PROCEEDINGS OF THE 5TH SYMPOSIUM OF THE SOIL TILLAGE AWARENESS AND DEVELOPEMENT INITIATIVE (ISTRO-NIGERIA)

THEME: RESILIENCE AND SUSTAINABILITY OF TILLAGE SYSTEMS IN NIGERIA: MITIGATING AND ADAPTING TO CLIMATE CHANGE

AT THE FACULTY OF ENGINEERING

UNIVERSITY OF ABUJA.

AIRPORT ROAD, ABUJA

05TH SEPTEMBER, 2024

PREFACE

One of the core objectives of the United Nations' **Sustainable Development Goals (SDGs)** is to eliminate hunger, eradicate extreme poverty, and foster a healthy, sustainable environment that improves the quality of life for people around the world. Achieving these goals requires a multi-faceted approach, with sustainable agriculture playing a pivotal role.

Soil tillage is an essential aspect of sustainable agricultural practices, as it directly influences soil health, crop productivity, food security, and environmental conservation. Ensuring that tillage systems are both resilient and sustainable is vital to safeguarding food supply chains and protecting ecosystems from the impacts of climate change.

The **2024 ISTRO-Nigeria symposium**, the fourth in the series, themed **"Resilience and Sustainability of Tillage Systems in Nigeria: Mitigating and Adapting to Climate Change,"** was organized to bring together a wide range of stakeholders, including scientists, researchers, policymakers, industry experts, and academics. The symposium aimed to provide a platform for these stakeholders to engage in discussions on how to develop and implement sustainable soil management practices that guarantee adequate food supply for both present and future generations. The theme of this symposium was particularly timely, as it addressed the urgent need for Nigeria to adapt its tillage systems to the changing climate while promoting agricultural resilience and environmental sustainability.

The symposium created an opportunity for participants from both government agencies and private organizations to collaborate on solutions to the challenges posed by climate change and the need for sustainable farming practices. Discussions focused on how sustainable tillage systems can be leveraged to increase resilience in agriculture, reduce the degradation of soil quality, and minimize environmental damage. This platform allowed for a comprehensive exchange of knowledge and experiences, particularly in the areas of soil conservation, tillage techniques, and climate adaptation strategies, which are critical to the future of food security in Nigeria.

The event featured a **keynote address** delivered by an expert in the field, which set the stage for subsequent discussions on the theme. The symposium also included the presentation of **eight lead papers**, each offering valuable insights into different aspects of sustainable tillage and soil management. In addition to these lead papers, **eight technical papers** were submitted, rigorously evaluated through a blind review process. The papers that met the required standards are published in this proceedings, contributing to the body of knowledge on sustainable tillage practices in Nigeria.

We are deeply appreciative of the efforts of all the authors who submitted their work, especially those who revised their papers based on the feedback provided by the reviewers. We also extend our sincere gratitude to the reviewers for their time and expertise, and to everyone who contributed to the successful organization and publication of this symposium's proceedings. Authors whose papers were not accepted are encouraged to continue their research efforts, and we acknowledge their participation and contributions to the symposium.

The recommendations outlined in this publication are intended to serve as a valuable resource for both policymakers and practitioners. If carefully implemented, these recommendations have the potential to significantly improve environmental health, boost agricultural resilience, and contribute to the eradication of hunger and extreme poverty in Nigeria. The insights presented in these papers will help inform the development of policies and strategies that promote sustainable tillage practices, ensuring that agricultural systems remain productive and resilient in the face of climate challenges.

This publication remains the intellectual property of ISTRO-Nigeria, and while ISTRO-Nigeria holds the rights to this work, the content of each individual paper is the sole responsibility of its respective author(s). We are confident that the findings and discussions documented in these proceedings will provide valuable guidance and inspiration for future research and action in the fields of soil management, tillage, and sustainable agriculture.

We thank you for your support and participation, and we hope this publication will contribute meaningfully to the ongoing efforts to create a more resilient and sustainable agricultural system in Nigeria and beyond.

Thank you.

Engr Dr. Utunji Isaac Tanam MISTRO, MNIAE, MNSE
Secretary, ISTRO Nigeria / Symposium Organizing Committee (SOC)
Department of Environmental Management
Bingham University, Karu – Nasarawa State

WELCOME ADDRESS

WELCOME ADDRESS BY PROFESSOR AZIKIWE PETER ONWUALU, FAS, PRESIDENT, SOIL TILLAGE AWARE AWARENESS AND DEVELOMENT INITIATIVE (ISTRO-NIGERIA) AT ISTRO-NIGERIA 2024 TILLAGE SYMPOSIUM HELD AT FACULTY OF ENGINEERING AUDITORIUM, UNIVERSITY OF ABUJA, SEPTEMBER 5, 2024

The Vice Chancellor, University of Abuja, President, Nigerian Society of Engineers, International President-Elect of ISTRO, other distinguished guests, lead speakers, members of Board of Trustees, Executive Committee, ISTRO-Nigeria members, students of university of Abuja, ladies and gentlemen. It gives me great pleasure to welcome you to the 2024 ISTRO-Nigeria annual symposium hosted by our colleagues at the University of Abuja. As I thank God for the safe trip granted all participants, I pray for safe trip back to your destinations at the end of the symposium.

ISTRO-Nigeria was revived in 2023 after some years of inactivity. Following the revival, a number of events have taken place. In 2023, we hosted a similar symposium at the African University of Science and Technology, Galadimawa, Abuja. The branch was formally registered with the Corporate Affairs Commission as a non-governmental, non-for-profit organization, following the formation of a Board of Trustees and an Executive Committee. The website of ISTRO-Nigeria is now operational: www.istro-nigeria.org. The organization currently holds regularly Board of Trustees meeting, Executive Committee meeting, congress meeting and participates actively in ISTRO International activities. One of the major projects of the organization is the development of a book on Tillage in Nigeria which is on-going.

The branch is participating actively in the forthcoming triennial conference of ISTRO International in Virginia, United States of America. In that conference, Professor Olaoye of the University of Ilorin who is also the National Chaiman of Nigerian Institution of Agricultural Engineers will be inaugurated as the President of ISTRO International. This means that the next ISTRO International conference after the United states will be held in Nigeria in 2027.

The conference team of this conference is: RESILIENCE AND SUSTAINABILITY OF TILLAGE SYSTEMS: MITIGATING AND ADAPTING TO CLIMATE CHANGE, with the following sub-themes: Climate Smart Agricultural Practices; Sustainable Soil Management; Precision Agriculture Techniques; Water Conservation and Irrigation Management; Agro-ecological principles in Tillage; Capacity Building and Extension Services in relation to tillage systems; Frameworks for Climate Resilience and Suitable Tillage Systems and Perspectives on Gender in Tillage Systems.

I enjoin all participants to critically analyse the theme and sub-themes of the conference and come up with policy recommendations that can enable Nigerian agriculture to be resilient and sustainable towards achieving the Sustainable Development Goals. I thank the Organising Committee of this symposium led by his Excellency, Professor M. Yisa and our able secretary, Dr. I. Tanam for a job well done. Once more, I welcome you to Abuja and wish us a fruitful symposium.

Professor Azikiwe Peter Onwualu, FAS
President, Soil Tillage Awareness Initiative (ISTRO-Nigeria)
5th September, 2024

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COMMUNIQUÉ OF 5TH INTERNATIONAL SOIL TILLAGE RESEARCH ORGANIZATION NIGERIA SYMPOSIUM

THEMED RESILIENCE AND SUSTAINABILITY OF TILLAGE SYSTEMS IN NIGERIA: MITIGATING AND ADAPTING TO CLIMATE CHANGE HELD THURSDAY ,5TH SEPTEMBER 2024, AT THE FACULTY OF ENGINEERING LECTURE THEATRE, UNIVERSITY OF ABUJA, NIGERIA.

