=2160565

DeLong, D. (2005). Business Book Review ™. *Business Book Review*, *22*(25).

Drewnowski, A. (2022). Food insecurity has economic root causes. Nature Food 2022 3:8, 3(8), 555–556. https://doi.org/10.1038/s43016-022-00577-w

D'Silva, B. C., & Raza, M. R. (1980). *Integrated rural development in Nigeria*. https://pdf.sciencedirectassets.com/271787/1-s2.0-S0306919200X0084X/1-s2.0-0306919280900573/main.pdf?X-Amz-Security-Token=IQoJb3JpZ2luX2VjEAAaCXVzLWVhc3QtMSJHMEUCIEWrhYDJN7zQv9mjOwSKgvEqXwyX9igyDSTA4JtYlyQbAiEAuJvLwvL7Tssu6VKYRW3FgKZNRsULpnufBLmvHhp1STIqswUIGRAFGgwwNTkwMDM1NDY4NjUiDADsJyizyyKfe1QWGyqQBc7K81rBkGNkWNd6jzBxmYF8Rvbf1sEBdUvtbCwWnp4ieeWeySLaDT4dc%2B%2BQ4fhH%2BJVGimrceAKv9VB7H6b7ARMIUkzzGurEJ%2FUMNGD9N67NlR%2Bl1iGIPkz0DXhyEOxeQjCH7iqR8XiiM52SQdtN8L4%2BqNXETVa%2BdMs0tVVttyjOj9O7xcGSIpcZcnoif08cJcevlJMplVLN1mgjTPLlYT%2BzBQswlVT9Lreogej9mNI25%2BCnfPpKiFsgjDh1z1wajNgIomC9B60W2%2F4ERIQLl7imTpOf2HaensUoVA1Yh45T3y%2FY%2BRV%2FBcFVXhAYeGqK3bvd6%2BKTJYNaMnUtpMPbKcuHZ3SFQE6qJ%2FEomuL84%2FD8R9%2B6%2F57QF3BOAbA8BdDevXALx%2F%2FGNCN%2FHYyRuCaGyP%2FOHfxLv0qCR281F2Kr9ndhCWt7jhrZRhY%2FTrgqHndHsZSgYTkMgQ9%2BaRgaHrlUUpbV23BD12rtLtwBjhxhvaGCTm092WSEFyK8m0vcdtCDxEarlpZGzV4aSG32RHueNI4quf1CkmheFZxcC633FncxmDw1z4i6OkFty8f4uDhnnwsBgqUfPpV3AI1%2FnWXIY0DMQueiJlpsxkgnGhSuFapkJEaPawuT2ZgdDMsPcFEurmcVa3MPDdUqMe2uDVWkBlVUZHPBeUSWqLiBh7zLt2C7kRtVl0sAHscszWK%2FtJLOO4wmCb37NmnTNzELMD5Cy7KwrU2oE2qUHGYw4vHoqQcTNX%2FZs%2B41wwNc6Z0mEEynIVE0iKAgTptdzOpacXYeNtM1AtAqtNQr3qDQmmcyQJoWOPaEgd1uXe7BPm6uW2C4nAtF59i6WdaAtheVA7UBPmnf84Dtzup5GQo%2FDeObCFVUMJmO7K8GOrEBluGr44lDJZ9t0aoVVSbSNDScIztSco%2BkZYtYD76PL9dJq9zFPrdWeOwwXUq%2FjrXxY7fw55OIeNhQZVqN80H193WfnaupOe4O3GGRiFXLLFK91HsEet5RxaJd0oJkqJo%2BBbl2XVdN58nEdYCynKZP8kf%2FTEJFsBCh9uW%2BjAOoRkX3ait5b1cF6MefHxn6FLVEikXn0l%2B4puZBaQHm30NovMQa%2BB9pDdrgkR4uxIlXUoXAF&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20240320T164734Z&X-Amz-SignedHeaders=host&X-Amz-Expires=300&X-Amz-Credential=ASIAQ3PHCVTY2HDSEEOF%2F20240320%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Signature=a5cb49ce05d64643fdaf416f4295b8c7bb214bcc7c60ca72018bca026ef587c0&hash=3ca6de3456c26ddcccc8d7b9d073f601e0d760775953a0c9ad805ad85a506a74&host=68042c943591013ac2b2430a89b270f6af2c76d8dfd086a07176afe7c76c2c61&pii=0306919280900573&tid=spdf-ebd0b55c-290c-41ea-94a2-6991b81311d8&sid=447af19a37b7b849838bb8298574abe3dcf7gxrqb&type=client&tsoh=d3d3LnNjaWVuY2VkaXJlY3QuY29t&ua=1d065c53545054095604&rr=86772f4c19c76554&cc=gb

Dunbar, G. S., & Udo, R. K. (1972). Geographical Regions of Nigeria. In *Geographical Review* (First, Vol. 62, Issue 2). University of California Press. https://doi.org/10.2307/213228

Dunne, J. P., & Edkins, B. (2008). The Demand for Food in South Africa 1. *South African Journal of Economics*, *76*(1), 104–117. https://doi.org/10.1111/j.1813-6982.2008.00162.x

Eboh, M. (2018). *Nigeria's Food Imports Dropping Drastically - FG - Vanguard News*. Vanguard. https://www.vanguardngr.com/2018/03/nigerias-food-imports-dropping-drastically-fg/

Ecker, O., Hatzenbuehler, P. L., & Mahrt, K. (2018). *Transforming Agriculture for Improving Food and Nutrition Security among Nigerian Farm Households* (Issue October).

El Bilali, H., Cardone, G., Kader, A., Jika, N., De Falcis, E., Rokka, S., Diawara, A. B., Nouhou, B., & Ghione, A. (2022). AGRO-BIODIVERSITY in NATIONAL PATHWAYS for FOOD SYSTEM

TRANSFORMATION: CASE of WEST AFRICA. *AGROFOR International Journal*, *7*(3). https://doi.org/10.7251/AGRENG2203005E

Elevitch, C. R., Mazaroli, N. D., & Ragone, D. (2018). Agroforestry Standards for Regenerative Agriculture. *Sustainability (Switzerland)*, *10*(9). https://doi.org/10.3390/SU10093337

Emmeche, C. (2004). The Significance of Complexity: Approaching a Complex World through Science, Theology and the Humanities. In K. Van Kooten Niekerk & H. BUHL (Eds.), *At Home in a Complex World:Lessons from the Frontiers of Natural Science* (pp. 20–43). Ashgate.

Ericksen, P. (2008). Global Environmental Change and Food Security. *Global Change NewsLetter*, *No. 71*. http://www.gecafs.org/publications/Publications/Global_Environmental_Change_&_Food_Security.pdf

EURACTIV. (2012). *Intensive farming: Ecologically sustainable? – EURACTIV.com*. Agriculture. https://www.euractiv.com/section/agriculture-food/linksdossier/intensive-farming-ecologically-sustainable/

Faber, M., Schwabe, C., & Drimie, S. (2009). Dietary Diversity in Relation to other Household Food Security Indicators. *International Journal of Food Safety, Nutrition and Public Health*, *2*(1), 1. https://doi.org/10.1504/IJFSNPH.2009.026915

Famoriyo, S., & Raza, M. R. (1982). The Green Revolution in Nigeria: Prospects for Agricultural Development. *Food Policy*, *7*(1), 27–38. https://doi.org/10.1016/0306-9192(82)90005-7

FAO. (2010). The State of Food Insecurity in the World Addressing Food Insecurity in Protracted Crises 2010 Key Messages. In *The State of Food Insecurity in the World*. FAO. http://www.fao.org/docrep/013/i1683e/i1683e.pdf

FAO. (2012a). *Decent Rural Employment for Food Security: A Case for Action KNOWLEDGE MATERIALS*.

FAO. (2012b). *The State of Food Insecurity in the World. Economic Growth is Necessary but not Sufficient to Accelerate Reduction of Hunger and Malnutrition*. FAO. http://www.fao.org/docrep/016/i3027e/i3027e.pdf

FAO. (2015). *Healthy Soils are the Basis for Healthy Food Production | FAO*. International Year of Soils. http://www.fao.org/soils-2015/news/news-detail/en/c/277682/

FAO. (2018e). *Food Security and Nutrition in the World. The State of Building Climate Resilience for Food Security and Nutrition* (2018th ed.). http://www.fao.org/publications

FAO. (2018b). *Small Family Farms Country Fact sheet ζ The Context of Agriculture and the Role of Small Family Farms Economic Situation and Diversification*.

FAO. (2018c). *Sustainable Food Systems Concept and Framework What is a Sustainable Food System? Why Take a Food Systems Approach? Changing Food Systems*. http://www.fao.org/3/ca2079en/CA2079EN.pdf

FAO. (2018d). The *10 Elements of Agroecology Guiding the Transition to Sustainable Food And Agricultural Systems*.

FAO. (2018a). *Transforming Food and Agriculture to Achieve Sustainable Development Goals*. http://www.fao.org/3/I9900EN/i9900en.pdf

Fao. (2018). *Transition towards Sustainable Food and Agriculture*.

FAO. (2019a). *Biodiversity Report*. The State of the World's Biodiversity for Food and Agriculture. http://www.fao.org/state-of-biodiversity-for-food-agriculture/en/

FAO. (2019b). *HLPE High Level Panel of Experts HLPE High Level Panel of Experts Agroecological and other Innovative Approaches A report by The High Level Panel of Experts on Food Security and Nutrition*. www.fao.org/cfs/cfs-hlpe

FAO. (2019c). *The State of the World's Biodiversity for Food And Agriculture FAO Commission on Genetic Resources for Food and Agriculture Assessments• 2019*. (http://www.fao.org/3/CA3129EN/CA3129EN.pdf)

FAO. (2020). • *Nigeria: Prevalence of Severe Food Insecurity 2014-2019 | Statista*. Suite of Food Security Indicators. https://www.statista.com/statistics/1135843/prevalence-of-severe-food-insecurity-in-nigeria/

FAO. (2022a). Thinking about the Future of Food Safety. In *Thinking about the future of food safety*. FAO. https://doi.org/10.4060/cb8667en

FAO Commission on Genetic Resources for Food and Agriculture. (2020). *How The World's Food Security Depends On Biodiversity*.

FAO, I. U. W. and W. (2022b). *Food Security and Nutrition in the World the State of Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable*. https://doi.org/10.4060/cc0639en

FAO, IFAD, UNICEF, WFP, & WHO. (2019). *State of Food Security and Nutrition in the World 2019. Safeguarding against Economic Slowdowns and Downturns*. http://www.fao.org/3/ca5162en/ca5162en.pdf

FAO-ILO-IUF, Hurst, P., Termine, P., & Karl, M. (2005). *Agricultural Workers and their Contribution to Sustainable Agriculture and Rural Development*. Sustainable Development Department, FAO SD Dimensions.

Federal Ministry of Agriculture and Rural Development. (2016). *The Agriculture Promotion Policy (2016 – 2020): Building on the Successes of the ATA, Closing Key Gaps*. http://fmard.gov.ng/wp-content/uploads/2016/03/2016-Nigeria-Agric-Sector-Policy-Roadmap_June-15-2016_Final.pdf

Fernández-Llamazares, Á., & Cabeza, M. (2018). Rediscovering the Potential of Indigenous Storytelling for Conservation Practice. *Conservation Letters*, *11*(3). https://doi.org/10.1111/CONL.12398

Fernández-Llamazares, Á., López-Baucells, A., Velazco, P. M., Gyawali, A., Rocha, R., Terraube, J., & Cabeza, M. (2021). The Importance of Indigenous Territories for Conserving Bat Diversity across the Amazon Biome. *Perspectives in Ecology and Conservation*, *19*(1), 10–20. https://doi.org/10.1016/J.PECON.2020.11.001

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N., & Snyder, P. K. (2005). Global Consequences of Land Use. *Science (New York, N.Y.)*, *309*(5734), 570–574. https://doi.org/10.1126/SCIENCE.1111772

Folorunso, R. O. (2013). Consumers' Buying Decisions of Foreign and Domestic Products in Nigeria: An Analysis. *European Journal of Business and Management*, *5*(25).

Food Research and Action Center. (2015). *Hunger and Obesity? Making the Connections*. https://cspinet.org/sites/default/files/attachment/hunger_and_obesity__frac_.pdf

Food Security Information Network. (2018). *GLOBAL Report on Food Crises 2018 FSIN Food Security Information Network*. https://docs.wfp.org/api/documents/WFP-0000069227/download/?_ga=2.236389189.552880058.1554560718-240482493.1550493195

Food Security Information Network. (2019). *FSIN Food Security Information Network Global Report on Food Crises Joint Analysis for Better Decisions 2019 FSIN Food Security Information Network Global Report on Food Crises*.

Forrester, J. W., & Senge, P. M. (1980). Tests for Building Confidence in System Dynamic Models. In *TIMS Studies in the Management Sciences* (14th ed., pp. 209–228). North-Holland Publishing Company.

Fraval, S., Hammond, J., Bogard, J. R., Ng'endo, M., van Etten, J., Herrero, M., Oosting, S. J., de Boer, I. J. M., Lannerstad, M., Teufel, N., Lamanna, C., Rosenstock, T. S., Pagella, T., Vanlauwe, B., Dontsop-Nguezet, P. M., Baines, D., Carpena, P., Njingulula, P., Okafor, C., …

van Wijk, M. T. (2019). Food Access Deficiencies in Sub-saharan Africa: Prevalence and Implications for Agricultural Interventions. *Frontiers in Sustainable Food Systems*, *3*(5), 480343. https://doi.org/10.3389/FSUFS.2019.00104/BIBTEX

Frison, E. A., Cherfas, J. , & Hodgkin, T. (2011). Agricultural biodiversity is Essential for a Sustainable Improvement in Food and Nutrition Security. *Sustainability*, *3*(1), 238–253.

Frison, E. A., Cherfas, J., Hodgkin, T., Frison, E. A., Cherfas, J., & Hodgkin, T. (2011). Agricultural Biodiversity Is Essential for a Sustainable Improvement in Food and Nutrition Security. *Sustainability*, *3*(1), 238–253. https://doi.org/10.3390/su3010238

Fritijof, C. (2002). *The Hidden Connections: A Science for Sustainable Living* (First, pp. 97–128). HarperCollins.

Fritz, T. (2011). *Globalising Hunger Globalising Hunger: Food Security and the EU's Common Agricultural Policy*.