PREAMBLE

The International Soil Tillage Research Organization is an international organization with a branch in Nigeria. The aim of the organization is promoting research, development, and adoption of sustainable soil management practices and also promote the understanding of the impacts of tillage on soil health and fertility, erosion, and crop productivity.

This year symposium tagged 5th National symposium of the International Soil Tillage Research Organization ISTRO - NIGERIA was held on Thursday 5th September 2024 at the Faculty of Engineering Lecture Theatre, University of Abuja, Nigeria with the theme "**Resilience and Sustainability of Tillage Systems in Nigeria: Mitigating and Adapting to Climate Change**. It had seventeen paper presentations including eight lead papers in relevant areas with over one hundred participants.

The one-day conference presented a unique forum to raise National, Regional and Continental awareness and engage in deep introspection and robust interactions on existing ways of promoting sustainable soil and water management practices. It discussed the need for understanding the impacts of tillage on soil health and fertility, erosion, and crop productivity. Problem areas were identified and recommendations made. The conference, attended by professionals and stakeholders across the various field of science, agriculture, engineering and the society, received presentations from resource persons in the agricultural sector and related fields.

The opening ceremony was addressed by the Acting Vice Chancellor of the University of Abuja Prof. Aisha Sani Maikudi (SAN). The President of the Nigerian Society of Engineers, Engr Margaret Aina Oguntala, FNSE, FNSChe, ably represented by the Chaiman of Giri Branch, was present to grace the occasion. The keynote paper, “Resilience and Sustainability of Tillage Systems in Nigeria: Mitigating and Adapting to Climate Change” presented by Professor Azikiwe Peter Onwualu, FNSE, FNIAE, FAEng a distinguished professor, outlined the need to take agriculture more seriously in a nation like Nigeria with exploding population. He noted that issues of insecurity, farmer’s/headers crises, are tied to hunger. He stressed the need for Nigeria to develop sustainable agricultural policies and programs that will enhance food production in Nigeria while conserving our natural resources through resilient and sustainable soil tillage and water management practices.

OBSERVATIONS

The following observations were made. That;

1. Agriculture is not yet taken seriously in Nigeria despite the exploding population and food insecurity which has culminated to hunger, insecurity of lives and livelihood of people. This is despite the immense agricultural potentials of the county.
2. There is lack of attention, awareness, required skills and management strategies on resilient and sustainable soil tillage systems among local farmers
3. There is no required national and international cooperation in supporting water conservation and irrigation management.
4. Optimization of field-level management with regard to crop science, environmental protection and economics is on the decline. This is consequent upon the inappropriate application of precision agriculture.
5. Nigeria like the world is still faced with increased frequency and intensity of extreme weather events and decline in food production which are implications of climate change affecting life and livelihood of Nigerians.

6. Nigeria lack the rapid economic growth it desired despite blessed with both human and natural resources.
7. There is Need for capacity building and extension services in order to ensure the resilience and sustainability of tillage systems.
8. Men generally have more decision-making power regarding tillage practices, often due to their control over machinery and inputs. Women face significant barriers to accessing resources such as land, credit, and technology, which are crucial for adopting improved tillage practices.

RECOMMENDATIONS

1. There is need for integration of agro- ecological principles into tillage systems through minimal soil disturbance, soil organic matter enhancement, crop diversity, and natural process integration which will improves soil health and productivity and also enhances ecosystem services, and mitigates climate change impacts. Crop diversity is also essential for global food security, resilience against climate change, and sustainable agriculture. It is essential to have continued research, policy support, and farmer education for scaling up agro-ecological tillage systems globally, ensuring food security while safeguarding natural resources for future generations.
2. For sustainable soil management (SSM) there is need for adopting practices that enhance soil health by farmers to mitigate the impacts of climate change, improve agricultural productivity, and ensure long-term food security. Overcoming the challenges to SSM requires concerted efforts from farmers, researchers, policymakers, and the international community. Through education, financial support, policy reform, and continued research, Nigeria can build a resilient and sustainable agricultural system that benefits both people and the environment.

3. The need for international cooperation and support in water conservation and irrigation management are essential for Nigeria to navigate the complexities of climate change and secure a sustainable future for its people. Regional bodies such

as Lake Chad Basin Commission, Niger Basin Authority and development Partners such as the World Bank, UNDP and FAO can tremendously contribute in the area of policy advocacy, technical, financial and institutional support. Proper hydrologic monitoring and improved weather forecasting, Structural or civil-works-based soil and water conservation techniques, Developing the requisite synergies between strong research institutions, private sector organizations and professional bodies and development of policies and programmes in the area of Climate Smart Agriculture that would bring about the building of resilience and sustainability are required.

4. There is need for continuous adoption and application of precision agriculture and its principles to agricultural practices which will leads to increased agricultural productivity hence promote economic growth and reduced environmental impact. Future of tillage systems lies in embracing emerging trends such as digital agriculture, precision technologies, and climate-smart practices.
5. There is need for agriculture to address simultaneously three intertwined challenges: ensuring food security through increased productivity and income, adapting to climate change and contributing to climate change which can be achieved by radical changes in our food systems through enhanced efficiency in resource use so as to become more resilient to changes and shocks. Emphases should be made on the need to addressing agriculture via the climate-smart strategy critical to achieving global climate change goals, both in terms of adaptation and mitigation.

There is need to develop a climatic framework that brings about sustainable environment through green alternatives and lowered emissions. Nigeria should develop frameworks based on Conservation Tillage (CT) to improve climate resilience. In the future, CT can be better implemented to achieve climate resilience under different conditions across Nigeria.

6. To stimulate economic growth and launch Nigeria onto a path of sustained and rapid socio-economic development, and industrialization, an agricultural revolution through the concept of Nature - Inclusive Agriculture (NIA) should be the catalyst.
7. There is need for Strengthening extension services through increased funding, better training, and improved infrastructure essential for achieving sustainable agricultural growth and food security in the country. The integration of effective capacity building and extension services is essential for promoting sustainable tillage systems and ensuring food security in a changing climate like Nigeria this is by addressing challenges, seizing opportunities, and embracing technological innovations.

8. Incorporating gender perspectives in tillage systems is essential for achieving equitable and sustainable agricultural development. Gender-sensitive policies and programs are needed to address these disparities. Addressing the disparities in labour division, resource access, economic opportunities, and social norms can empower women and enhance the overall productivity and sustainability of our agricultural practices.

APPRECIATION

ISTRO - Nigeria expressed profound gratitude to the Acting Vice Chancellor of University of Abuja Professor Aisha Maikudi and Faculty of Engineering for hosting this timely and important symposium. It also deeply appreciated the financial and moral support by the executives of ISTRO-NIGERIA. Unique appreciation went to the Chairman LOC and HOD Agricultural Engineering Department University of Abuja together with his team for making the symposium successful.

Engr. Professor Mohammed G. Yisa.
Chairman, Local Organizing Committee

Professor Azikiwe Peter Onwualu
President, ISTRO-Nigeria

KEYNOTE SPEAKER

RESILIENCE AND SUSTAINABILITY OF TILLAGE SYSTEMS: MITIGATING AND ADAPTING TO CLIMATE CHANGE

Azikiwe Peter Onwalu

RESILIENCE AND SUSTAINABILITY OF TILLAGE SYSTEMS: MITIGATING AND ADAPTING TO CLIMATE CHANGE

Professor Azikiwe Peter Onwualu
FAS, FAEng, FNSE, FNIAE, FNIM
President, African University of Science and Technology, Abuja.
President, Soil Tillage Awareness Initiative (International Tillage Research Organization, Nigeria Chapter (ISTRO -Nigeria)

Keynote Address at ISTRO-Nigeria 2024 Tillage Symposium held at Faculty of Engineering Auditorium, University of Abuja.
September 5, 2024

African University of Science and Technology, Abuja, Prof Onwualu, 2024 1

IS AGRICULTURE REALLY IMPORTANT?

- Uncontrolled Population Growth
- Economic growth, making more demand on the land
- Economic hardship leading to extreme poverty
- Insecurity, farmer-herder crisis, kidnapping
- Dysfunctional Infrastructure
- These and others mean more continuous demand for food at affordable price
- Food insecurity is real and it leads to other insecurities – ethnic conflicts, political instability, civil disobedience, protests, kidnapping, youth restiveness, excessive migration and insurgency.

African University of Science and Technology, Abuja, Prof Onwualu, 2024 2

STRATEGIES FOR DEALING WITH FOOD CRISIS AND FOOD INSECURITY

- Price control
- Food handouts
- Grow more food through agricultural intensification and mechanization
- Use of chemical fertilizers and other soil improvement chemicals
- These put more pressure on the land, leading to soil degradation, loss of soil quality, loss of sustainability of production.

CLIMATE CHANGE

- In addition to pressure on agricultural land, some natural and man made perturbations are disrupting the agricultural production system.
- Soil erosion and desertification
- Global warming
- Increased temperatures
- Changing weather patterns and extreme weather events
- Increased drought
- More severe storms
- Flooding
- Rise in sea levels and hurricanes
- Increased wild fires

CLIMATE CHANGE EFFECT ON AGRICULTURE

- Less predictable growing seasons
- Lower crop yields
- Food shortage
- Food losses
- Higher cost of food production
- Higher food prices

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COMBATING CLIMATE CHANGE IN AGRICULTURE

- Reduction in green house has emissions through reduced use of energy systems that emit such gases
- Use of carbon sinks, decarbonization of production systems, carbon sequestration
- Climate smart seed varieties and livestock
- Resilient tillage systems
- Sustainability of tillage systems
- Precision Farming
- Conservation tillage systems

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SYMPOSIUM THEME AND SUB-THEMES

➢ This symposium is about how we, as soil scientists, engineers, agronomists and farmers can find sustainable solutions for the challenge of climate change in agriculture using the following sub themes:

- Climate Smart Agricultural Practices
- Sustainable Soil Management
- Precision Agriculture Techniques
- Water Conservation and Irrigation Management
- Agro-ecological principles in Tillage
- Capacity Building and Extension Services in relation to tillage systems
- Frameworks for Climate Resilience and Suitable Tillage Systems
- Perspectives on Gender in Tillage Systems

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CONCLUDING REMARKS

- I believe in this Symposium we have the best brains Nigeria has in academia, government and industry in the area of soil management and sustainable tillage systems for optimum crop production.
- We should come up with strategies and policy recommendations towards fostering the ability and capacity of Nigerian farmers to understand and deploy climate smart, resilient and sustainable farming systems for sustainable agriculture in Nigeria.
- I seize this opportunity to call on the federal and state governments and their relevant organs to implement sustainable, resilient and climate smart agricultural systems and practices towards improved food security in Nigeria

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THANK YOU
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LEAD PAPERS

CLIMATE-SMART AGRICULTURAL PRACTICES: ANTIDOTE FOR ENHANCING FOOD PRODUCTION

Martins Yusuf Otache

Federal University of Technology, Minna Nigeria.

ABSTRACT

Climate change is significantly affecting agricultural production in Africa, with increasing temperatures, changes in precipitation patterns, and more frequent extreme weather events, leading to challenges such as soil degradation, water scarcity, and reduced crop yields. As a result, there is an urgent need for sustainable farming solutions to ensure food security and environmental sustainability. Climate-Smart Agriculture (CSA) has emerged as a critical strategy for mitigating the negative impacts of climate change on agricultural systems. This paper explores the role of CSA in enhancing food production in Nigeria, focusing on how climate-smart agricultural practices can increase productivity, build resilience, and reduce greenhouse gas emissions. By integrating these practices, farmers can adopt resource-efficient technologies such as conservation tillage, crop rotation, and water conservation techniques. The study also emphasizes the need for policy support, institutional frameworks, and capacity building to promote widespread adoption of CSA practices. Through real-world examples from Nigeria and other African countries, the paper illustrates the success of CSA in boosting crop yields, improving soil health, and enhancing farmers' resilience to climate shocks. Ultimately, CSA is proposed as an essential tool for addressing the interconnected challenges of food security, climate adaptation, and environmental preservation in Nigeria's agricultural sector.

KEYWORDS: sustainable farming, food security, climate change adaptation, conservation tillage, crop rotation, water conservation

1. INTRODUCTION

1.1 Context

Agriculture constitutes the mainstay of most African economies. It is frequently the largest contributor to GDP and about two-third of manufacturing value-added is based on agricultural raw materials. Thus, the focus of this presentation is on Africa and Nigeria in particular. According to the World Bank report (2011), Agriculture is also a main source of employment, remaining essential for pro-poor economic growth in most African countries, as rural areas support around 70-80 % of the total population. Despite increasing urbanisation, Africa's poorest households are rural and small holder agriculture remains essential for lifting large numbers of Africans out of poverty and hunger according to NEPAD (2002) in Branca et al. (2011); this is however being affected by climate change impacts. The IPCC predicts that Africa will be the region most affected by climate change, due to both changes in mean temperatures and rainfall, as well as increased variability associated with both (IPCC, 2007a).

The African continent has warmed about 0.5 degrees Celsius over the last century and average annual temperatures are expected to continue to rise in future (3-4°C by 2080, which is greater than the global average) according to the FAO and World Bank report (2011). The seeming characteristics of this climate change phenomenon shall include but

not limited to increased temperatures and changes in precipitation which will stress agricultural and natural systems, through increased water shortages, shorter growing periods in some areas, increased magnitude and frequency of flooding as well as drought, changes in plant/animal disease and pest distribution patterns, and more generally, reduced suitability of some areas for agriculture. Parts of sub-Saharan Africa, where high vulnerability to weather shocks already exists, are expected to be hardest hit, with decreases in agricultural productivity between 15-35 % (Stern, 2006; Cline, 2007; Fisher et al. 2005; IPCC, 2007a). Hence, against this backdrop, widespread and severe decline of soil quality in almost all production regions also raises questions about the sustainability of current agricultural production practices. According to IPCC-based climate change predictions, most of the rainfall will occur in the form of high-intensity short-duration rain events due to global climate change effects (IPCC, 2007a). This holds true as current climate change variability attest to it; as such, this warrants that more proactive efforts should be made for developing and adopting resource-conserving technologies to increase global food production in a sustainable way amid the confounding challenges facing agriculture.

To surmise, it is expected that climatic changes will be more rapid and intense, requiring adaptation that is faster and more profound than in the past. Recent food volatility showed that climate change can be an important threat multiplier to food security and that it is introducing another source of risk and uncertainty into food systems from farms to global levels. The compounding effects of spiking food and fuel prices vis-a-vis the global weather anomalies are estimated to have reversed the steady decline in the proportion of undernourished in the population (FAO, 2009a).