FSIN. (2017). Global Report on Food Crises 2017. In *World Food Programme*. http://www.fao.org/3/a-br323e.pdf

FSIN. (2020). Global Report on Food Crises: Acute Food Insecurity and Malnutrition forecasts for 2020. In *Food Security Information Network*. https://www.wfp.org/publications/2020-global-report-food-crises

Ghaffarzadegan, N., Lyneis, J., & Richardson, G. P. (2011). How Small Models Can Help the Public Policy Process. *System Dynamics Review*, *27*, 22–44. http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=42A8D71854775452586877921BB1A793?doi=10.1.1.407.8702&rep=rep1&type=pdf

Giller, K. E., Hijbeek, R., Andersson, J. A., & Sumberg, J. (2021). Regenerative Agriculture: An agronomic perspective. *Outlook on Agriculture*, *50*(1), 13–25. https://doi.org/10.1177/0030727021998063/ASSET/IMAGES/LARGE/10.1177_0030727021998063-FIG4.JPEG

Gliessman, S., & Tittonell, P. (2015). Editorial : Agroecology for Food Security and Nutrition. *Agroecology and Sustainable Food Systems*, *39*(2), 131–133. https://doi.org/10.1080/21683565.2014.972001

Global Forest Watch (GFW). (2023). *Global Forest Watch- Nigeria*. Global Forest Watch. https://www.globalforestwatch.org/dashboards/country/NGA/?category=undefined

Goodman, M. (2018). *The Systems Thinker – Systems Thinking: What, Why, When, Where, and How? - The Systems Thinker*. System Thinker. https://thesystemsthinker.com/systems-thinking-what-why-when-where-and-how/

Gorbea, C., Lindemann, U., & De Weck, O. (2011). System Dynamics Modeling of New Vehicle Architecture Adoption. *18th International Conference on Engineering Design, ICED 11, August 15, 2011 - August 18, 2011*, *10*(August 2011), 278–289.

Gorski, M. T., & Roberto, C. A. (2015). Public Health Policies to Encourage Healthy Eating Habits: Recent Perspectives. *Journal of Healthcare Leadership*, *7*, 81–90. https://doi.org/10.2147/JHL.S69188

Guasa, P. (2005). *The Coping Strategies Index (CSI) Follow-Up Survey 2005 : World Food Programme (WFP) Assisted Refugees in Western Tanzania*.

Guma, I. P., Rwashana, A. S., & Oyo, B. (2017). Food Security Policy Analysis Using System Dynamics. *International Journal of Information Technologies and Systems Approach*, *11*(1), 72–90. https://doi.org/10.4018/IJITSA.2018010104

Gunstone, T., Cornelisse, T., Klein, K., Dubey, A., & Donley, N. (2021). Pesticides and Soil Invertebrates: A Hazard Assessment. *Frontiers in Environmental Science*, *9*. https://doi.org/10.3389/FENVS.2021.643847/FULL

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijck, R., & Meybeck, A. (2011a). Extent of food losses and waste. *Global Food Losses and Food Waste*, 4–9.

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijck, R., & Meybeck, A. (2011b). Extent of Food Losses and Waste. *Global Food Losses and Food Waste*, 4–9.

Hammond, R. A., & Dubé, L. (2012). A Systems Science Perspective and Transdisciplinary Models for Food and Nutrition Security. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(31), 12356–12363. https://doi.org/10.1073/pnas.0913003109

Hardy, D., Palakshappa, N., & Venkateswar, S. (2024). *School-and Community-Based Approaches to Healthy Eating and Food Security in Aotearoa New Zealand*.

Harris, M. A., & Mohammed, S. (2003). Relying on Nature: Wild Foods in Northern Nigeria on JSTOR. *Royal Swedish Academy of Science*, *32*(1). https://www.jstor.org/stable/4315328?seq=1#metadata_info_tab_contents

He, C., Okada, N., Zhang, Q., Shi, P., & Zhang, J. (2006). Modeling Urban Expansion Scenarios by Coupling Cellular Automata Model and System Dynamic Model in Beijing, China. *Applied Geography*, *26*(3–4), 323–345. https://doi.org/10.1016/j.apgeog.2006.09.006

Headey, D., & Ecker, O. (2013). *Rethinking the Measurement of Food Security : from First Principles to Best Practice*. 327–343. https://doi.org/10.1007/s12571-013-0253-0

Headey, D., Hirvonen, K., & Hoddinott, J. (2018). Animal Sourced Foods and Child Stunting. *American Journal of Agricultural Economics*, *100*(5), 1302–1319. https://doi.org/10.1093/AJAE/AAY053

Heller, M. C., & Keoleian, G. A. (2003). Assessing the Sustainability of the US Food System: A Life Cycle Perspective. *Agricultural Systems*, *76*(3), 1007–1041. https://doi.org/10.1016/S0308-521X(02)00027-6

Hernandez Marentes, M. A., Venturi, M., Scaramuzzi, S., Focacci, M., & Santoro, A. (2022). Traditional Forest-Related Knowledge and Agrobiodiversity Preservation: the Case of the Chagras in the Indigenous Reserve of Monochoa (Colombia). *Biodiversity and Conservation*, *31*(10), 2243–2258. https://doi.org/10.1007/S10531-021-02263-Y

Herrero -, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S., & Rufino, M. C. (2013). 7:s1, pp 3-18 & The Animal Consortium. *Animal*. https://doi.org/10.1017/S1751731112001954

Herrero, M., Thornton, P. K., Notenbaert, A. M., Wood, S., Msangi, S., Freeman, H. A., Bossio, D., Dixon, J., Peters, M., Van De Steeg, J., Lynam, J., Rao, P., MacMillan, S., Gerard, B., McDermott, J., Seré, C., & Rosegrant, M. (2010). Smart Investments in Sustainable Food Production: Revisiting Mixed Crop-Livestock Systems. *Science (New York, N.Y.)*, *327*(5967), 822–825. https://doi.org/10.1126/SCIENCE.1183725

Hinrichs, C. C., & Lyson, T. A. (2007). *Remaking the North American Food System : Strategies for Sustainability*. University of Nebraska Press.

Hoddinott, J., & Yohannes, Y. (2002). Dietary Diversity as a Food Security Indicator. *Food Consumption and Nutrition Division Discussion Paper*, *136*(136), 2002.

Horlings, L. G., & Marsden, T. K. (2011). Towards the Real Green Revolution? Exploring the Conceptual Dimensions of a New Ecological Modernisation of Agriculture that Could "Feed the World." *Global Environmental Change*, *21*(2). https://doi.org/10.1016/j.gloenvcha.2011.01.004

Igbozurike, U. M. (1978). Polyculture and Monoculture: Contrast And Analysis. In *GeoJournal* (Vol. 2). https://about.jstor.org/terms

Ike, C. U. (2015). *Measuring Household Food Security Status in Taraba State, Nigeria: Comparing Key Indicators* [MPhil Thesis]. Stellenbosch Unversity.

Ike, C. U., Jacob, P. T., & Kelly, C. (2016). Towards Comprehensive Food Security Measures: Comparing Key Indicators. *African Insight*, *45*(3), 91–110.

Ike, C. U., Jacobs, P. T., & Kelly, C. (2017). A Multidimensional Approach to Measuring Household Food Security in Taraba State , Nigeria : Comparing Key Indicators in Taraba State , Nigeria : *Development in Practice*, *27*(2), 234–246. https://doi.org/10.1080/09614524.2017.1281225

Ikerd, J. (2021). THE ECONOMIC PAMPHLETEER: Realities of regenerative agriculture. *Journal of Agriculture, Food Systems, and Community Development*, *10*(2), 7–10. https://doi.org/10.5304/jafscd.2021.102.001

ILO. (2016). *Decent work for food security*. An ILO Sectoral Programme. http://ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_161946.pdf

Ingram, J. (2011). A food systems approach to researching food security and its interactions with global environmental change. *Food Security*, *3*(4), 417–431. https://doi.org/10.1007/s12571-011-0149-9

Ingram, J. (2019). Food system models. *Healthy and Sustainable Food Systems*, 49–62. https://doi.org/10.4324/9781351189033-5

Ingram, J., & Zurek, M. (2018). Food systems approaches for the future. *Agriculture & Food Systems To 2050: Global Trends, Challenges And Opportunities*, 547–567. https://doi.org/10.1142/9789813278356_0016

Integrated Food Security Phase Classification. (2021, March). *Nigeria: Over One Million Children Acutely Malnourished in North East Nigeria | IPC Global Platform*. IPC Nigeria Alert. http://www.ipcinfo.org/ipcinfo-website/alerts-archive/issue-36/en/

International Monetary Fund Dept. African. (2023). Nigeria: Selected Issues. *IMF Staff Country Reports*, *2023*(094). https://doi.org/10.5089/9798400234545.002.A001

Iwuchukwu, J., & Igbokwe, E. (2012). *Lessons from Agricultural Policies and Programmes in Nigeria* (Vol. 5).

Jacobs, P. T. (2010). The Status of Household Food Security Targets in South Africa. *Agrekon : Agricultural Economics Research , Policy and Practice in Southern Africa*, *48*(4), 410–433. https://doi.org/10.1080/03031853.2009.9523834

Jacques, P. J., & Jacques, J. R. (2012). Monocropping Cultures into Ruin: The Loss of Food Varieties and Cultural Diversity. *Sustainability*, *4*(11), 2970–2997. https://doi.org/10.3390/su4112970

Janvry, A. De, & Sadoulet, E. (2010). Agriculture for Development in Sub-Saharan Africa: An Update. *African Journal of Agricultural and Resource Economics*, *05*(1), 1–11. https://doi.org/10.22004/AG.ECON.156657

Jayne, T., Mather, D., Mghenyi, E., Jayne, T., Mather, D., & Mghenyi, E. (2010). Principal Challenges Confronting Smallholder Agriculture in Sub-Saharan Africa. *World Development*, *38*(10), 1384–1398. https://EconPapers.repec.org/RePEc:eee:wdevel:v:38:y:2010:i:10:p:1384-1398

Jerome, A. (2015). Nigeria ' s Food Security Programs : Implications for MDG ' s Goal of Extreme Hunger Eradication . *International Journal of Business and Social Science*, *3*(9), 243–253.

John Hopkins. (2014). *Industrialization of Agriculture - Food Production - Food System Primer - Johns Hopkins University*. Center for a Livable Future at Johns Hopkins University. http://www.foodsystemprimer.org/food-production/industrialization-of-agriculture/index.html

Johns, T., & Eyzaguirre, P. B. (2006). Linking biodiversity, diet and health in policy and practice. *Proceedings of the Nutrition Society, *, *65*(2), 182–189.

Jones, A. D., Ngure, F. M., Pelto, G., & Young, S. L. (2013). What are We Assessing When We Measure Food Security ? A Compendium and Review of Current Metrics 1 , 2. *Advances in*

Nutrition (Bethesda, Md.), *4*(5), 481–505. https://doi.org/10.3945/an.113.004119.disciplines

Kassie, B. T., Rötter, R. P., Hengsdijk, H., Asseng, S., Van Ittersum, M. K., Kahiluoto, H., & Van Keulen, H. (2014). Climate variability and change in the Central Rift Valley of Ethiopia: challenges for rainfed crop production. *The Journal of Agricultural Science*, *152*(1), 58–74. https://doi.org/10.1017/S0021859612000986

Kassie, M., Zikhali, P., Pender, J., Köhlin, G., Kassie, M., Zikhali, P., Pender, J., & Köhlin, G. (2010). The Economics of Sustainable Land Management Practices in the Ethiopian Highlands. *Journal of Agricultural Economics*, *61*(3), 605–627. https://doi.org/10.1111/J.1477-9552.2010.00263.X

Kaur, M., & Kaur, P. (2016). Transformation of Punjab's Malwa Region from Cotton Belt to Cancer Belt. *International Research Journal of Social Sciences*, *5*(9), 35–40. http://isca.in/IJSS/Archive/v5/i9/7.ISCA-IRJSS-2016-137.pdf

Kemi, F. O., Azeez, M.-L., & Damilare, E. I. (2014). Assessment of Hired Labour Use and Food Security among Rural Farming Households in Kwara State, Nigeria. *Journal of Agricultural Science*, *59*(3), 353–361. https://doi.org/10.2298/JAS1403353O

Kennedy, G., Ballard, T., Dop, M. C., & FAO. (2011). *Guidelines for measuring household and Individual Dietary Diversity* (G. Kennedy, T. Ballard, & M. Dop, Eds.; Reprint 20). Food and Agriculture Organization of the United Nations.

Kennedy, G., Razes, M., Ballard, T., & Dop, M. C. (2010). Measurement of Dietary Diversity for Monitoring the Impact of Food Based Approaches 1 , 2 Gina Kennedy, Maylis Razes, Terri Ballard and Marie Claude Dop. *Food and Nutrition Security: Food-Basesapproaches for Improving Diet and Raising Level of Nutrition*.

Kennedy, G., Wang, Z., Maundu, P., & Hunter, D. (2022). The Role of Traditional Knowledge and Food Biodiversity to Transform Modern Food Systems. *Trends in Food Science & Technology*, *130*, 32–41. https://doi.org/10.1016/J.TIFS.2022.09.011

Khush, G. S. (2016). Biodiversity Use for Food Security. *Indian Journal of Plant Genetic Resources*, *29*(3), 251. https://doi.org/10.5958/0976-1926.2016.00038.3

Kloppenburg, J. (2010). Impeding Dispossession, Enabling Repossession: Biological Open Source and the Recovery of Seed Sovereignty. *Journal of Agrarian Change*, *10*(3), 367–388. https://doi.org/10.1111/J.1471-0366.2010.00275.X

Kolawole, O., & Ojo, S. O. (2007). Economic Efficiency of Small Scale Food Crop Production in Nigeria: A Stochastic Frontier Approach. *Journal of Social Sciences*, *14*(2), 128–130. https://doi.org/10.1080/09718923.2007.11978363

Koppmair, S., Kassie, M., & Qaim, M. (2017). Farm production, Market Access and Dietary Diversity in Malawi. *Public Health Nutrition*, *20*(2), 325–335. https://doi.org/10.1017/S1368980016002135

Kowalczuk, I., Stangierska, D., Gębski, J., Tul-Krzyszczuk, A., & Zmudczyńska, E. (2021). Digital Consumers in the Foodservices Market. *Sustainability 2021, Vol. 13, Page 7403*, *13*(13), 7403. https://doi.org/10.3390/SU13137403

KPMG International. (2023). *KPMG Global Economic Outlook - H1 2023 report*.

Kuku-shittu, O., Mathiassen, A., & Myles, L. (2013). Comprehensive Food Security and Vulnerability Analysis. In *IFPRI Discussion Paper01225* (01275; July 2013, Issue July). http://nssp.ifpri.info/2013/08/21/comprehensive-food-security-and-vulnerability-analysis-nigeria/

Kuokkanen, A., Linnanen, L., Mikkilä, M., Kahiluoto, H., & Kuisma, M. (2015). *Capturing socio-Economic Complexity (of Food System) to Navigate within the Nitrogen and Phosphorus boundaries*. https://www.ucl.ac.uk/bartlett/sustainable/sites/bartlett/files/lassi-linnanen.pdf

Kuyek, D. (2000, August). *GRAIN | Blast, biotech and Big Business: Implications of Corporate strategies on rice research in Asia*. GRAIN. https://grain.org/en/article/36-blast-biotech-and-big-business-implications-of-corporate-strategies-on-rice-research-in-asia

Labour-Intensive Public Works for Food Security in Africa: Past Experience and Future Potential. (n.d.). *International Labour Review*. Retrieved January 29, 2019, from https://heinonline.org/HOL/Page?collection=journals&handle=hein.journals/intlr131&id=34&men_tab=srchresults

Lang, T., & Heasman, M. (2004). Food Wars: "The Global Battle for Mouths, Minds and Markets." *Food Wars: "The Global Battle for Mouths, Minds and Markets," 9781849776011*, 1–365. https://doi.org/10.4324/9781849776011

Laurance, W. F., Sayer, J., & Cassman, K. G. (2014). Agricultural expansion and its impacts on tropical nature. *Trends in Ecology and Evolution*, *29*(2), 107–116. https://doi.org/10.1016/J.TREE.2013.12.001

Lentz, E. C., & Barrett, C. B. (2013). The Economics and Nutritional Impacts of Food Assistance Policies and Programs. *Food Policy*, *42*, 151–163.