In the views of Accatino (2022), agriculture is coping with economic, environmental, social and institutional challenges that are expected to further accumulate in the future. Hence, identifying strategies to cope with these challenges requires understanding of the mechanisms that make farming systems resilient. In the light of this, African policymakers are thus challenged to ensure that agriculture contributes to addressing food security, development and climate change (adaptation and mitigation). Approaches that seek to maximise the benefits and minimise the trade-offs across these multiple objectives (which are closely linked within the agriculture sector) require more integrated and coordinated planning, policies, institutional arrangements, as well as financing and investment. Such approaches and their related enabling requirements in this context are sometimes referred to as climate-smart agriculture (CSA).

1.2 General need for Climate-Smart Agriculture (CSA)

Climate change accelerates degradation processes in already-degraded environments and has negative impact on food production and food system. This has heightened the need to embrace the notion of Climate-Smart Agriculture (CSA) in the face of climatic vagaries to reduce the negative impacts of climate change on agricultural systems. As reported by Vandana et al.

(2022), a transformation of the agricultural sector, including crop and livestock production, fisheries and forestry, is urgently needed to respond to climate change and sustainably increase agricultural productivity and incomes. Climate-smart agriculture is rooted in sustainable agriculture and rural development objectives which, if reached, would contribute to achieving the Sustainable Development Goals (SDGs) of reducing hunger and improved environmental management. It suffices to note that contrary to conventional agricultural development, CSA systematically integrates climate change into the planning and development of sustainable agricultural systems. The implementation of CSA is hinged on a tripod which are conceptually interrelated; these are basically increased productivity, enhanced resilience and emission reduction. However, according to Vandana et al. (2022), the resultant trade-offs often cannot maximise the pillars simultaneously, only optimises them.

Thus, CSA attempts to ensure the sustainability of these services, preventing their degradation though by implication, not a rigid set of particular practices, technologies or methodologies; it is only a concept amenable to adaptation. To this end therefore, increased planning is vital in order to address trade-offs and synergies between the three pillars of productivity, adaptation and mitigation (Vermeulen et al., 2012). In a more general context, and by way of characteristic need, "Climate-smart agriculture is an approach that helps guide actions to transform agri-food systems towards green and climate resilient practices (FAO, 2010)". The perception of the Climate Technology

Centre of Denmark (2017) corroborates this fact; according to the Centre, CSA practices coordinate the priorities of multiple countries and stakeholders in order to achieve more efficient, effective and equitable food systems. While the concept is not really new though evolving, many of the practices that make up CSA already exist worldwide and are currently used by farmers to cope with various production risks. Therefore, for effective policy paradigm shift in tune with current climate change realities, mainstreaming CSA calls for critical analysis of successfully completed, on-going practices and their relationship with current and future institutional and financial enablers.

2. CLIMATE-SMART AGRICULTURE (CSA) AND DEVELOPMENT

2.1 What is CSA?

As a response for the need to increase food security without compromising environmental quality and in support of the Paris Agreement on climate change, FAO developed the concept of Climate-Smart Agriculture (CSA) (FAO, 2018, IPCC, 2019). Climate-smart agriculture (CSA) is an approach employed to transform farming that aims to deliver positive outcomes on three impact pillars, namely, intensification, adaptation, and mitigation to support food security under the new realities of climate change (Lipper et al., 2014). Thus, in the opinion of Alexander and Adesola (2023), the climate-smart agriculture (CSA) concept reflects an ambition to improve the integration of agriculture development and climate responsiveness. It therefore aims to achieve food security and broader development goals under a changing climate and increasing food demand; these initiatives sustainably increase productivity, enhance resilience, and reduce greenhouse gases (GHGs).

For operational policy action purposes, in line with Steenwerth et al. (2014), CSA essentially can be an initiative or paradigm designed to achieve the following objectives both in the short and long-term:

i. Meet the growing demand for food, fiber and fuel, despite the changing climate and fewer opportunities for agricultural expansion onto additional lands

ii. Contribute to economic development, poverty reduction and food security

iii. Maintain and enhance productivity and resilience of natural an d agricultural ecosystem functions, thus building natural capital

iv. Develop adaptation and mitigation approaches, and

v. Reduce tradeoffs encountered in the pursuit of these goals

To achieve this to the extent possible, in the submission of Steenwerth (2014) and FAO (2010), the practice should be anchored on **Transdisciplinary Research** that focuses on: (1) models that include adaptation and transformation at either the farm or landscape level (2) capacity approaches to examine multifunctional solutions for agronomic, ecological and socioeconomic challenges (3) scenarios that are validated by direct evidence and metrics to support behaviours that foster resilience and natural capital (4) reductions in the risk that can present formidable barriers for farmers during adoption of new technology and practices (5) an understanding of how climate affects the rural labor force, land tenure and cultural integrity, and thus the stability of food production. To this end, the overall strategy can be achieved by embarking on (i) conservation agriculture based on no soil disturbance by tillage, permanent soil cover and crop rotation (ii)Natural Forest restoration and (iii) pasture reclamation. This is only workable by spreading the principles of: manage more by disturbing less soil, diversifying soil biota with plant diversity, keeping roots growing all year round, and by extension, keeping the soil covered as much as possible and producing more from less. To operationalise this concept, **Table 1** provides an exemplar of a robust CSA practice protocol within a realistic practical context.

Table 1: Exemplar CSA Practices scheme

Crop mgt	**Livestock mgt**	**Soil & Water mgt**	**Agroforestry**	**Integrated food energy system**
Intercropping to maximise space, pest control & cash crop	Improve feeding strategies (e.g. cut and carry)	Conservation agriculture (e.g. minimum tillage)	Boundary trees & wind brakes	Biogas
Croprotations Should include legumes	Rotational grazing	Contour planting	Nitrogen-fixing trees on farms (e.g. legumes)	Improve d stoves
New crop varieties (e.g. drought, wind & flood tolerant)	Grow suitable crops (with proper management) to feed animals	Use mounds to plant on slopes	Multipurpose trees (e.g. fruit trees used as wind breaker)	Solar power
Improved storage & Processing techniques	Manure treatment (well-rotted/ decomposed)	Grass barriers	Fruit orchards	Ram pumps for irrigation
Greater crop diversity	Improved livestock health	Stone barriers		Gravity-fed irrigation systems
Underground crops (e.g. tuber crops like yam, etc.)	Animal husbandry improvements	Check dams		
Stake plants to reduce wind damage		Use bench/eyebrow terraces to plant on slopes		
Composting & Organic fertiliser		Encase beds (pallets, bamboo)		
Mulching crops		Water storage (e.g., rainwater harvesting)		
Shade house		Improved Irrigation (e.g. drips)		

Source: Neufedt et al. (2011) and Philip (2014) in: www.facebook.com/INCCAS/Grenada

3. CLIMATE-SMART AGRICULTURE IN ACTION

3.1 General perspectives

Africa's population has just passed 1 billion and is due to double by 2050 (FAO, 2011a). FAO estimated that Sub-Saharan Africa remains the region with the highest proportion of undernourished people in the population (30 % in 2010), compared with a 16 % average for developing countries (FAO, 2011a). FAO (2009c) estimated that Africa will need to provide adequate food supplies for more than 20 million additional people each year and improve the nutritional status of the more than 239 million people currently undernourished. This is equivalent to achieving a 4.6 % growth in food supplies. Thus, increasing food production will be an important part of addressing food insecurity in the 21st century in Africa.

But the implication of this against the backdrop of the submissions by Branca et al. (2011), however, is that there is no blueprint for climate-smart agriculture and the specific contexts of countries and communities would need to shape how it is ultimately implemented; though, Climate-smart agricultural production technologies can provide significant climate change mitigation and adaptation co-benefits. For African governments, promoting climate-smart agriculture is a priority (WBG, 2016).

3.2 Snapshot of CSA: Africa and Nigeria in Particular

It is imperative to state that under the framework of Comprehensive Africa Agriculture Development Program (CAADP), things began to change with modest results across the continent. The goal of CAADP, which is owned and led by African governments, is to help reach and sustain higher economic growth through agriculture-led development that reduces hunger and poverty and enables food and nutrition security. This has resulted in more strategic and integrated planning, as well as increased investment in the sector as advocated. But, it is also noteworthy that African work on integration of agriculture and climate change issues is taking place but without commensurate international policy advances within UN Framework Convention on Climate Change (UNFCCC) processes (Branca, 2011). Despite this though, **Table 2** shows the general pattern of awareness of the need for CSA with the associated results across Africa.

Table 2: Sample of CSA adoption success cases across Africa

S/ No.	Country	CSA Objective	Status
1	Kenya	Building resilient farming systems (Specific: Bee-Siness of Agriculture	*i.* Honey production increased by over 131 % *ii.* Income grew by nearly 356 %
2	Uganda	Harnessing Science for private sector collaboration in agriculture (Specific: Coffee production)	➢ Intercropping changed the micro-climate in coffee growing areas and reduced temperatures by 2-5 ºC
3	Tanzania	Raising productivity through irrigation investment (Specific: Rice production)	*i.* 228,000 farmers adopted improved farming *ii.* Rice production increased by 30 %
4	Ethiopia	Soil health enhancement	*i.* Mapping of over 60 % districts across Ethiopia *ii.* 4 regions have improved crop productivity
5	Zambia	*(a)* Conservation through sustainable agricultural practices *(b)* Enhancing livestock production	*i.* Annual household income grew over 260 % *ii.* One (1) million hectares set aside as country conservation areas *i.* 353,000 livestock farmers adopted improved husbandry practices *ii.* Contagious bovine pleuropneumonia has been verifiably cleared from 11 of the targeted 18 districts
6	Morocco	Combating drought	Drip irrigation saves 25 % of water use in irrigated areas Tree crops provide higher returns and are better adapted to drought and climate change than cereal crops in rainfed areas

Source: WBG (2016)

In Nigeria, some CSA practices like intercropping/multiple cropping, agroforestry, conservation agriculture, etc. are quite widespread and their proliferation has been facilitated by ease of adoption, and multiple benefits such as food, income diversification and improved resilience. Although there are a wide range of organisations conducting CSA-related work in Nigeria, most have focused largely on food security, environmental management and adaptation as reported by FAO (2019). Recent studies documenting adoption on CSA practices in Nigeria established that high levels of adoption of early maturing and drought tolerant varieties (Onoja et al., 2019, Wahab et al., 2020), changing of planting dates, and diversification of crops (Onoja et al., 2019) especially, CSA tools and practices like resistance traits against biotic and abiotic stress. For example, in 2017 in Benue State, 595 high-yielding drought, disease and pest resistant varieties were released and catalogued, ranging from tubers, cereals and forage legumes to vegetables (NACGRAB, 2016). Among those were two drought-tolerant varieties of cowpea (FUAMPEA 1 and FUAMPEA 2) from the Federal University of Agriculture in Makurdi, which produced about two tonnes per hectare in the experimental fields and showed strong resistance to the parasitic weeds **Striga gesnerioides and Alectra vogelii** (Omoigui et al., 2017). This is indicative of the extent of awareness of CSA and its associated benefits.

Beside the aforementioned, orchestrated CSA policy actions by the Government have being developed and implemented with tangible results. For instance, the National Adaptation Strategy and Plan of Action for Climate Change seeks to minimise climate risks, improve local and national adaptive capacity, and leverage new opportunities for facilitating international collaboration (FME, 2011). The policy supports improved agricultural systems and practices for crops and livestock and access to climate information, such as early warning and meteorological forecasts, with stated roles and responsibilities of the federal, state and local governments, the private sector, civil society organisations, communities and individuals for these improved systems and practices. The policy also emphasises the link between improved management of natural resources and climate adaptation actions in agriculture. To this end too, Nigeria's third intended nationally determined contribution recognised that climate- smart agriculture is a key means towards meeting the ambitions of agricultural transformation. The document (FGN, 2015), which was submitted to the 2015 United Nations Framework Convention on Climate Change (UNFCCC), aims to sustainably increase agricultural productivity and support equitable increases in farm incomes, enhancing food security and development while reducing greenhouse gas emissions. The recommended practices include halting deforestation and promoting agroforestry. The estimated benefits from agroforestry include total (lifetime) carbon emission reductions ranging between 158 million tonnes and 712 million tonnes (FGN, 2015).

However as reported by Gabriel et al. (2023), the adoption of solutions that more knowledge-intense or substantial up-front investment, such as soil management and testing and agroforestry, is generally low. This, among other factors can partially be explained by the lack of local extension networks that demonstrate and help farmers adopt such solutions. Moreover, access to investment capital and risk management tools may be also required to further de-risk farmer adoption (Klauser and Negra, 2020). The general pattern as illustrated in **Table 3** for selected cases portrays the aggregate CSA practices and strategies vis-à-vis the associated return enhancement levels.

In addition, there have been interventions generally by way of agricultural planning; in this regard, Nigeria's National Agricultural Investment Plan (NAIP) is based on 5 component programs: (a) Agricultural productivity enhancement (b) Support to commercial agriculture (c) Land and water management (d) Linkages and support to input and product markets (e) Program coordination, Monitoring and Evaluation (M&E). The NAIP does not provide estimates of the total cost of each of these programs or its sub-programs, but does provide an estimate of the financing gap (**See** http://www.naspanigeria.org/); this is based on the CSA screening results of the agricultural sector for the period of 2011-2014. It is not clear whether this financing gap refers to the gap between planned investments and current budget allocations of the federal government and donors, or between planned investments and a CAADP 10 % allocation of federal budget to agriculture (Nwajiuba, 2008). The majority of sub- programs in Nigeria's NAIP have been identified as having potential climate benefits. About 80 % of all identified climate benefits could be provided by two programs: the program on agricultural productivity enhancement and the program on land and water management. 70 % of sub-programs may have climate change mitigation benefits (**See** http://www.naspanigeria.org/).