Lin, B. B. (2011). Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change. *BioScience*, *61*(3), 183–193. https://doi.org/10.1525/bio.2011.61.3.4

Liverpool-Tasie, L. S., Kuku, O., & Ajibola, A. (2011). A Review of Literature on Agricultural Productivity, Social Capital and Food Security in Nigeria THE NIGERIA STRATEGY SUPPORT PROGRAM (NSSP). In *NSSP Working Paper 21* (21; NSSP 2011). International Food Policy Research Institute (IFPRI). http://www.ifpri.org/publication/review-literature-agricultural-productivity-social-capital-and-food-security-nigeria

Lowder, S. K., Skoet, J., & Raney, T. (2016). The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. *World Development*, *87*, 16–29. https://doi.org/10.1016/j.worlddev.2015.10.041

Luján Soto, R., Cuéllar Padilla, M., & de Vente, J. (2020). Participatory Selection of Soil Quality Indicators for Monitoring the Impacts of Regenerative Agriculture on Ecosystem Services. *Ecosystem Services*, *45*, 101157. https://doi.org/10.1016/J.ECOSER.2020.101157

Luján Soto, R., Martínez-Mena, M., Cuéllar Padilla, M., & de Vente, J. (2021). Restoring soil Quality of Woody Agroecosystems in Mediterranean Drylands through Regenerative Agriculture. *Agriculture, Ecosystems & Environment*, *306*, 107191. https://doi.org/10.1016/J.AGEE.2020.107191

Mäder, P. , Fliessbach, A., Dubois, D., Gunst, L. , Fried, P. , & Niggli, U. (2002). Soil Fertility and Biodiversity in Organic Farming. *Science*, 1694–1697.

Maiangwa, M. (2008). Adoption of Mixed Cropping by Farmers in the Northwest Zone of Nigeria. *Global Journal of Agricultural Sciences*, *7*(2), 167–175. https://doi.org/10.4314/GJASS.V7I2.2381

Maiangwa, M. G. (2008). Adoption of Mixed Cropping by Farmers in the North-West Zone of Nigeria. *Global Journal Of Agricultural Science*, *7*(2), 167–175.

Mailumo, S. S., Adepoju, A. O., Oyewole, S. O., & Onuwa, G. C. (2022). Assessment of agro-crop Biodiversity among Smallholder Farmers in Kogi State, Northern Nigeria. *Biodiversity*, *23*(1), 3–10. https://doi.org/10.1080/14888386.2022.2058613

Majeed, A. (2018). Application of Agrochemicals in Agriculture: Benefits, Risks and Responsibility of Stakeholders. *J Food Sci Toxicol*, *2*(1). http://www.imedpub.com/

Makate, C., Wang, R., Makate, M., & Mango, N. (2016). Crop Diversification and Livelihoods of Smallholder Farmers in Zimbabwe: adaptive management for environmental change. *SpringerPlus*, *5*(1), 1135. https://doi.org/10.1186/s40064-016-2802-4

Mango, N., Makate, C., Mapemba, L., & Sopo, M. (2018). The role of crop diversification in Improving Household Food Security in Central Malawi. *Agriculture and Food Security*, *7*(1). https://doi.org/10.1186/s40066-018-0160-x

Martin, R., & Schlüter, M. (2015). Combining System Dynamics and Agent-Based Modeling to Analyze Social-Ecological Interactions-an Example from Modeling Restoration of a Shallow Lake. *Frontiers in Environmental Science*, *3*(OCT), 154494. https://doi.org/10.3389/FENVS.2015.00066/BIBTEX

Matchaya, G., & Guthiga, P. (2023). Food System Diagnostics and Policy Implications: The Malawi Case Introduction. In *ReSAKSS Annual Trends and Outlook Report* (Vol. 37).

Matemilola, S., & Elegbede, I. (2017). The Challenges of Food Security in Nigeria. *OALib*, *04*(12), 1–22. https://doi.org/10.4236/oalib.1104185

Maxwell, D., & Caldwell, R. (2008). *The Coping Strategies Index: Field Methods Manual* (Second Edi, Issue January). CARE USA. http://www.seachangecop.org/sites/default/files/documents/2008 01 TANGO - Coping Strategies Index.pdf

Maxwell, D., Vaitla, B., & Coates, J. (2014). How do Indicators of Household Food Insecurity Measure up? An Empirical Comparison from Ethiopia. *Food Policy*, *47*, 107–116. https://doi.org/10.1016/J.FOODPOL.2014.04.003

Maxwell, D., Watkins, B., Wheeler, R., & Collins, G. (2003). The Coping Strategies Index: A tool for Rapidly Measuring Food Security and the Impact of Food Aid Programs in Emergencies. *Nairobi, Kenya: CARE and World Food Programme*, *September*, 23–25.

Mayowa, A. E. (2020, December 13). Tasty Food of the Northern Nigeria- A Culinary Tale. *Life: Everything You Need to Live Well*.

McGuire, S., & Sperling, L. (2016a). Seed SystemsSsmallholder Farmers Use. *Food Security*, *8*(1), 179–195. https://doi.org/10.1007/S12571-015-0528-8/TABLES/9

McGuire, S., & Sperling, L. (2016b). Seed systems smallholder farmers use. *Food Security*, *8*(1), 179–195. https://doi.org/10.1007/S12571-015-0528-8/TABLES/9

McGuire, S., & Sperling, L. (2016c). Seed systems smallholder farmers use. *Food Security*, *8*(1), 179–195. https://doi.org/10.1007/S12571-015-0528-8

Mgbenka, R. N., Mbah, E. N., & Ezeano, C. I. (2015). A Review of Small holder Farming in Nigeria: Need for Transformation. *Agricultural Engineering Research Journal*, *5*(2), 19–26. https://doi.org/10.5829/idosi.aerj.2015.5.2.1134

Mistry, J. (2009). Indigenous Knowledges. *International Encyclopedia of Human Geography*, 371–376. https://doi.org/10.1016/B978-008044910-4.00101-2

Mjonono, M., Ngidi, M., & Hendriks, S. L. (2009). Investigating Household Food Insecurity Coping Strategies and the Impact of Crop Production on Food Security Using Coping Strategy Index (csi). *Fram Management*, *17th inter*(July 2009), 312–326.

Mohammed, S. S., & Mahmood, M. B. (2023). The Effect of the Power Plant on the Biodiversity of Zooplankton. *Bionatura*, *8*(CSS2). https://doi.org/10.21931/RB/CSS/2023.08.02.15

Molinero Gerbeau, Y., & Avallone, G. (2016). Producing Cheap Food and Labour: Migrations and Agriculture in the Capitalistic World-Ecology World-ecology Migrations Capitalism Agriculture Seasonal workers. *Social Change Review ▪ Winter*, *14*(2), 121–148. https://doi.org/10.1515/scr-2016-0025

Mongabay. (2020). *Deforestation statistics for Nigeria*. Forest Data for Nigeria. https://rainforests.mongabay.com/deforestation/archive/Nigeria.htm

Monteiro, C. A., Cannon, G., Moubarac, J. C., Levy, R. B., Louzada, M. L. C., & Jaime, P. C. (2018). The UN Decade of Nutrition, the NOVA Food Classification and the Trouble with Ultra-Processing. *Public Health Nutrition*, *21*(1), 5–17. https://doi.org/10.1017/S1368980017000234

Moodie, R., Stuckler, D., Monteiro, C., Sheron, N., Neal, B., Thamarangsi, T., Lincoln, P., & Casswell, S. (2013). Profits and Pandemics: Prevention of harmful ffects of tobacco, Alcohol, and Ultra-Processed Food and Drink Industries. *The Lancet*, *381*(9867), 670–679. https://doi.org/10.1016/S0140-6736(12)62089-3/ASSET/57495C1C-B058-497D-9F86-2438B0B97959/MAIN.ASSETS/GR2.JPG

Morton, J. F. (2007). The Impact of Climate Change on Smallholder and Subsistence Agriculture. *Proceedings of the National Academy of Sciences*, 19680–19685.

Musango, J. K., Brent, A., & Bassi, A. (2019). *South African Energy model: A System Dynamics Approach*.

Musango, J. K., Brent, A. C., & Tshangela, M. (2014). Green Economy Transitioning of the South African power sector: A System Dynamics Analysis approach. *Development Southern Africa*, *31*(5), 744–758. https://doi.org/10.1080/0376835X.2014.930792

Mustoe, S. (2021, April 25). *How Many Years to Restore the Planet's Ecosystems?* Wildlife in the Balance.

Napoli, M., De Muro, P., & Mazziotta, M. (2011). *Towards a Food Insecurity Multidimensional Index (FIMI): Vol. Masters*. http://www.fao.org/fileadmin/templates/ERP/uni/FIMI.pdf

National Bureau of Statistics Nigeria. (2005). *Poverty Profile for Nigeria*.

National Bureau of Statistics Nigeria. (2019). *Nigeria Unemployment Rate | 2019 | Data | Chart | Calendar | Forecast | News*. Unemployment Rate. https://tradingeconomics.com/nigeria/unemployment-rate

National Population Commission. (2006). *2006 Population and Housing Census of the Federal Republic of Nigeria: Vol. I* (Issue Volume I). National Population Commission. http://www.population.gov.ng/index.php/censuses

NBS (National bureau of statistics). (2019). Nigerian 2016 Q4 & Full Year Gross Domestic Product Report. *National Bureau of Statistics*, *February*, 2–147. National Bureau of Statistics

Ndaeyo, N. U., Umoh, G. S., & Ekpe, E. O. (2001). Farming Systems in Southeastern Nigeria: Implications for Sustainable Agricultural Production. *Journal of Sustainable Agriculture*, *17*(4), 75–89. https://doi.org/10.1300/J064v17n04_07

Newton, P., Civita, N., Frankel-Goldwater, L., Bartel, K., & Johns, C. (2020). What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. In *Frontiers in Sustainable Food Systems* (Vol. 4). Frontiers Media S.A. https://doi.org/10.3389/fsufs.2020.577723

Nigerian food takes backseat at 'Nigerian Flavour' festival - Premium Times Nigeria. (2019, October 4). *Premium Times*. https://www.premiumtimesng.com/entertainment/travels/262177-nigerian-food-takes-backseat-at-nigerian-flavour-festival.html

Nwankwo, C. U., Ikehi, M. E., Ejiofor, T. E., & Ifeanyieze, F. O. (2024). Successive national agricultural policies/programmes, growth of gross domestic product (GDP) and expansion of agribusinesses in Nigeria. *PLOS ONE*, *19*(2), e0291999. https://doi.org/10.1371/JOURNAL.PONE.0291999

Nyako, A.-A. M. (Senate-E. (2015). *North East Development Commission: An Institutional Framework for a Sustainable Solution to the North-East National Security Challenge* (p. 27). Nigerian Senate.

Ogundel, A. T., Oladipo, M., & Adebisi, O. M. (2016). Deforestation in Nigeria: The Needs for Urgent Mitigating Measures. *IIARD International Journal of Geography and Environmental Management*, *2*(1). www.iiardpub.org

Olaniyi, O. (2014). *Assessment of Households' Food Access and Food Insecurity in Urban Nigeria: A Case Study of Lagos Metropolis*. https://globaljournals.org/GJHSS_Volume14/4-Assessment-of-Households-Food-Access.pdf

Olasantan, F. O. (1992). Vegetable Production in Traditional Farming Systems in Nigeria. *Outlook on Agriculture*, *21*(2), 117–127. https://doi.org/10.1177/003072709202100207

Oliva, F., & Revetria, R. (2008). A System Dynamic Model to Support Cold Chain Management in Food Supply Chain. *12th WSEAS International Conference on SYSTEMS*, 361–365. http://www.iaph.uni-bonn.de/Coldchain/

Oloyede, F. M., Ola, D. S., & Iwalewa, E. A. (2023a). Biodiversity Conservation of the Neglected and Underutilized Nigerian Horticultural Crops. *Acta Horticulturae et Regiotecturae*, *26*(1), 64–72. https://doi.org/10.2478/ahr-2023-0010

Oloyede, F. M., Ola, D. S., & Iwalewa, E. A. (2023b). Biodiversity Conservation of the Neglected and Underutilized Nigerian Horticultural Crops. *Acta Horticulturae et Regiotecturae*, *26*(1), 64–72. https://doi.org/10.2478/AHR-2023-0010

Olurounbi, R. (2021, March 15). *Nigeria Unemployment Rate Rises to 33%, Second Highest on Global List*. Economics. https://www.bloombergquint.com/business/nigeria-unemployment-rate-rises-to-second-highest-on-global-list

Oluwatayo, I. B., & Sekumade, A. B. (2008). Resource Use Efficiency of Maize Farmers in Rural Nigeria: Evidence from Ekiti State. *World Journal of Agricultural Sciences*, *Vol. 4*(1), 91–99. https://www.cabidigitallibrary.org/doi/full/10.5555/20083210114

Omonona, B., Titus, A., & Adetokunbo, G. (2007). *AN ANALYSIS OF FOOD SECURITY SITUATION AMONG NIGERIAN URBAN HOUSEHOLDS: EVIDENCE FROM LAGOS STATE, NIGERIA* (Vol. 8, Issue 3). https://pdfs.semanticscholar.org/2ad2/c357187d400eeec59f08610a1d5e9d3e2099.pdf

Onimawo, I. (2010). Nigerian Traditional Food System and Nutrition Security. *International Scientific Symposium Biodiversity and Sustainable Diets United Against Hunger*, *November*.

Online Nigeria. (2003). *Nigeria: Taraba State*. Taraba State. http://www.onlinenigeria.com/links/tarabastateadv.asp?blurb=374

Onyekakeyah, L. (2021, October 26). Why the Naira is on Free-Fall | The Guardian Nigeria News - Nigeria and World News - Opinion - The Guardian Nigeria News – Nigeria and World News. *The Guardian*.

Opsomer, J. D., Jensen, H. H., & Pan, S. (2003). An evaluation of the U.S. Department of Agriculture Food Security Measure with Generalized Linear Mixed Models. *The Journal of Nutrition*, *133*(2), 421–427.

Orewa, S., & Iyangbe, C. (2009). The Food Insecurity Profile among the Rural and Low-Income Urban Dwellers in Nigeria. *Geography American-Eurasian Journal of Sustainable Agriculture*.