Table 3: Selected CSA adoption success cases across Nigeria

S/ No.	Region/State	CSA Objective	Status
1	North West and North Central	Building resilient farming systems (Specific: Conservation Agriculture; e.g. Zero tillage & Intercropping)	Regional adoption of CSA is 87.2 % **Results**: Water use efficiency has been enhanced by 42 %; Productivity increased by 54 %
2	Yobe State	Food security enhancement (Specific: Micro dosing, Conservation agriculture)	➢ Micro dosing adoption: 80 %; enhanced yield by 2000kg/ha against 1200 kg/ha for control ➢ Conservation agriculture led to: reduction in runoff, enhanced infiltration and soil moisture retention ➢ Zero or minimum tillage: minimised labour costs; enables early planting to synchronise the onset of rainfall.
3	Delta State (sampled case: North East LGA)	Food security enhancement (Specific: Agro-forestry, crop rotation, intercropping and composting, etc.)	Enhanced food security by 71 %)
4	Ebonyi State	Food security **<u>Practices</u>** *i.* Conservation agriculture: Zero or minimum tillage *ii.* Basic management: Intercropping & mixed farming *iii.* Water mgt Irrigation *iv.* Improved seed varieties (Early maturing) Drought & flood resistant varieties *v.* Soil fertility mgt Combined chemical with organic soil fertility Improvement practices	Smartness Score (CSA) **<u>Yield</u>** 7 (10) 8 (10) & 9 (10) 7 (10) 9 (10) 9(10) 8 (10) 7 (10)

Source: Gabriel et al. (2023); FAO (2019); Opeyemi et al. (2021); Onyeneke et al. (2020)

3.3 Opportunities and Challenges of CSA in Nigeria

Climate-smart agriculture fully incorporates attention to climate risk management; but generally, agriculture is an extremely risky business, and climate change will exacerbate this if proper action plans are not developed and implemented with robust intervention framework. This is so considering the fact that feeding a growing global population enjoying strong economic growth is made complicated by the onset of climate change (FAO, 2013a). The increased unpredictability and prevalence of extreme weather events threaten the achievement of improved agricultural yield. As a result, agricultural production could diminish resulting in significant lowering of incomes in vulnerable areas. Climatic events can contribute to global food prices and, thereby, affect the global and regional economy. According to Ancog and Ticsay in Asia Pacific Adaptation Network: **apan** report (2015), the urgent challenge lies in the need to improve the resilience of the agricultural sector to climate change, with visible improvements in technical and financial mechanisms. It suffices therefore to note that the types and severity of the risks confronting farmers vary by farming system, agro- climatic region, local policy and institutional settings. Beyond the global perspectives, the case of Nigeria, is not in any particular way too different.

Some CSA practices (e.g. intercropping/multiple cropping, agroforestry, conservation agriculture etc.) are quite widespread and their proliferation has been facilitated by ease of adoption, and multiple benefits such as food, income diversification and improved resilience. Although there are a wide range of organisations conducting CSA- related work in Nigeria, most have focused largely on food security, environmental management and adaptation FAO (2019). But, in the views of Alexander and Adesola (2023), despite substantial efforts to mainstream climate change adaptation into the country's developmental agenda and policies, Nigeria is still grappling with challenges in achieving the desired results. Some of these challenges include funding, capacity building, and poor technical skills. Other challenges include lack of synergy, coordination and collaboration by stakeholders, and a lack of target-setting, monitoring, and evaluation, which gave room to overlaps, duplication of efforts and a greater cost burden (Alexander and Adesola, 2023). Perhaps, it is also imperative to state that poor communication is another problem reducing the effectiveness of

adaptation efforts in the country. The lack of active involvement of the sub-national governments (especially the local governments) and indigenous people constitutes a major barrier to effective and inclusive National Action Plan (NAP) implementation in the country. For obvious reasons, Nigeria has limited domestic resources to finance climate change adaptation activities. The country's budget is primarily focused on addressing immediate development needs, leaving limited funds for long-term adaptation planning and implementation (Alexander and Adesola, 2023); though, the government seen to be committed to increasing its financial commitment to adaptation and to this end, it has developed a number of strategies to mobilise additional resources (UNFCCC, 2021). More generally, the challenges or issues in this context, can be discussed under two broad categories: physical or hardware (e.g., limited access to appropriate farm equipment and tools, inadequate farm inputs) and non-physical or software (e.g. inadequate knowledge and information, etc.) barriers exemplified by a copious lack of knowledge and access to credit and climate finance which can increase and sustain adoption of CSA measures.

3.4 Probable recourse or road map for sustainable CSA

To tackle the underlying barriers for the adoption of CSA tools and practices, it is important to consider the subject in a holistic manner; this, in the views of Giller et al. (2021) as reported in Alexander and Adesola (2023), the solution concept should not just be canvassed without considering the exacerbating environment. This situation has limited the impact of many interventions to promote climate-smart and regenerative farming systems to date; hence, bundled efforts that combine access to knowledge, finance and risk management strategy seem to be the viable panacea that can drive adoption of more complex CSA solutions. Since climate change impacts agriculture in different ways, the type of impact dictates the nature of the entry point when introducing CSA interventions. Therefore, each entry point under each thematic area should be analysed in terms of productivity, mitigation and adaptation potential. To this end, the enabling CSA environments are the framework conditions that facilitate and support the adoption of climate-smart technologies and practices; these are basically policies, institutional arrangements, stakeholder involvement, gender considerations, infrastructure and insurance schemes, as well as access to weather

information and advisory services. They help build institutional capacity at all levels and reduce the risks that deter farmers from investing in new technologies and practices (https://www.csa.guide/csa/enabling environments).

A key element required for sustainable and transformational development in agriculture within the context of the aforementioned is ensuring that investments are informed by robust evidence about past and future climate risks by paying attention to climate resilience. Climate resilience is a fundamental concept of climate risk management. In this context, resilience refers to the ability of an agricultural system to anticipate and prepare for, as well as adapt to, absorb and recover from the impacts of changes in climate and extreme weather. But this involves holistic planning and finance. Hence, there is need to explore opportunities to access and utilise international climate finance from sources such as the Green Climate Fund and Global Environment Facility and through readiness and capacity building programs. In a way, this practically calls for orchestrated interventions like the development of climate-smart agriculture investment plans (CSAIP) which should be a strategic and thorough planning document for proposing high potential and high-suitability agricultural development projects. The process of creating a CSAIP leverages stakeholder engagement and capacity building by conducting a situation analysis, listing and prioritising potential CSA investments, and developing preliminary designs and guidance for implementing and monitoring project investments; the result of which is a suite of country-supported and scientifically vetted investments ready to present to potential investors.

Besides, one of the ways through this, is to mainstream CSA by considering factors like:

(1) Climate-Smart Agriculture expenditure and planning, (2) Land tenure regimes or title deeds, (3) Private Sector Investments, (4) Improve market accessibility, policy and financial instruments, (5) Incentives for Climate-Smart Agriculture investments, (6) Development of policies to mobilise non-state actors, and (7) Development of policies to link CSA with adaptation and mitigation measures to climate change and show synergies, and more importantly, developing climate-smart village (s).

4. CONCLUSIONS

In conclusion, it is imperative to take cognisance of the fact that agriculture has to address simultaneously three intertwined challenges: ensuring food security through increased productivity and income, adapting to climate change and contributing to climate change; to do this, require radical changes in our food systems. By implication, there must be enhanced efficiency in resource use (i.e., use less land, water, and inputs to produce more food sustainably) so as to become more resilient to changes and shocks. In this context, evidences abound as to the proficiency of CSA; climate-smart agriculture offers some unique opportunities to tackle food security, adaptation and mitigation objectives especially for developing countries globally like the case of Africa. African countries will particularly benefit given the central role of agriculture as a means to poverty alleviation and the major negative impacts that climate change is likely to have on the African continent. Thus, addressing agriculture via the climate-smart strategy is critical to achieving global climate change goals, both in terms of adaptation and mitigation; basically through increased systemic efficiency and resilience (in terms of policies, institutions and finances) by imbibing the culture of resource and system efficiencies (plant production, livestock production, reduction in losses and waste; reduction in vulnerability and enhanced resilience).

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SUSTAINABLE SOIL MANAGEMENT

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ABSTRACT

Sustainable soil management (SSM) is essential for maintaining soil health, agricultural productivity, and resilience in the face of climate change. In Nigeria, where agriculture is a major economic sector, soil degradation due to improper management practices, climate-induced stressors, and over-exploitation poses significant challenges to food security. This paper explores the principles and benefits of SSM, emphasizing the importance of preserving soil biodiversity, promoting organic matter, and adopting conservation tillage practices. Techniques such as crop rotation, agroforestry, and integrated nutrient management are highlighted as effective methods to improve soil structure, fertility, and water retention. The paper also addresses the impact of climate change on soil health, including erosion, fertility loss, and changing moisture levels. Through case studies from different regions of Nigeria, the study demonstrates the positive outcomes of SSM in mitigating these challenges and enhancing resilience. The paper concludes by advocating for policy support, farmer education, and investment in sustainable practices to ensure long-term soil productivity and environmental sustainability in Nigeria.

Keywords: Sustainable soil management, soil health, climate change, conservation tillage, crop rotation, agroforestry, soil fertility, water management, Nigeria agriculture.

1. INTRODUCTION

1.1. Sustainable Soil Management: A Cornerstone for Nigerian Agriculture

Sustainable soil management (SSM) is paramount for ensuring the longevity and productivity of agricultural systems, particularly in the face of an increasingly volatile climate. Soil, a non-renewable resource, is the foundation of food security and ecosystem health. Its judicious management is crucial for maintaining its fertility, structure, and biological activity.

In Nigeria, agriculture remains a mainstay of the economy, providing sustenance and livelihoods for millions. However, the sector is under siege from the impacts of climate change, including erratic rainfall patterns, rising temperatures, and extreme weather events. These climate-induced stressors degrade soil health, erode productivity, and exacerbate food insecurity. To counteract these challenges and build resilience, the adoption of sustainable soil management practices is imperative.

The cornerstone of SSM lies in understanding and preserving soil biodiversity. A thriving soil ecosystem, teeming with microorganisms, enhances nutrient cycling, improves soil structure, and promotes plant growth. Practices such as crop rotation, cover cropping, and green manuring contribute to building and maintaining soil organic matter, which is essential for water retention, nutrient availability, and soil aggregation.

Tillage systems, a fundamental aspect of agricultural practices, significantly impact soil health. Conventional tillage, characterized by frequent and deep ploughing, can lead to soil erosion, nutrient loss, and compaction. Conversely, conservation tillage practices, such as reduced tillage and no-till, minimize soil disturbance, conserve moisture, and enhance soil carbon sequestration. By adopting these practices, Nigerian farmers can mitigate the adverse effects of climate change and improve soil fertility.

Nutrient management is another critical component of SSM. The judicious use of organic and inorganic fertilizers is essential for replenishing soil nutrients and maintaining crop productivity. Precision agriculture technologies can optimize fertilizer application, reducing waste and minimizing environmental impacts. Furthermore, integrating livestock with crop production can provide a sustainable source of organic manure, enhancing soil fertility and reducing reliance on synthetic inputs.

Water management is equally crucial for sustainable soil management. Efficient irrigation systems, such as drip and sprinkler irrigation, can reduce water waste and improve water use efficiency. Additionally, rainwater harvesting and storage can help mitigate the impacts of drought.

By embracing SSM principles, Nigerian farmers can improve soil health, enhance crop yields, and build resilience against climate change. The benefits extend beyond increased agricultural productivity, including improved water quality, reduced soil erosion, and increased carbon sequestration. It is essential to provide farmers with access to training, extension services, and financial incentives to facilitate the adoption of sustainable practices. By investing in soil health, Nigeria can secure a more sustainable and resilient agricultural future

2. UNDERSTANDING SOIL HEALTH

2.1 Definition and Components of Soil Health

Soil health is a measure of the soil's ability to function as a living ecosystem, supporting plant, animal, and human life. It's more than just the physical properties of the soil; it's a dynamic interplay of physical, chemical, and biological processes.

2.1.1 Physical Properties:

- **Soil texture:** This refers to the proportion of sand, silt, and clay particles in the soil. It impacts water infiltration, drainage, and nutrient holding capacity. A balanced texture, with a good mix of all three particle sizes, is ideal for optimal soil health.
- **Soil structure:** This refers to the arrangement of soil particles into aggregates or clumps. Good soil structure creates pore spaces that allow for air and water movement, essential for root growth and microbial activity.
- **Soil porosity:** This is the amount of pore space in the soil. Porosity is directly linked to soil structure and influences water infiltration, drainage, and aeration.

2.1.3 Chemical Properties:

- **Soil pH:** This measures the acidity or alkalinity of the soil. A balanced pH is crucial for nutrient availability and microbial activity. Most plants prefer a slightly acidic to neutral pH.

- **Nutrient availability:** Soil contains essential nutrients like nitrogen, phosphorus, and potassium, which are vital for plant growth. Healthy soil provides a steady supply of these nutrients in forms that plants can easily absorb.
- **Cation exchange capacity (CEC):** This is the soil's ability to hold onto essential nutrients, preventing them from being leached away by water. A high CEC ensures nutrient availability for plants.

2.1.4 Biological Properties:

- **Soil biodiversity:** A diverse community of microorganisms, including bacteria, fungi, and protozoa, is essential for soil health. These organisms break down organic matter, cycle nutrients, and suppress plant diseases.
- **Organic matter:** This is the decomposed remains of plants and animals. It improves soil structure, water holding capacity, nutrient availability, and provides a food source for soil organisms.
- **Soil fauna:** Earthworms, insects, and other soil animals play a crucial role in soil health by creating pores, mixing soil, and breaking down organic matter.

2.1.4 The Interconnectedness of Soil Health Components:

These physical, chemical, and biological components are interconnected. For example, good soil structure (physical) enhances water infiltration and aeration, which promotes microbial activity (biological) and nutrient availability (chemical). Organic matter improves soil structure, providing a habitat for microorganisms and enhancing nutrient retention. Maintaining healthy soil is essential for sustainable agriculture, environmental protection, and human well-being. By understanding and managing these components, we can ensure the long-term productivity and health of our soils.

2.2 Importance of Organic Matter

Organic matter is a critical component of soil health, providing nutrients, improving soil structure, and enhancing water retention. It consists of decomposed plant and animal residues, which contribute to the formation of humus—a stable form of organic matter that binds soil particles and enhances fertility.

2.3 Role of Microbial Activity

Microbial activity is essential for maintaining soil health. Microorganisms decompose organic matter, releasing nutrients that plants can absorb. They also help in forming soil aggregates, which improve soil structure and water infiltration. Promoting microbial diversity through practices like crop rotation and organic amendments can significantly enhance soil health.

3. CURRENT SOIL MANAGEMENT PRACTICES IN NIGERIA

3.1 Traditional Practices

Traditional soil management practices in Nigeria include shifting cultivation, fallowing, and the use of organic amendments like manure. While these practices have sustained agricultural productivity for centuries, they face limitations in the context of increasing population pressure and reduced land availability.

3.2 Modern Practices

Modern soil management practices involve the use of chemical fertilizers, pesticides, and mechanized tillage. While these methods can increase short-term productivity, they often lead to soil degradation, reduced biodiversity, and pollution of water resources.

3.3 Assessment of Sustainability

The sustainability of current practices varies widely. Traditional methods, while ecologically sound, may not meet the demands of modern agriculture. Conversely, modern practices, although productive, can degrade soil health over time. A balanced approach, integrating the strengths of both traditional and modern practices, is essential for sustainable soil management.