Oteh, O. U., Mbanasor, J. A., Agwu, N. M., Hefferon, K., Onwusiribe, C. N., & De Steur, H. (2023). *Understanding the biofortified Cassava Market in Nigeria: Determinants of consumer demand and farmer supply*. https://doi.org/10.1080/23311932.2023.2263972

Owoo, N. S. (2018). Food Insecurity and Family Structure in Nigeria. *SSM - Population Health*, *4*, 117–125. https://doi.org/10.1016/j.ssmph.2017.12.004

Owoo, N. S. (2020). Demographic Considerations and Food Security in Nigeria. *Journal of Social and Economic Development*, *23*, 128–167. https://doi.org/10.1007/s40847-020-00116-y

Owoo, N. S., Upton, J., & Bageant, E. (2017). *Food Insecurity and Family Structure in Nigeria*. 2017 Annual Meeting, July 30-August 1, Chicago, Illinois 258469, Agricultural and Applied Economics Association. https://ideas.repec.org/p/ags/aaea17/258469.html

Oyaniran, T. (2020). *Current State of Nigeria Agriculture and Agribusiness Sector AfCFTA WORKSHOP*.

Ozughalu, U. M., & Ogwumike, F. O. (2013). Vulnerability to Food Poverty in Nigeria. *African Development Review*, *25*(3), 243–255. https://doi.org/DOI: 10.1111/j.1467-8268.2013.12027.x

P Bundy Nilanthi de Silva Susan Horton Dean T Jamison George C Patton, D. A., Brown, G., Gillard, J., Banham Lesley Drake Bradford Strickland Child, L., & Health, A. (2018). *DISEASE CONTROL PRIORITIES • THIRD EDITION 8 EDITORS WITH A FOREWORD BY WITH A PREFACE BY WITH A PROLOGUE BY Optimizing Education Outcomes: High-Return Investments in School Health for Increased Participation and Learning*.

Pasqualino R, Monasterolo I, & Jones AW. (n.d.). *BHP Billiton Sustainable Communities/UCL Grand Challenge Symposium Series Global Food Security: Adaptation, Resilience and Risk An Integrated Global Food and Energy Security System Dynamics Model for Addressing Systemic Risk and Supporting Short term Sustainable Policy Making*. Retrieved July 7, 2019, from https://www.ucl.ac.uk/bartlett/sustainable/sites/bartlett/files/roberto-pasqualino.pdf

Paterson Guma, I., Rwashana, A. S., & Oyo, B. (2016). Household Food Security Policy Analysis: A System Dynamics Perspective. *International Journal of Scientific & Technology Research*, *5*, 7. www.ijstr.org

Pautasso, M. (2015). Network simulations to Study Seed Exchange for agrobiodiversity conservation. *Agronomy for Sustainable Development*, *35*(1), 145–150. https://doi.org/10.1007/S13593-014-0222-9/METRICS

Pautasso, M., Aistara, G., Barnaud, A., Caillon, S., Clouvel, P., Coomes, O. T., Delêtre, M., Demeulenaere, E., De Santis, P., Döring, T., Eloy, L., Emperaire, L., Garine, E., Goldringer, I., Jarvis, D., Joly, H. I., Leclerc, C., Louafi, S., Martin, P., … Tramontini, S. (2013). Seed Exchange Networks for Agrobiodiversity Conservation. A Review. *Agronomy for Sustainable Development*, *33*(1), 151–175. https://doi.org/10.1007/S13593-012-0089-6/METRICS

Pérez-Escamilla, R. (2017). Food Security and the 2015–2030 Sustainable Development Goals: From Human to Planetary Health. *Current Developments in Nutrition*, *1*(7). https://doi.org/10.3945/cdn.117.000513

Pérez-Neira, D., Schneider, M., Esche, L., & Armengot, L. (2023). Sustainability of Food sScurity in different Cacao Production Systems: A Land, Labour, Energy and Food Quality Nexus approach. *Resources, Conservation and Recycling*, *190*. https://doi.org/10.1016/j.resconrec.2023.106874

Perrin, R. M., & Phillips, M. L. (1978). Some Effects of Mixed Cropping in the Population Dynamics of Insect Pests. In *Ned. Entomol. Ver* (Vol. 24).

Pimbert, M. P. (2008). *Towards food sovereignty: Reclaiming autonomous food systems*.

Pimentel, D., Zuniga, R., & Morrison, D. (2004). *Update on the environmental and economic costs associated with alien-invasive species in the United States*. https://doi.org/10.1016/j.ecolecon.2004.10.002

Pingali, P. L. (2012). Green revolution: Impacts, limits, andthe path ahead. In *Proceedings of the National Academy of Sciences of the United States of America* (Vol. 109, Issue 31, pp. 12302–12308). https://doi.org/10.1073/pnas.0912953109

Popescu, S. S., & Popescu, O. (2016, December 4). *The Link Between Biodiversity and Food Security | Greentumble*. Greentumble. https://greentumble.com/the-connection-between-biodiversity-and-food-security/

Pretty, J. (2008). Agricultural Sustainability: Concepts, Principles and Evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 447–465. https://doi.org/10.1098/RSTB.2007.2163

Pretty, J., Benton, T. G., Bharucha, Z. P., Dicks, L. V., Flora, C. B., Godfray, H. C. J., Goulson, D., Hartley, S., Lampkin, N., Morris, C., Pierzynski, G., Prasad, P. V. V., Reganold, J., Rockström, J., Smith, P., Thorne, P., & Wratten, S. (2018). Global Assessment of Agricultural System Redesign for Sustainable Intensification. *Nature Sustainability*, *1*(8), 441–446. https://doi.org/10.1038/s41893-018-0114-0

Pretty, J., & Hine, R. (2001). *Reducing Food Poverty with Sustainable Agriculture: A Summary of New Evidence Final Report from the "SAFE-World" (The Potential of Sustainable Agriculture to Fe ed the World) Research Project*. https://s3.amazonaws.com/academia.edu.documents/30927229/SAFE_FINAL_-_Pages1-22.pdf?response-content-disposition=inline%3B filename%3DReducing_food_poverty_with_sustainable_a.pdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIAIWOWYYGZ2Y53UL3A%2F201

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, *9*(1), 5–24. https://doi.org/10.3763/IJAS.2010.0583

Princy, A. J. (2020, April 15). *Agrochemicals – Everything you Need to Know About Them*. ResearchDive. https://www.researchdive.com/blog/agrochemicals-and-their-importance-in-agriculture

Pruyt, E. (1999). Small System Dynamics Modelling for Big Issues. In *Journal of Manufacturing Systems* (First Edit, Vol. 18, Issue 5). TU Delft Library, Delft, The Netherlands. https://doi.org/10.1016/S0278-6125(99)90101-2

Puoane, T., Matwa, P., Bradley, H., & Hughes, G. (2006). *Socio-cultural Factors Influencing Food Consumption Patterns in the Black African Population in an Urban Township in South Africa*.

Ramanathan, V., Von Braun, J., Tiarv, D., & Dnvs, S. (2022). *Resilience of People and Ecosystems under Climate Stress*.

Reed, M. S., Stringer, L. C., Fazey, I., Evely, A. C., & Kruijsen, J. H. J. (2014). Five Principles for the Practice of Knowledge Exchange in Environmental Management. *Journal of Environmental Management*, *146*, 337–345. https://doi.org/10.1016/J.JENVMAN.2014.07.021

Reganold, J. P., & Wachter, J. M. (2016). Organic Agriculture in the Twenty-First Century. *Nature Plants 2016 2:2*, *2*(2), 1–8. https://doi.org/10.1038/nplants.2015.221

Reliefweb. (2015). Northeast Nigeria Conflict – Adamawa, Borno, Gombe, and Yobe states. In *Secondary Data Review*.

Rezai, A., Taylor, L., & Mechler, R. (2013). Ecological Macroeconomics: An Application to Climate Change. *Ecological Economics*, *85*, 69–76. https://doi.org/10.1016/J.ECOLECON.2012.10.008

ROA. (2023). *A-Frame Farm, Minnesota*. https://regenorganic.org/

Roberto, C. A., Swinburn, B., Hawkes, C., Huang, T. T. K., Costa, S. A., Ashe, M., Zwicker, L., Cawley, J. H., & Brownell, K. D. (2015). Patchy Progress on Obesity Prevention: Emerging Examples, Entrenched barriers, and New thinking. *The Lancet*, *385*(9985), 2400–2409. https://doi.org/10.1016/S0140-6736(14)61744-X/ASSET/7159E479-9900-4302-B23A-B6DAA107178D/MAIN.ASSETS/GR1.JPG

Rose, D., & Charlton, K. E. (2002). Community and International Nutrition Quantitative Indicators from a Food Expenditure Survey Can Be Used to Target the Food Insecure in South Africa 1 , 2. *Journal of Nutrition*, *August*, 3235–3242. http://jn.nutrition.org/content/132/11/3235.full.pdf+html

Rosset, P., & Altieri, M. (2017). Chapter 5 - The Politics of Agroecology. *Agroecology*, 119–138. https://doi.org/10.3362/9781780449944.006

Ruben, R., & Verhagen, J. (2019). *Towards Sustainable Global Food Systems: Conceptual and Policy Analysis of Agriculture, Food and Environment Linkages*. www.mdpi.com/journal/sustainability

Rubin, O. (2009). The Niger Famine. *Journal of Asian and African Studies*, *44*(3), 279–298. https://doi.org/10.1177/0021909609102899

Sabo, B. B., Isah, S. D., Chamo, A. M., & Rabiu M.A. (2017). (15) (PDF) Role of Smallholder Farmers in Nigeria's Food Security. *Scholarly Journal of Agricultural Science* , *7*(1), 1–5.

https://www.researchgate.net/publication/324908957_Role_of_Smallholder_Farmers_in_Nigeria's_Food_Security
Sarumi, M. B., Ladipo, D. O., Denton, L., Olapade, E. O., Badaru, K., & Ughasoro, C. (1996). *Nigeria: Country Report to the Fao International Technical Conference on Plant Genetic Resources*.
Sasu, D. D. (2023). *Nigeria: Agricultural Land | Statista*. Statista. https://www.statista.com/statistics/1263810/agricultural-land-in-nigeria/
Schapiro, M. (2018, September 16). *Seed Diversity is Disappearing - and 3 Chemical Companies Own more than Half | Salon.com*. Salon. https://www.salon.com/2018/09/16/seed-diversity-is-disappearing-and-3-chemical-companies-own-more-than-half/
Schreefel, L., Schulte, R. P. O., de Boer, I. J. M., Schrijver, A. P., & van Zanten, H. H. E. (2020). Regenerative Agriculture – The Soil is the Base. *Global Food Security*, *26*, 100404. https://doi.org/10.1016/J.GFS.2020.100404
Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., & Yu, T. H. (2008). Use of U.S. Croplands for Biofuels Increases greenhouse gases through emissions from land-use change. *Science*, *319*(5867), 1238–1240. https://doi.org/10.1126/SCIENCE.1151861/SUPPL_FILE/SEARCHINGER.SOM.PDF
Sen, A. (1976). *Famines as Failures of Exchange Entitlements*. https://about.jstor.org/terms
Seufert, V. (2012). Organic Agriculture as an Opportunity for Sustainable Agricultural Development Funded by the Canadian International Development Agency (CIDA). Executive summary. *Institute for the Study of International Development*, *Policy Beif No.13*, 1–26. https://www.mcgill.ca/globalfoodsecurity/files/globalfoodsecurity/seufert_presentation.pdf
Shaibu, U. M., & Shaibu, U. M. (2023). Agricultural Sector Policy Periods and Growth Pattern in Nigeria (1960–2020): Implications on Agricultural Performance. *Rural Areas - Development and Transformations [Working Title]*. https://doi.org/10.5772/INTECHOPEN.111382
Sheane, R., McCosker, C., & Royston, S. (2017). *FOOD SYSTEM FRAMEWORK a focus on food sustainability A word from the president*.
Shepherd, S. P. (2014). A Review of System Dynamics models applied in transportation. *Transportmetrica B: Transport Dynamics*, *2*(2), 83–105. https://doi.org/10.1080/21680566.2014.916236
Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B. M., & Menkir, A. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes*, *3*, 67–79. https://doi.org/10.1016/J.WACE.2014.04.004
Sidiq, F. F., Coles, D., Hubbard, C., Clark, B., & Frewer, L. J. (2022). The Role of Traditional Diets in Promoting Food Security for Indigenous Peoples in Low- and Middle-Income Countries: A Systematic Review. *IOP Conference Series: Earth and Environmental Science*, *978*(1). https://doi.org/10.1088/1755-1315/978/1/012001
Smith, L. C., & Haddad, L. (2015). Reducing Child Undernutrition: Past Drivers and Priorities for the Post-MDG Era. World Development, 68(1), 180–204. https://doi.org/10.1016/J.WORLDDEV.2014.11.014
Sources, I., & Traits, H. S. (2010). *Sources of Income for Households in Nigeria Wage Income*. 1–3.
Sterman, J. D. (2001). System Dynamics Modeling: Tools for Learning in a Complex world. *California Management Review*, *4*, 8–25. https://doi.org/10.2307/41166098/ASSET/41166098.FP.PNG_V03

Stone, G. D., & Flachs, A. (2014). The Problem with the Farmer's Voice. *Agriculture and Human Values*, *31*(4), 649–653. https://doi.org/10.1007/S10460-014-9535-1/METRICS

Story, M., Kaphingst, K. M., Robinson-O'Brien, R., & Glanz, K. (2008). Creating healthy food and Eating Environments: Policy and Environmental approaches. *Annual Review of Public Health*, *29*(Volume 29, 2008), 253–272. https://doi.org/10.1146/ANNUREV.PUBLHEALTH.29.020907.090926/CITE/REFWORKS

Struik, P. C., & Kuyper, T. W. (2017). Sustainable Intensification in agriculture: The RIcher Shade of Green. A Review. *Agronomy for Sustainable Development*, *37*(5). https://doi.org/10.1007/S13593-017-0445-7

Sunderland, T. (2011). Food Security: why is Biodiversity Important? *International Forestry Review*, *13*(3), 265–274. https://doi.org/10.1505/146554811798293908

Sunderland, T. (2015). *Forests, food security and nutrition*.

Sunderland, T. C. H. (2011). Food security: why is biodiversity important? *International Forestry Review*, *13*(3), 265–274. https://doi.org/10.1505/146554811798293908

Swindale, A., & Bilinsky, P. (2006a). *Advances in Developing Country Food Insecurity Measurement Development of a Universally Applicable Household Food Insecurity Measurement Tool : Process , Current Status , and Outstanding Issues 1 – 3*. 1449–1452.

Swindale, A., & Bilinsky, P. (2006b). Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide. *Washington, DC: Food and Nutrition Technical Assistance Project, Academy for Educational Development*.

The Guardian. (2020, March 1). Soil Fertility Decline Threatens Food sufficiency - Features - The Guardian Nigeria News – Nigeria and World News. *BusinessAgro*.

Thibiebi, L. (2018). *An Evaluation of Nigeria's Food Import b\Bill - Ships & Ports*. Ship & Ports. http://shipsandports.com.ng/2018/09/03/evaluation-nigerias-food-import-bill/

Thomas, E., Riley, M., & Spees, J. (2019). *Knowledge Flows: Farmers' Social Relations and Knowledge sharing practices in "Catchment Sensitive Farming."* https://doi.org/10.1016/j.landusepol.2019.104254

Thrupp, L. A. (2000). Linking Agricultural Biodiversity and Food Security: The Valuable Role of Agrobiodiversity for sustainable agriculture. *International Affairs*, *76*(2), 265–281. https://doi.org/10.1111/1468-2346.00133

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural Sustainability and Intensive Production Practices. *Nature*, *418*, 671–677.

Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J., & Whitbread, A. (2012). Global food security, biodiversity conservation and the future of Agricultural Intensification. *Biological Conservation*, *151*(1), 53–59. https://doi.org/10.1016/J.BIOCON.2012.01.068

Tscharntke, T., Tylianakis, J. M., Rand, T. A., Didham, R. K., Fahrig, L., Batáry, P., Bengtsson, J., Clough, Y., Crist, T. O., Dormann, C. F., Ewers, R. M., Fründ, J., Holt, R. D., Holzschuh, A., Klein, A. M., Kleijn, D., Kremen, C., Landis, D. A., Laurance, W., … Westphal, C. (2012). Landscape Moderation of Biodiversity Patterns and rocesses - Eight Hypotheses. *Biological Reviews*, *87*(3), 661–685. https://doi.org/10.1111/J.1469-185X.2011.00216.X

Tschersich, J., Sievers-Glotzbach, S., Gmeiner, N., & Kliem, L. (2023). The transformative potential of Seed Commons: Applying the Social-Ecological Transformation Framework to Agri-Food Systems. *Journal of Rural Studies*, *97*, 290–302. https://doi.org/10.1016/J.JRURSTUD.2022.12.005

Tsolakis, N., & Srai, J. S. (2017). A System Dynamics Approach to Food Security through Smallholder Farming in the UK. In G. Editors, S. Pierucci, J. Jaromír Klemeš, L. Piazza, S. Bakalis, N. Tsolakis, & J. Singh Srai (Eds.), *CHEMICAL ENGINEERING TRANSACTIONS* (VOL. 57, 2, Vol. 57). www.aidic.it/cet

Tsue, P. T. (2015). *Effects of Arable Land Tenure and Utilisation on Environmental Degradation Among Small-Scale Farmers in North-Central Nigeria* [PhD, University of Nigeria, Nsukka]. http://www.unn.edu.ng/publications/files/17691_EFFECTS_OF_ARABLE_LAND_TENURE_AND_UTILISATION_ON_ENVIRONMENTAL_DEGRADATION_AMONG_SMALL-SCALE_FARMERS_IN_NORTH-CENTRAL_NIGERIA.pdf

Turner, B. L., Menendez Iii, H. M., Gates, R., Tedeschi, L. O., Atzori, A. S., & Quinn, C. H. (2015). resources System Dynamics Modeling for Agricultural and Natural Resource Management Issues: Review of Some Past Cases and Forecasting Future Roles. *Resources*, *5*, 40. https://doi.org/10.3390/resources5040040

Tutundjian, S., Clarke, M., Egal, F., Dixson-Decleve, S., Candotti, S. W., Schmitter, P., & Lovins, L. H. (2021). Future Food Systems. *The Palgrave Handbook of Climate Resilient Societies*, 1–29. https://doi.org/10.1007/978-3-030-32811-5_43-1

Ubah Jeremiah Ifeanyi. (2021, November 16). *World Bank says 5.6 Million Nigerians will Fall into Poverty Due to High Inflation - Nairametrics*. Nairametrics. https://nairametrics.com/2021/11/15/world-bank-says-5-6-million-nigerians-will-fall-into-poverty-due-to-high-inflation/

UNDP. (2017). *Accelerating Development Investments in Famine Response and Prevention NORTH-EAST NIGERIA*.

UNICEF. (2017). *400,000 children in north-east Nigeria at risk of severe acute malnutrition | UNICEF*. Article. https://www.unicef.org/stories/400000-children-north-east-nigeria-risk-severe-acute-malnutrition

Utebor, S. (2016, September 12). Nigeria Spends $22bn Yearly on Food Imports – Punch Newspapers. *Punch Newspaper*.

Vallance, P., Finkelstein, T., Diamond, I., & O' Connor, T. (2022). *Systems Thinking: An Introductory Toolkit for Civil Servants*.

Van den Berg, L., Behagel, J. H., Verschoor, G., Petersen, P., & Gomes da Silva, M. (2022). Between institutional reform and building popular movements: The political articulation of agroecology in Brazil. *Journal of Rural Studies*, *89*, 140–148. https://doi.org/10.1016/J.JRURSTUD.2021.11.016

Vanguard. (2018). *Nigeria: Happy World Meal Gate - Tackling the Hunger & Malnutrition Challenge - allAfrica.com*. Vanguard. https://allafrica.com/stories/201801120038.html

Vidal, J. (2019, November 13). *Why Indigenous Peoples and Traditional Knowledge are Vital to Protecting Future global biodiversity | Ensia*. Environmental Editor. https://ensia.com/features/indigenous-knowledge-biodiversity/

Von Braun, J. (1995). *Employment for poverty Reduction and Food SEecurity*. International Food Policy Research Institute. https://books.google.co.uk/books?hl=en&lr=&id=7q1ZUsatasIC&oi=fnd&pg=PR7&dq=labor+intensive+agriculture+for+food+security&ots=xUREMaFmWu&sig=T89AnK4hYUa391SDYGfu2IWHGtU#v=onepage&q=labor%20intensive%20agriculture%20for%20food%20security&f=false

von Braun, J. (2003). Ethical Questions of Equitable Worldwide Food Production Systems. *PLANT PHYSIOLOGY*, *133*(3), 1040–1045. https://doi.org/10.1104/pp.103.024695

Von Braun, J., Afsana, K., Fresco, L. O., & Hassan, M. (2021). *Science and Innovations for Food Systems Transformati on and Summit Actions Science and Innovations for Food Systems Transformations*.

Wang, L., & Zhang, X. (2017). System Dynamic Model for Simulating Demand-Supply Interaction of Railway Express Freight System. *Mathematical Problems in Engineering*, *2017*, 1–10. https://doi.org/10.1155/2017/8481708

Webb, P., Coates, J., Frongillo, E. A., Rogers, B. L., Swindale, A., & Bilinsky, P. (2006). Measuring Household Food Insecurity: Why it's so Important and yet so Difficult to do. *The Journal of Nutrition*, *136*(5), 1404S-1408S. https://doi.org/136/5/1404S [pii]

Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., & David, C. (2009). Agroecology as a Science, a Movement and a Practice. A Review. *Agronomy for Sustainable Development 2009 29:4*, *29*(4), 503–515. https://doi.org/10.1051/AGRO/2009004

Wezel, A., Casagrande, M., Celette, F., Vian, J.-F., Ferrer, A., & Peigné, J. (2014). *Agroecological Practices for Sustainable Agriculture. A Review Agroecological Practices for Sustainable Agriculture. A review. Agronomy for Sustainable Develop-ment Agroecological practices for Sustainable Agriculture. A Review*. *34*(1), 1–20. https://doi.org/10.1007/s13593-013-0180-7ï

Wezel, A., Herren, B. G., Kerr, R. B., Barrios, E., Gonçalves, A. L. R., & Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development*, *40*(6), 1–13. https://doi.org/10.1007/S13593-020-00646-Z/FIGURES/5

Wiggins, E. S. (2015). *Raising agricultural productivity in sub-Saharan Africa Event report*.

Wolstenholme, E. F. (1999). Qualitative vs quantitative modelling: the evolving balance. *Journal of the Operational Research Society*, *50*(4), 422–428. https://doi.org/10.1057/PALGRAVE.JORS.2600700

Woodward, L., Smith, J., Pearce, B. M., Wolfe, P., & Nic, L. (2010). *The biodiversity benefits of organic farming*. Organic Research Center. https://doi.org/10.1111/j.1365

World Agroforestry Centre. (2008). *Agroforestry for Food Security and Healthy Ecosystems*. www.worldagroforestry.org

World Resources Institute. (2021, June 28). *Nigeria Deforestation Rates & Statistics | GFW*. Global Forest Watch. https://www.globalforestwatch.org/dashboards/country/NGA/?category=summary&dashboardPrompts=eyJzaG93UHJvbXB0cyI6dHJ1ZSwicHJvbXB0c1ZpZXdlZCI6W10sInNldHRpbmdzIjp7Im9wZW4iOmZhbHNlLCJzdGVwSW5kZXgiOjAsInN0ZXBzS2V5IjoiIn0sIm9wZW4iOnRydWUsInN0ZXBzS2V5IjoiZG93bmxvYWREYXNoYm9hcmRTdGF0cyJ9&location=WyJjb3VudHJ5IiwiTkdBIl0%3D&map=eyJjZW50ZXIiOnsibGF0Ijo5LjExMzU5MjUzNTcyNTI3NSwibG5nIjo4LjY3MDg2Mzk4NTAwNTA2MX0sInpvb20iOjQuMDI1MjQ2Nzg3MjkxNjA5LCJjYW5Cb3VuZCI6ZmFsc2UsImRhdGFzZXRzIjpbeyJkYXRhc2V0IjoicG9saXRpY2FsLWJvdW5kYXJpZXMiLCJsYXllcnMiOlsiZGlzcHV0ZWQtcG9saXRpY2FsLWJvdW5kYXJpZXMiLCJwb2xpdGljYWwtYm91bmRhcmllcyJdLCJib3VuZGFyeSI6dHJ1ZSwib3BhY2l0eSI6MSwidmlzaWJpbGl0eSI6dHJ1ZX0seyJkYXRhc2V0IjoidHJlZS1jb3Zlci1sb3NzIiwibGF5ZXJzIjpbInRyZWUtY292ZXItbG9zcyJdLCJvcGFjaXR5IjoxLCJ2aXNpYmlsaXR5Ijp0cnVlLCJwYXJhbXMiOnsidGhyZXNob2xkIjozMCwidmlzaWJpbGl0eSI6dHJ1ZX19XX0%3D

World Vegetable Centre. (2022). *HEALTHY DIETS*. Enhancing Consumption.

Yeleliere, E., Yeboah, T., Antwi-Agyei, P., & Peprah, P. (2022). Traditional agroecological knowledge and practices: The Drivers and Oportunities for Adaptation Actions in the Northern Region of Ghana. *Regional Sustainability*, *3*(4), 294–308. https://doi.org/10.1016/j.regsus.2022.11.002

Young, L., Norton, D., & Lambert, M. (2016). One Hundred Years of Vegetation Change at Cass, Eastern South Island High country. *New Zealand Journal of Ecology*, *40*(3), 289–301. https://doi.org/10.20417/nzjecol.40.38

Yusuf, A. A., & Yusuf, H. A. (2008). Evaluation of strategies for soil fertility improvement in Northern Nigeria and the way forward. *Journal of Agronomy*, *7*(1), 15–24. https://doi.org/10.3923/JA.2008.15.24

Zhang, W., Kato, E., Bianchi, F., Bhandary, P., Gort, G., & van der Werf, W. (2018). Farmers' Perceptions of Crop Pest Severity in Nigeria are Associated with Landscape, Agronomic and Socio-economic Factors. *Agriculture, Ecosystems & Environment*, *259*, 159–167. https://doi.org/10.1016/J.AGEE.2018.03.004

Zurek, M., Ingram, J., Sanderson Bellamy, A., Goold, C., Lyon, C., Alexander, P., Barnes, A., Bebber, D. P., Breeze, T. D., Bruce, A., Collins, L. M., Davies, J., Doherty, B., Ensor, J., Franco, S. C., Gatto, A., Hess, T., Lamprinopoulou, C., Liu, L., … Withers, P. J. A. (2022). Food System Resilience: Concepts, Issues, and Challenges. In *Annual Review of Environment and Resources* (Vol. 47, pp. 511–534). Annual Reviews Inc. https://doi.org/10.1146/annurev-environ-112320-050744

Appendices

1. Food System and Food Security Household Questionnaire

Enumerator number
Local government number
HOUSEHOLD NUMBER
Household size
Household with children below 18 ◯ Yes ◯ No
3) Gender of the household head ◯ Male ◯ Female
Age of the household head

Marital Status of the household head ◯ Married/living together ◯ single ◯ separated
The highest educational qualification in your household * ◯ first school leaving ◯ O level ◯ NCE/OND ◯ first degree/HND ◯ post graduate ◯ No education
How many years did the household head spent in formal education

Number of persons in the household with paid employment

Years of farming experience
Primary occupation of the household head Civil servant student unemployed trader artisan farmer Private sector unemployed

Secondary occupation of the household head

Civil servant

student

unemployed

trader

artisan

farmer

Private

sector

unemployed

In the last 24 hours what did your household eat for

*

Breakfast , snacks, lunch, snack, dinner, snack

breakfast, snack, Lunch, snack dinner, snack

Cereal - corn/maize, rice, wheat, sorghum, millet or any other grains or foods made from these (e.g.

*

bread, noodles, porridge or other grain products)

Yes

No
how many days in the last 7 days did your household consume cereal
white root and tuber -white potatoes, yam, cassava, or other foods made from these roots (e.g. alibo, garri, fufu, tuwo) Yes No
how many days in the last 7 days did your household consume white root and tuber
Vitamin A rich vegetables and tubers- pumpkin, carrot, squash, or sweet potato that are orange in colour inside + other locally available vitamin A rich vegetables (e.g. red/ yellow sweet pepper,) Yes No
how many days in the last 7 days did your household consume Vitamin A rich vegetables and tubers

Dark green leafy vegetables - dark green leafy vegetables, including wild forms + locally available * vitamin A rich leaves such as Amaranth, cassava leaves, yakwa/zogole (Moringa), fluted pumpkin, pumpkin leave, garden egg leave,utazi, okazi, bitter leave, oziza, spinach, Ayoyo, oha, Uturukpa. ◯ Yes ◯ No
How many days in the last 7 days did your household consume Dark green vegetables ....
Other vegetables - other vegetables (e.g. tomato, onion, eggplant, garlic) + other locally available * vegetables ◯ Yes ◯ No
How many days in the last 7 days did your household consume other vegetables ....

Vitamin A rich fruits - ripe mango, cantaloupe, apricot (fresh or dried), ripe papaya (pawpaw), dried

*

peach, and 100% fruit juice made from these + other locally available vitamin A rich fruits, palm fruit, palm oil,

Yes

No

How many days in the last 7 days did your household consume Vitamin A rich fruits

....

Other fruits - other fruits, e.g. debino, gingiya, including wild fruits and 100% fruit juice made from

*

these

Yes

No

How many days in the last 7 days did your household consume other fruits

....

Organ meat (offal) - liver, kidney, Intestine, heart or other organ meats or blood-based foods *

- Yes
- No

How many days in the last 7 days did your household consume organ meat

....

Flesh meats - Beef, pork, lamb, goat, rabbit, game, turkey, guinea fowl, chicken, duck, other birds, and. insects (termites, locust, crickets). *

- Yes
- No

How many days in the last 7 days did your household consume flesh meats

....

Eggs - Eggs from chicken, quail, duck, guinea fowl or any other egg *

- Yes
- No

How many days in the last 7 days did your household consume eggs

....

Fish and seafood - Fresh or dried fish or shellfish, crayfish, prawns, lobster, crab, shellfish and other sea foods *

◯ Yes

◯ No

How many days in the last 7 days did your household consume Fish and sea foods

....

Legumes, nuts and seeds - Dried beans, dried peas, palm kernel nut, beniseed, lentils (pigeon pea), nuts, walnut, Ukwa (African bread fruits), Barbara nut, groundnut, Aya seed, seeds or foods made from these (e.g. moi-moi, akara, Kunu gida, peanut butter) *

◯ Yes

◯ No

How many days in the last 7 days did your household consume legumes, nuts and seeds

....

Milk and milk products Milk, cheese, yogurt or other milk products like nunu or fresh milk *

◯ Yes

◯ No

How many days in the last 7 days did your household consume milk and milk products

....

Oil and fat - Margarine, butter, vegetable oil, bleached palm oil, beniseed oil groundnut oil, olive oil, sunflower oil etc. *

- ◯ Yes
- ◯ No

How many days in the last 7 days did your household consume oil and fat

....

Sweets, Sugar cane - sugar, honey, sweetened soda or sweetened juice drinks, sugary foods such as chocolates, candies, cookies and cakes *

- ◯ Yes
- ◯ No

Spices, condiments, Beverages - Black pepper, salt, condiments (soy sauce, Maggi cube, Royco cube, Knor, Jumbo, Ajino moto, hot sauce, Uda, and other local spices etc.), coffee, tea, alcoholic beverages *

- ◯ Yes
- ◯ No

How many days in the last 7 days did your household consume spices, condiments and Beverages

....

Ultra-processed foods- Soft drinks, Packaged bread, puffpuff, buns, Chips, Candy, ice cream, cup cake, Instant noodles, Infant formula, Breakfast cereal, Energy bars, Flavored yogurt, Chicken nuggets, Fast food burgers, hot dogs

- ○ yes
- ○ no

If you ate ultra-processed foods, how much in naira did you spend buying it……..

………

What is the reason for Ultra-processed food consumption instead of traditional foods

- ☐ always available
- ☐ nutritious and tastier
- ☐ its classy to eat it ☐ convenient
- ☐ cheap

I will eat Ultra-processed foods often, if I have the money

- ○ yes
- ○ no

Did you or anyone in your household eat any food OUTSIDE the home yesterday *

- ○ Yes
- ○ No

How many meals did you eat out in the last one week

....

if yes where did the person eat from *

- ☐ street food
- ☐ Restaurant
- ☐ local food kiosk
- ☐ food relief/ aid project
- ☐ others, specify

What is the primary source of your food?

- ○ Own production, gathering, hunting, fishing ○

Purchased

- ○ Borrowed, bartered, exchanged for labour, gift from friends or relatives ○

Food aid

- ○ other, specify

what Farming system do you practice?

- ◯ Crop farming ◯
- livestock farming ◯
- mixed farming

What Crop farming system do you practice?

- ◯ monocropping
- ◯ mixed cropping

how many crop species did you plant

Yam, cassava, cowpea, rice, maize = 5

how many varieties of yam, beans, groundnut and cassava do you produce in your farms

white yam, tree leave yam and water yam plus small white bean and iron bean = 5 white yam,

yellow yam, water yam =3, yellow maize, white maize = 2. So, ans -5

List crop species you planted in the last one year

what is the main source of your planting materials ◯ own stored from previous harvest ◯ seedling from breeding companies ◯ buy from neighbours or farmer in local market
Total cost of planting materials per annum ....
Total farmland owned by the household in plots *the one under fallow and the one under cultivation* ....
how many plots did you farm Crop in 2019......................................(number of plots (50ft x 100ft)) ....
how many plots did you farm in 2018 ....
How many plots did you crops in 2017 ....

What kind of crop do you produce?

- [ ] Vegetables and fruits
- [ ] ornamental plants [ ] Plantation crops
- [ ] food crops [ ] cash crops

Under-utilised crops

Which under-utilised crop do you have

- [ ] ogbono
- [ ] yam bean
- [ ] fio fio
- [ ] cocoyam

Group

How many breeds of Pig do you keep

Landrace, Largewhite, and Localbreed =3

....

How many breeds of Cattle do you keep

....

How many breeds of Poultry do you keep ....
How many breeds of Sheep and Goat do you keep ....
Number of Pigs in the farm ....
Number of Cattle in the farm ....
Number of Poultry in the farm ....
Number of Sheep and Goat in the farm ....
Number of of Bee hives do you keep ....

What type of animal do you keep

- ◯ Exotic
- ◯ local
- ◯ hybrid
- ◯ Both exotic and local

What production system do you use

- ◯ fully Automated
- ◯ semi-automated
- ◯ complete manual handling

What is the distance between you home and farm in KM

....

where do you sell you produce

◯ At farm gate

◯ harvested and taken to the market ◯

harvest and process before sale

What is the distance to the closest accessible forest from home in KM ....
Do you get some of your food from the forest ◯ Yes ◯ No
What type of food do you get from the forest ☐ Bush meat ☐ Vegetables and fruits ☐ Mushroom
How many time in a month do you go to the forest to search for food ....
Do you sell forest products ◯ Yes ◯ No
How much do you realise from the sale of the forest harvests ....

Do you buy forest foods

- ◯ Yes ◯
- No

how much do you spend buying forest product in a year

....

How much of your forest food harvest do you sell

- ◯ <1%
- ◯ 1-20%
- ◯ 21-40%
- ◯ 41-60%
- ◯ 61-80%
- ◯ 81-100%

What forest food do you buy

- ☐ Bush meat and wild fish
- ☐ vegetables and fruits ☐
- Mushroom

Group

Labour in person days per plot for Clearing …………………………………………………………
Cost of Labour in person days for Clearing …………………………………………………………
Labour in person days per plot for Tilling …………………………………………………………
Cost of Labour in person days for Tilling …………………………………………………………
Labour in person days per plot for Planting …………………………………………………………
Cost of Labour in person days for Planting …………………………………………………………
Labour in person days per plot for Weeding …………………………………………………………
Cost of Labour in person days for Weeding

…………………………………………………………

Labour in person days per plot for Harvesting

Cost of Labour in person days for Harvesting

What is the total number of labourers need/plot/annum

What is/are the source of your labour

- ☐ family member
- ☐ voluntary service
- ☐ hired labour

how many person day did your family put in your farm during the last season

If a family of 5 worked for 3 days in the farm, the answer is 5x3=15

Farm labour is available

- ○ always
- ○ often
- ○ rarely

what method do you use for cultivation ◯ tractors machines ◯ animal traction ◯ manual labour ◯ tractors machines and manual labour
How much do you spend on tractors and agrochemicals/plot …………………………………………………………………………
Clearing …………………………………………………………………………
Tilling …………………………………………………………………………
Planting …………………………………………………………………………
Weeding …………………………………………………………………………
Harvesting …………………………………………………………………………
Tractors …………………………………………………………………………
…………………………………………………………………………

Agrochemicals

Group

How much do you spend on tractors/plot for Clearing ....
How much do you spend on agrochemical/plot for Clearing ....
How much do you spend on tractors/plot for Tilling ....
How much do you spend on agrochemical/plot for Tilling ....
How much do you spend on tractors/plot for Planting ....

How much do you spend on agrochemical/plot for Planting ....
How much do you spend on tractor/plot for weeding ....
How much do you spend on agrochemical/plot for weeding ....
How much do you spend on tractor/plot for Harvesting ....
How much do you spend on agrochemical/plot for Harvesting ....
how much is your average total household income/month ....
how much is your Total farm income/year ....
how much is your average household total expenditure/month ....

how much is your household Food expenditure /month

Group

How much of your household Vegetable and Fruits consumption is from your farm

- <1%
- 1-20%
- 21-40%
- 41-60%
- 61-80%
- 81-100%

How much of your household Grain consumption is from your farm

- <1%
- 1-20%
- 21-40%
- 41-60%
- 61-80%
- 81-100%

How much of your household Root and Tuber consumption is from your farm

- <1%
- 1-20%
- 21-40%
- 41-60%
- 61-80%
- 81-100%

What share of your farm produce do you sell

- <20%
- 20 -50%
- 51 -80%
- 81 – 100%

What share of all your produce do you consume ◯ half ◯ more than half ◯ all ◯ none ◯ Less than half
What share of all your household foods consumption do you produce ◯ half ◯ more than half ◯ all ◯ none ◯ Less than half

2. Validation of Sustainable Food Security Policy Trust

Focus Group Discussion guide for food security and sustainable development policies.

Rate these policies in a 5-point scale with 1 being -ineffective, 2- slightly effective, 3- moderately effective, 4- effective and 5 very effective in the following key areas of development.

How do you rate the effectiveness of these agricultural development policies in achieving these key sustainable development goals and why?

Policies	**Key sustainable Development Goal**					
	Food price stability	**Access to/ Availability of diversity of food for improved nutrition of households**	**Biodiversity/ improved environment benefits**	**Increase employment for the poor farmer**	**Improved soil health**	**Increase income for poor households**
Fortification of food crops with vitamins and micronutrient, and animal through breeding programmes						
Creating balance diet awareness in schools and social gatherings						
Strategic national food reserve						
School feeding programme						
Increasing food production by the use of agrochemicals and tractors quality control and testing						
Increase focus on Forest foods						
Encouraging organic farming						
Supporting small farmers mixed farming/cropping system with credit and labour subsidies						

Supporting large scale and specialised farming						
Promoting commercial seeds to farmers						
Allocation of 10% of Nigerian land to nomadic pastoralists						
Others, specify						

3. Food System Feedback Loops

The first 50 feedback loops leading to food security are listed to show the different interacting feedback routes that leads to a decrease or increase in food security. To study the relationships in the food system for the purpose of achieving a sustainable food security, the feedback loops for food security where extracted. The first 50 loops in achieving food security had 33 balancing loops and 17 reinforcing loops.

First 50 loops of food security

Loop 1 of length 6

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- food expenditure

Loop 2 of length 8

- food security level
- Health and nutrition
- birth
- population
- available labour force
- farm labour
- wage
- household income
- food expenditure

Loop 3 of length 11

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedlings from seed companies
- seeds preserved
- crop planted/animal kept
- food harvested from farm
- food harvest consumed

Loop 4 of length 11

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- Education, experience, and skill training
- labour productivity
- food harvested from farm
- food harvest consumed

Loop 5 of length 11

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- soil quality
- food harvested from farm
- food harvest consumed

Loop 6 of length 11

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- biodiversity
- forest foods
- forest food consumed

Loop 7 of length 11

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- monocropping system
- Food for other use-ethanol, animal feeds
- food harvest consumed

Loop 8 of length 11

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- biodiversity
- forest foods
- forest food consumed

Loop 9 of length 12

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- monocropping system
- crop planted/animal kept
- food harvested from farm
- food harvest consumed

Loop 10 of length 12 ⊕-ve

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- crop planted/animal kept
- food harvested from farm
- Food for other use-ethanol, animal feeds
- food harvest consumed

Loop 11 of length 12 ⊕-ve

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- soil quality
- food harvested from farm
- food lost
- food harvest consumed

Loop 12 of length 12 ⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- Education, experience, and skill training
- labour productivity
- food harvested from farm
- Food for other use-ethanol, animal feeds
- food harvest consumed

Loop 13 of length 12 ⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- land holding
- land for agriculture
- biodiversity
- forest foods
- forest food consumed

Loop 14 of length 12 ⊕-ve

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- soil quality
- food harvested from farm
- Food for other use-ethanol, animal feeds
- food harvest consumed

Loop 15 of length 12 ⊕-ve

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- crop planted/animal kept
- food harvested from farm
- food lost
- food harvest consumed

Loop 16 of length 12 ⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- soil quality
- food harvested from farm
- processed foods
- processed foods consumed

Loop 17 of length 12 ⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- mixed farming and mixed cropping system
- crop planted/animal kept
- food harvested from farm
- food harvest consumed

Loop 18 of length 12 ⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- biodiversity
- soil quality
- food harvested from farm
- food harvest consumed

Loop 19 of length 12 ⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- land holding
- land for agriculture
- monocropping system

- Food for other use- ethanol, animal feeds
- food harvest consumed

Loop 20 of length 12
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- Education, experience, and skill training
- labour productivity
- food harvested from farm
- food lost
- food harvest consumed

Loop 21 of length 12
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- soil quality
- biodiversity
- forest foods
- forest food consumed

Loop 22 of length 12
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- biodiversity
- soil quality
- food harvested from farm
- food harvest consumed

Loop 23 of length 12
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- crop planted/animal kept
- food harvested from farm
- processed foods
- processed foods consumed

Loop 24 of length 12
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- Education, experience, and skill training
- labour productivity
- food harvested from farm
- processed foods
- processed foods consumed

Loop 25 of length 12
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- mixed farming and mixed cropping system
- biodiversity
- forest foods
- forest food consumed

Loop 26 of length 12
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- monocropping system
- biodiversity
- forest foods
- forest food consumed

Loop 27 of length 13
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- mixed farming and mixed cropping system
- crop planted/animal kept
- food harvested from farm
- processed foods
- processed foods consumed

Loop 28 of length 13
- food security level
- Health and nutrition
- death
- population
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- crop planted/animal kept
- food harvested from farm
- food harvest consumed

Loop 29 of length 13
- food security level
- Health and nutrition
- birth
- population
- available labour force
- farm labour
- wage
- household income

- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- monocropping system
- Food for other use- ethanol, animal feeds
- food harvest consumed

Loop 30 of length 13⊖

- food security level
- Health and nutrition
- birth
- population
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- crop planted/animal kept
- food harvested from farm
- food harvest consumed

Loop 31 of length 13⊕

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- monocropping system
- crop planted/animal kept
- food harvested from farm
- processed foods
- processed foods consumed

Loop 32of length 13⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- land holding
- land for agriculture
- mixed farming and mixed cropping system
- crop planted/animal kept
- food harvested from farm
- food harvest consumed

Loop 33 of length 13⊕-ve

- food security level
- Health and nutrition
- death
- population
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- biodiversity
- forest foods
- forest food consumed

Loop 34 of length 13⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- land holding
- land for agriculture
- biodiversity
- soil quality
- food harvested from farm
- food harvest consumed

Loop 35 of length 13⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- biodiversity
- soil quality
- food harvested from farm
- processed foods
- processed foods consumed

Loop 36 of length 13⊕

- food security level
- Health and nutrition
- birth
- population
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- Education, experience, and skill training
- labour productivity
- food harvested from farm
- food harvest consumed

Loop 37 of length 13⊖

- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- monocropping system
- crop planted/animal kept
- food harvested from farm
- food lost
- food harvest consumed

Loop 38 of length 13⊕-ve

- food security level
- Health and nutrition
- death
- population
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- soil quality
- food harvested from farm
- food harvest consumed

Loop 39 of length 13 ⊕
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- household saving
- household non-farm investments
- Education, experience, and skill training
- labour productivity
- food harvested from farm
- processed foods
- processed foods sold
- processed foods consumed

Loop 40 of length 13 ⊖
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- biodiversity
- mixed farming and mixed cropping system
- crop planted/animal kept
- food harvested from farm
- food harvest consumed

Loop 41 of length 13 ⊖
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- biodiversity
- mixed farming and mixed cropping system
- crop planted/animal kept
- food harvested from farm
- food harvest consumed

Loop 42 of length 13 ⊖
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- soil quality
- food harvested from farm
- processed foods
- processed foods sold
- processed foods consumed

Loop 43 of length 13 ⊖
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- monocropping system
- Deforestation
- biodiversity
- forest foods
- forest food consumed

**Loop 44 of length 13 ⊖
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- crop planted/animal kept
- food harvested from farm
- processed foods
- food lost
- food harvest consumed

Loop 45 of length 13 ⊕-ve
- food security level
- Health and nutrition
- death
- population
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- monocropping system
- Food for other use- ethanol, animal feeds
- food harvest consumed

Loop 46 of length 13 ⊖
- food security level
- Health and nutrition
- birth
- population
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- biodiversity
- forest foods
- forest food consumed

**Loop 47 of length 13 ⊖
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- soil quality
- food harvested from farm
- processed foods
- food lost
- food harvest consumed

Loop 48 of length 13 ⊖
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- monocropping system
- Deforestation

- soil quality
- food harvested from farm
- food harvest consumed

Loop 49 of length 13 -ve

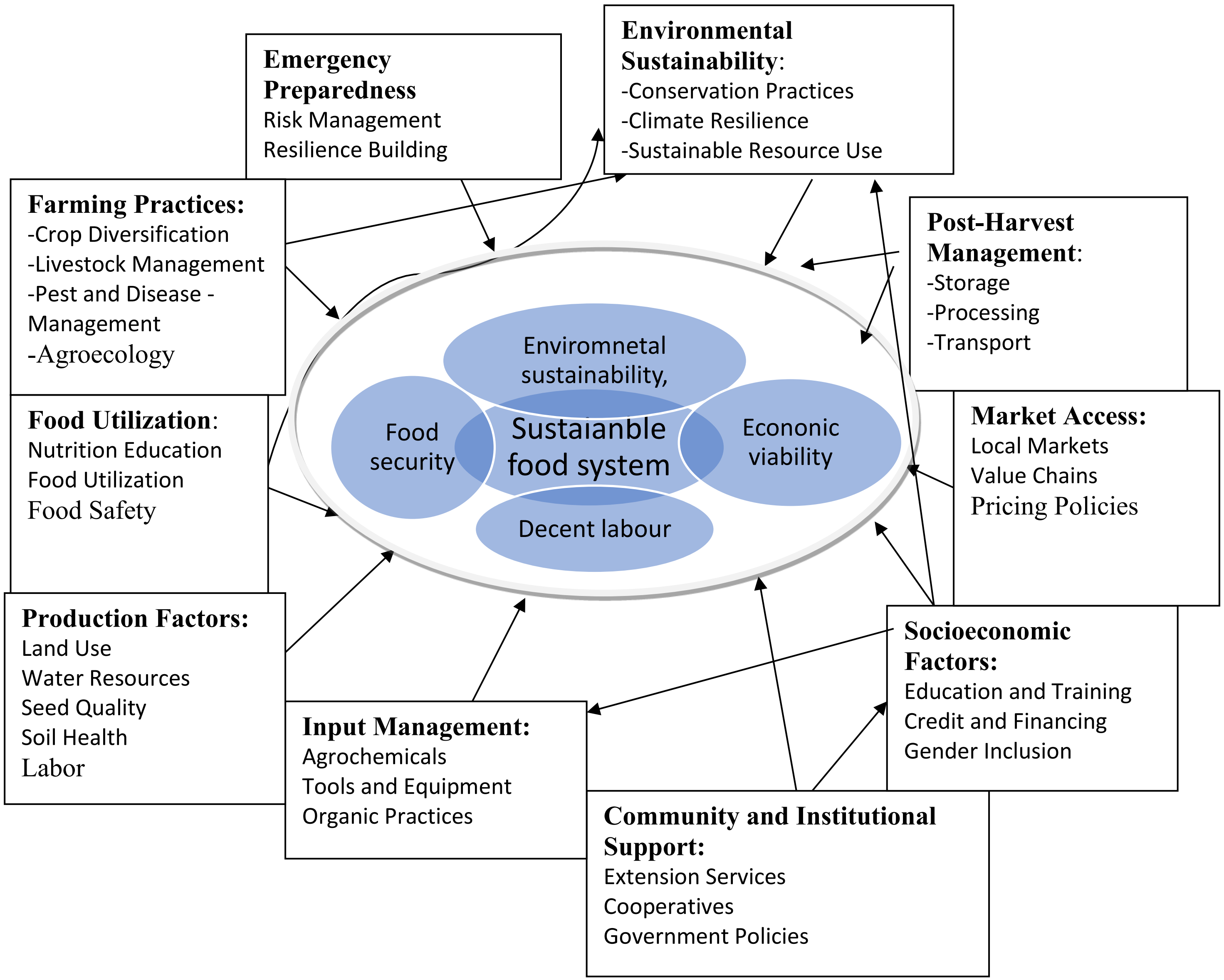
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- Agrochemicals and tractors
- biodiversity
- soil quality
- food harvested from farm
- food lost
- food harvest consumed

Loop 50 of length 13 -ve

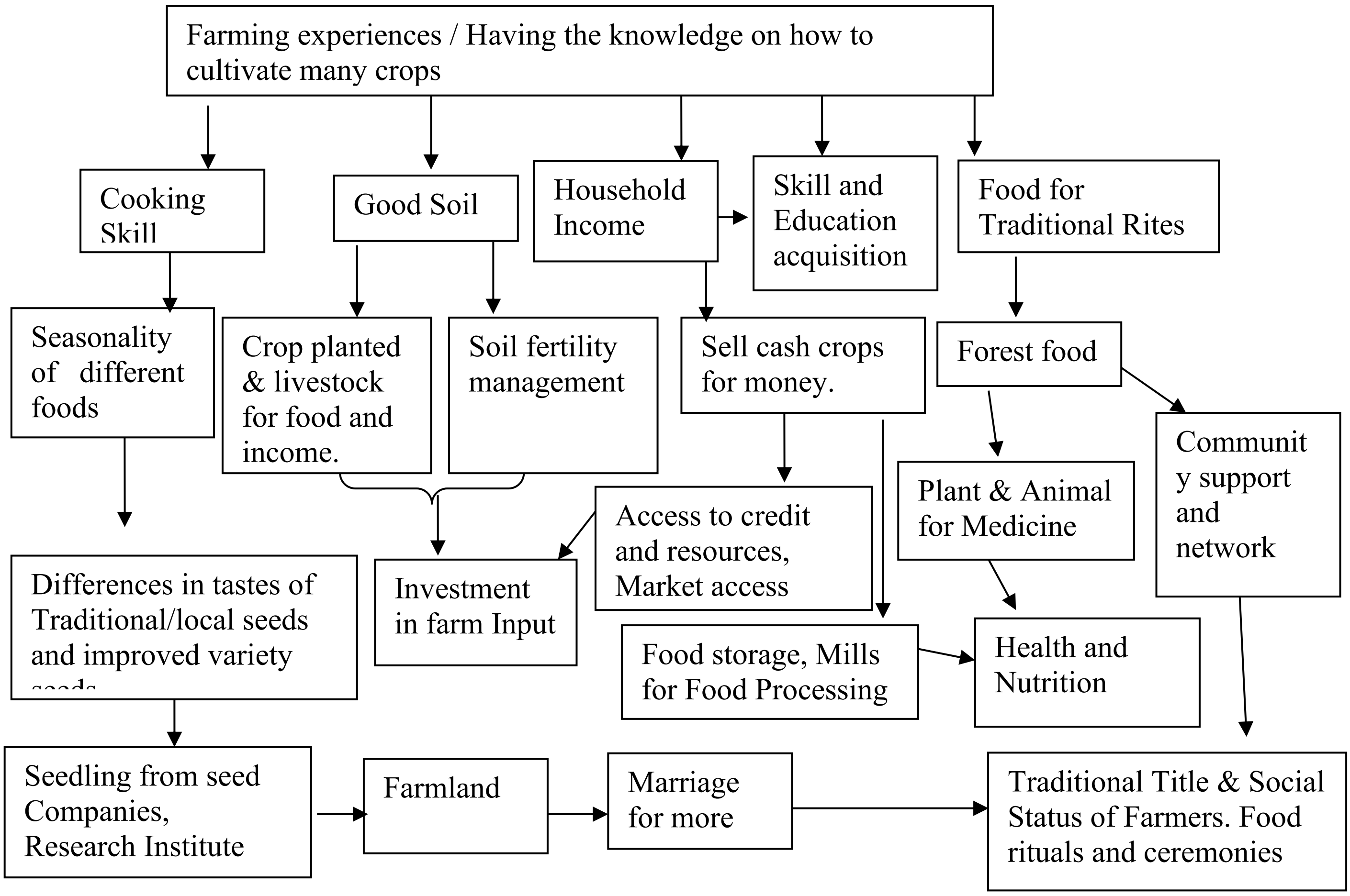
- food security level
- Health and nutrition
- available labour force
- farm labour
- wage
- household income
- investment in farm input
- Seedling from seed companies
- seeds preserved
- biodiversity
- soil quality
- food harvested from farm
- Food for other use- ethanol, animal feeds

food harvest consumed

4. Causal/Feedback Loops Participants' Mental Models of Food System of Northeast Nigeria



An Agricultural Extension Agent's Mental model of the food system of Nigeria



A food system Mental model of a small-scale mixed crop farmer- (1.5ha of land) with 5 goats, 21 chicken.

Food Availability

Agricultural Production
farm practices, harvest, farm labour

Land Use - farm size, soil fertility, fertilizers.

Climate and Weather Conditions- rain, irrigation, hybrid seeds to suit changing climates.

Water Resources- water for planting, for preparing food fish and other food from the water

Food Access

Economic Access
-household income
-Farm labour
-sourcing seed
-food expenditure

Physical Access
-Distribution
-Home garden and own farms
Security of lives and propertied in farms

Market system- Functioning of local, regional, and national markets

Food Price
-price stability
-Food Storage facility
-Food loss

Food Utilization

Nutrition and Diet Quality
-Healthy population
-Food harvest
-Food diversity
-Adequate food quality

Food Safety
-Agrochemicals
-Food hygiene
-Food storage

Food Processing and Storage
-food loss
-seasonality

Cultural acceptability
-Food culture

Stability

Economic Stability
-Household income
-Seasonality of farm produce and labour wage
-Skill training
-Off farm jobs
-Investment
-Subsidies

Environmental Sustainability
-Sustainable farming
-Resilient seed
-Improved seeds
-Biodiversity
-Crop and animal diversity.

Policy and Governance
-Effective agricultural policies and food security programs

Social Stability
-Religious and social conflicts, and migrations

Food Distribution Systems

Supply Chains/ Value chain

Logistics and Transportation

Farm gate sales, Middlemen, Retail Networks

Food Assistance Programs

Institutional and Policy Frameworks

Agricultural Policies

Trade Policies

Land Tenure Systems

Research and development.

Community and Social Elements

Community Support Systems

Education and Awareness

Cooperatives and Farmer Organizations

An Agricultural Economist Mental model of the food system of Nigeria

Agricultural Production

Crop | Crop | Soil Health | Water | Pest and Disease

Agricultural Practices

Sustainable Farming Practices | Use of Agrochemicals | Technological

Post-Harvest Handling

Storage | Processing | Transportation | Food lost and waste

Market Access

Market | Pricing Mechanisms | Trade Policies

Economic Factors

Income levels | Credit Access

Socio-Cultural Factors

Dietary Preferences | Education and Training

Environmental Factors

Climate | Biodiversity | Land Use

Policy and Governance

Agricultural | Land Tenure | Support

Nutritional Aspects

Food Quality and | Food Distribution

Community Resilience

Disaster | Social Safety Nets

Soil Health and Quality

Soil Fertility | oil Structure | Erosion & | Water Management

Water Management

Water | Water Quality | Water

Nutrient Management

Fertilization | Nutrient

Crop Management

Crop Rotation | Cover | Mixed

Land Use and Management

Land Use Tillage Agroforestr

Agrochemical Use

Pesticides and Fertilizer Application

Sustainable Practices

Conservation Agriculture Organic Regenerative

Climate Resilience

Adaptation Strategies Carbon Sequestration

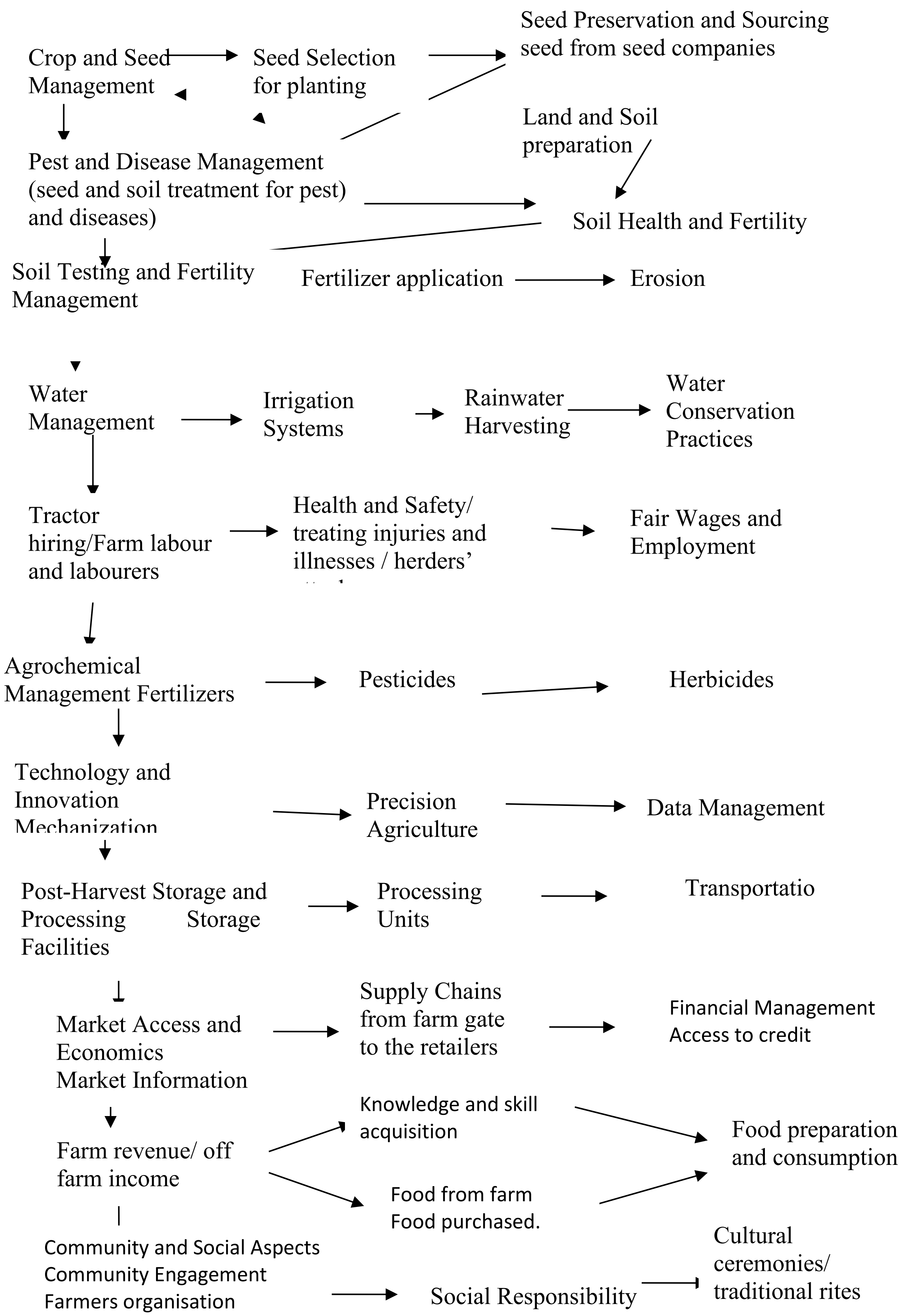
Socio-Economic Factors

Farmer Knowledge and Access to Resources Market Access

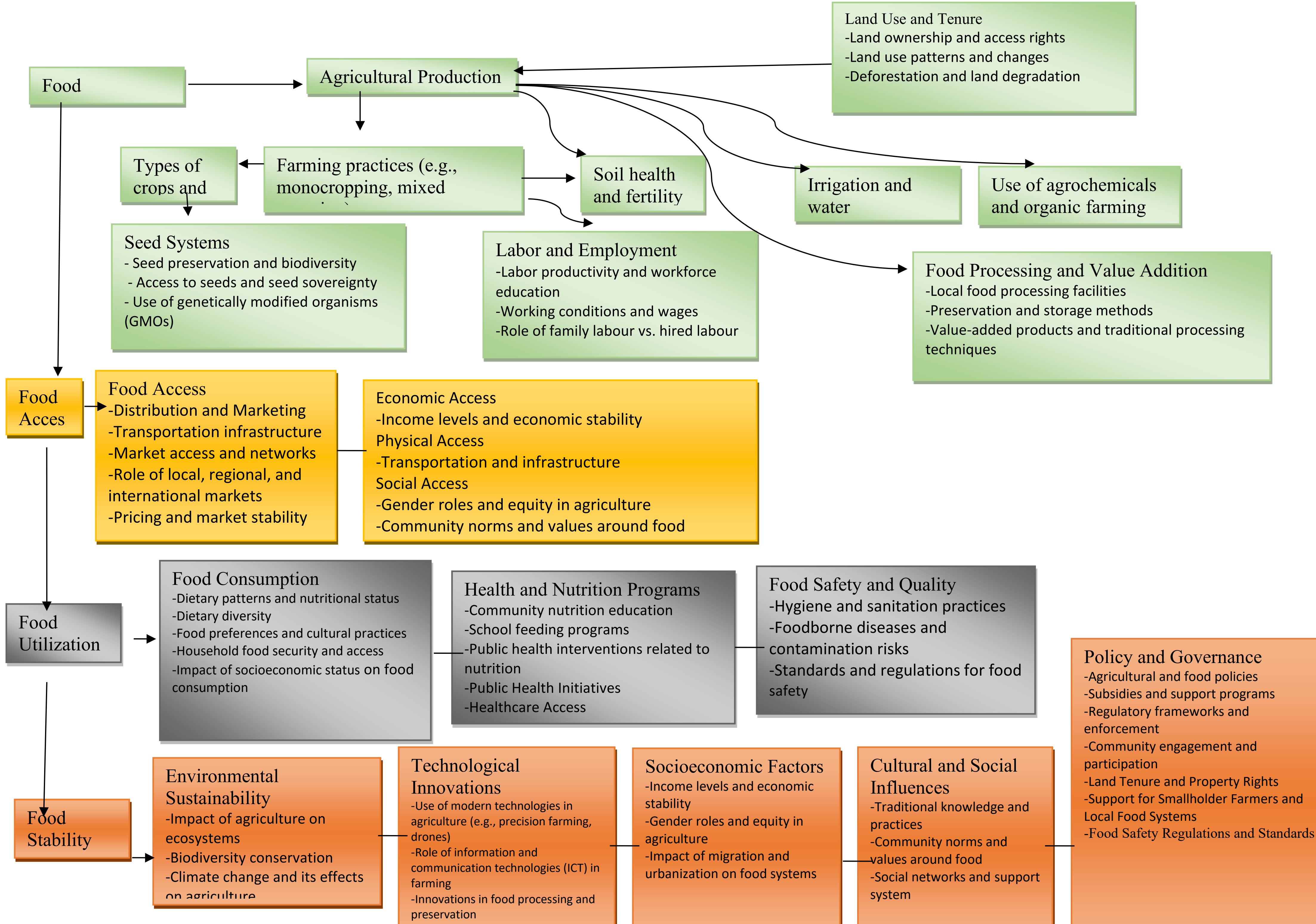
Policy and Governance

Regulations Support

An Agronomist Mental Model of the Food System of Northeast Nigeria



Mental model of a Large-scale farmer- (54 ha) with 74 cows, 70 sheep and goats, 260 guinea fowls, 4 ostriches, 15 peacock


Food
Agricultural Production
Land Use and Tenure
-Land ownership and access rights
-Land use patterns and changes
-Deforestation and land degradation
Types of crops and
Farming practices (e.g., monocropping, mixed
Soil health and fertility
Irrigation and water
Use of agrochemicals and organic farming
Seed Systems
- Seed preservation and biodiversity
- Access to seeds and seed sovereignty
- Use of genetically modified organisms (GMOs)
Labor and Employment
-Labor productivity and workforce education
-Working conditions and wages
-Role of family labour vs. hired labour
Food Processing and Value Addition
-Local food processing facilities
-Preservation and storage methods
-Value-added products and traditional processing techniques
Food Acces
Food Access
-Distribution and Marketing
-Transportation infrastructure
-Market access and networks
-Role of local, regional, and international markets
-Pricing and market stability
Economic Access
-Income levels and economic stability
Physical Access
-Transportation and infrastructure
Social Access
-Gender roles and equity in agriculture
-Community norms and values around food
Food Utilization
Food Consumption
-Dietary patterns and nutritional status
-Dietary diversity
-Food preferences and cultural practices
-Household food security and access
-Impact of socioeconomic status on food consumption
Health and Nutrition Programs
-Community nutrition education
-School feeding programs
-Public health interventions related to nutrition
-Public Health Initiatives
-Healthcare Access
Food Safety and Quality
-Hygiene and sanitation practices
-Foodborne diseases and contamination risks
-Standards and regulations for food safety
Policy and Governance
-Agricultural and food policies
-Subsidies and support programs
-Regulatory frameworks and enforcement
-Community engagement and participation
-Land Tenure and Property Rights
-Support for Smallholder Farmers and Local Food Systems
-Food Safety Regulations and Standards
Food Stability
Environmental Sustainability
-Impact of agriculture on ecosystems
-Biodiversity conservation
-Climate change and its effects
Technological Innovations
-Use of modern technologies in agriculture (e.g., precision farming, drones)
-Role of information and communication technologies (ICT) in farming
-Innovations in food processing and preservation
Socioeconomic Factors
-Income levels and economic stability
-Gender roles and equity in agriculture
-Impact of migration and urbanization on food systems
Cultural and Social Influences
-Traditional knowledge and practices
-Community norms and values around food
-Social networks and support system

A Food and Nutrition Scientist Mental model of the food system of Nigeria

5. Food system Tree Diagram

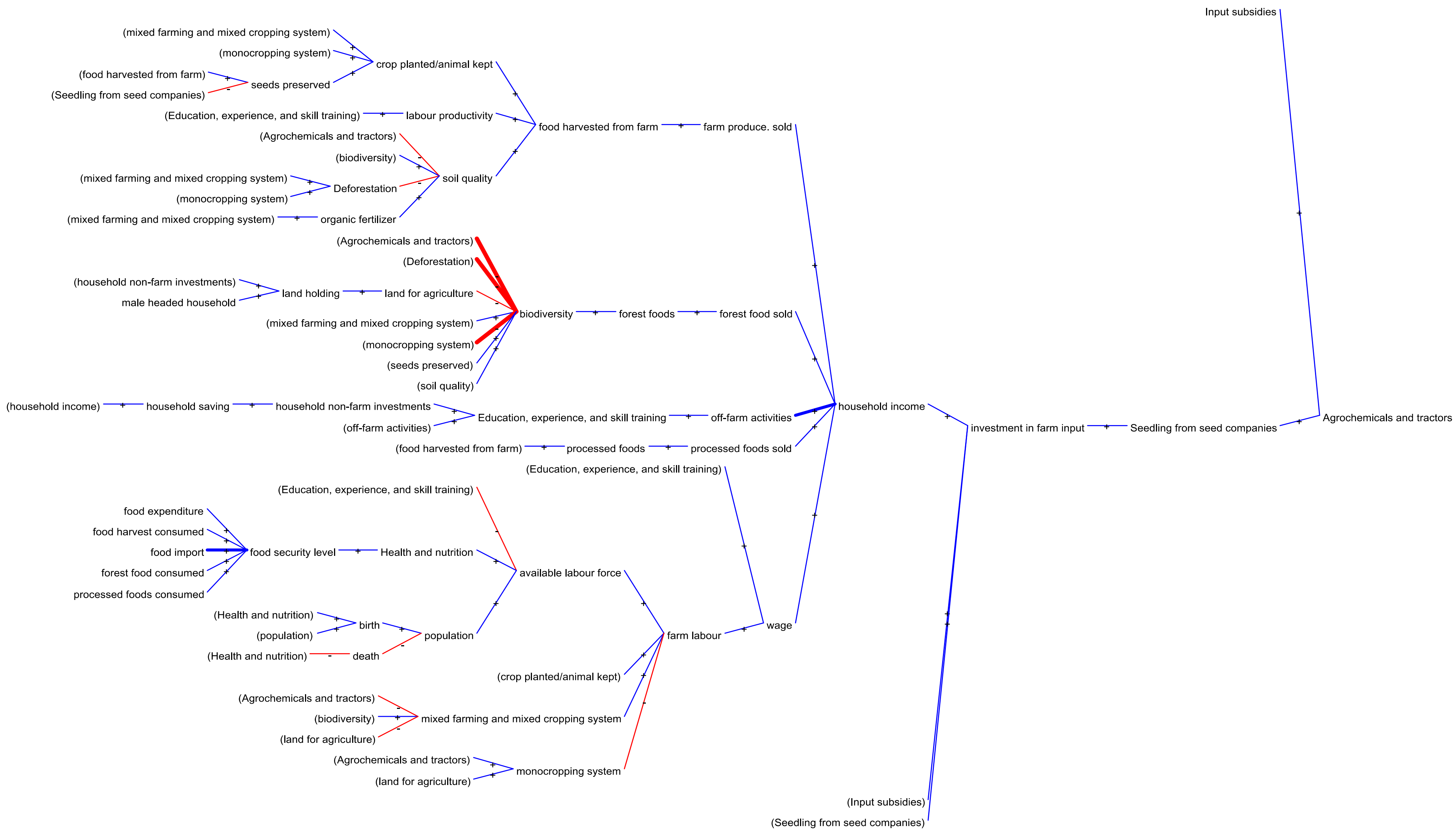


Figure 7. 20 Agrochemicals and Tractors cause tree (Blue link= positive arrow. Red Links = negative arrow)

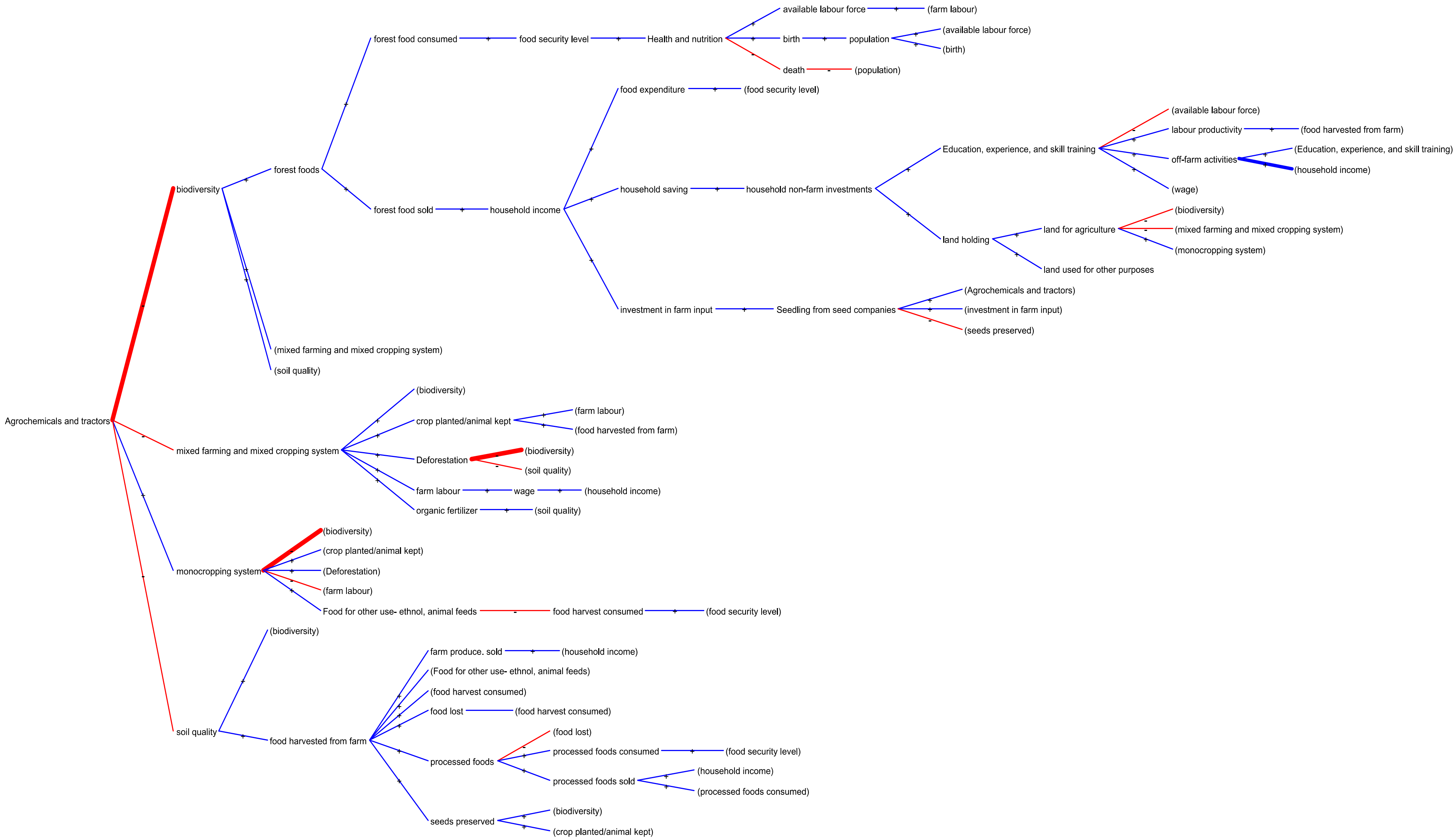


Figure 7. 21 Agrochemical and Tractors uses tree (Blue link= positive arrow. Red Links = negative arrow)