3.4 Challenges in Adopting Sustainable Practices

Farmers in Nigeria face several challenges in adopting sustainable soil management practices:

- **Economic Constraints:** Many smallholder farmers lack the financial resources to invest in sustainable practices.
- **Lack of Awareness:** There is limited awareness and education about the benefits of sustainable soil management.
- **Policy and Institutional Barriers:** Inadequate policies and support mechanisms hinder the widespread adoption of sustainable practices.

4. IMPACT OF CLIMATE CHANGE ON SOIL HEALTH

4.1 Soil Erosion

Climate change exacerbates soil erosion through increased rainfall intensity and frequency. Heavy rains wash away topsoil, reducing soil fertility and crop yields. In Nigeria, regions with steep slopes and deforested areas are particularly vulnerable to erosion.

4.2 Loss of Fertility

Rising temperatures and changing precipitation patterns affect soil organic matter decomposition and nutrient cycling. These changes can lead to nutrient imbalances and reduced soil fertility, making it challenging for crops to thrive.

4.3 Changes in Soil Moisture

Climate change affects soil moisture levels through altered rainfall patterns and increased evaporation rates. Prolonged dry periods can lead to soil compaction and reduced infiltration, while excessive rainfall can cause waterlogging and nutrient leaching.

4.4 Case Examples from Nigeria

In Northern Nigeria, desertification and soil degradation are exacerbated by climate change, threatening agricultural productivity and food security. Conversely, in the southern regions, increased rainfall and flooding pose significant challenges to soil health and crop production.

5. SUSTAINABLE SOIL MANAGEMENT TECHNIQUES

5.1 Conservation Tillage

Conservation tillage involves minimal soil disturbance, preserving soil structure and organic matter. Techniques such as no-till and reduced-till practices reduce erosion, enhance water infiltration, and increase soil organic carbon storage, contributing to climate change mitigation (Lal, 2004).

5.2 Crop Rotation and Diversification

Crop rotation and diversification enhance soil fertility and disrupt pest and disease cycles. By alternating crops with different rooting systems and nutrient requirements, farmers can improve soil structure and nutrient availability, reducing dependency on chemical fertilizers (Altieri, 1999).

5.3 Agroforestry

Agroforestry integrates trees and shrubs into agricultural landscapes, enhancing soil fertility and biodiversity. Trees provide shade, reduce wind erosion, and contribute organic matter through leaf litter, improving soil health and resilience (Nair, 1993).

5.4 Organic Farming

Organic farming emphasizes the use of natural inputs and processes to maintain soil health. Practices such as composting, green manuring, and biological pest control enrich soil organic matter and microbial activity, promoting sustainable crop production (Drinkwater et al., 1998).

5.5 Integrated Nutrient Management

Integrated nutrient management combines organic and inorganic inputs to optimize soil fertility. By using organic amendments like compost and manure alongside chemical fertilizers, farmers can enhance nutrient availability and reduce environmental impacts.

5.6 Soil Erosion Control Measures

Soil erosion control measures, such as terracing, contour farming, and cover cropping, prevent soil loss and degradation. These practices protect the soil surface from water and wind erosion, maintaining soil productivity and ecosystem services (Morgan, 2005).

6. CASE STUDIES AND SUCCESS STORIES

6.1 Conservation Agriculture in Northern Nigeria

In Northern Nigeria, conservation agriculture practices have been successfully implemented to combat soil erosion and improve soil fertility. Farmers adopting no-till practices, crop rotation, and organic amendments have reported increased yields and improved soil health, demonstrating the potential of SSM to enhance agricultural sustainability (Kassam et al., 2009).

6.2 Agroforestry in the Sahel

Agroforestry practices in the Sahel region, including parts of Nigeria, have shown remarkable success in restoring degraded lands and improving soil fertility. The integration of trees and crops has increased soil organic matter, reduced erosion, and enhanced water retention, providing a sustainable solution to land degradation and climate change adaptation (Garrity et al., 2010).

6.3 Integrated Nutrient Management in Southern Nigeria

In Southern Nigeria, integrated nutrient management practices have improved soil fertility and crop yields. By combining organic amendments with chemical fertilizers, farmers have enhanced nutrient availability and reduced soil degradation, leading to more sustainable farming systems.

7. Policy and Institutional Support

7.1 ROLE OF GOVERNMENT POLICIES

Government policies play a crucial role in promoting sustainable soil management. Policies that support conservation practices, provide financial incentives, and invest in research and education are essential for widespread adoption of SSM.

7.2 Current Policies in Nigeria

Nigeria has several policies aimed at promoting sustainable agriculture, including the National Agricultural Policy and the Agricultural Transformation Agenda. However, implementation challenges and lack of coordination often hinder their effectiveness.

7.3 Recommendations for Improvement

To enhance the effectiveness of policies, the following recommendations are proposed:

- **Strengthening Institutional Frameworks:** Improving coordination between government agencies and stakeholders.
- **Providing Financial Incentives:** Offering subsidies and grants for sustainable practices.
- **Investing in Research and Education:** Supporting research on SSM and providing training programs for farmers.

8. FUTURE DIRECTIONS AND RESEARCH NEEDS

8.1 Identifying Gaps in Knowledge

There are several gaps in our understanding of sustainable soil management practices and their long-term impacts. Further research is needed to develop context-specific solutions that address the unique challenges faced by Nigerian farmers.

8.2 Areas for Future Research

Key areas for future research include:

- **Climate-Resilient Cropping Systems:** Developing crop varieties and farming systems that can withstand climate variability.
- **Soil Health Monitoring:** Creating reliable methods for monitoring and assessing soil health.
- **Socioeconomic Impacts:** Understanding the socioeconomic implications of adopting sustainable practices.

8.3 Future Trends in SSM

Future trends in SSM are likely to focus on integrating technology, such as precision agriculture and remote sensing, to enhance soil management practices. Additionally, there will be an increasing emphasis on sustainable intensification, which aims to increase productivity while minimizing environmental impacts.

9. CONCLUSION

Sustainable soil management is essential for the resilience and sustainability of tillage systems in Nigeria. By adopting practices that enhance soil health, farmers can mitigate the impacts of climate change, improve agricultural productivity, and ensure long-term food security. Overcoming the challenges to SSM requires concerted efforts from farmers, researchers, policymakers, and the international community. Through education, financial support, policy reform, and continued research, Nigeria can build a resilient and sustainable agricultural system that benefits both people and the environment.

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PRECISION AGRICULTURE TECHNIQUES: A REVIEW

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ABSTRACT

Precision agriculture (PA) represents a transformative approach to farming that leverages technology to optimize crop and livestock production. This method involves observing and responding to spatial and temporal variability in agricultural fields, with the goal of maximizing productivity while minimizing environmental impact. PA technologies, including GPS, sensors, and unmanned aerial vehicles, enable farmers to collect detailed data on soil conditions, crop health, and environmental factors. These innovations support variable-rate applications of inputs such as fertilizers and pesticides, enhancing efficiency and sustainability. The review highlights how PA has evolved globally, from its origins in the 1980s to its current application in advanced economies like the United States and Europe, as well as its emerging relevance in regions such as Sub-Saharan Africa and Latin America. Despite the clear benefits, adoption remains slow in some areas, including Nigeria, due to technical, economic, and educational barriers. The paper calls for further research and the development of region-specific PA systems and education programs to fully realize its potential in improving agricultural productivity and environmental sustainability.

1. INTRODUCTION

A better understanding of soil and crop conditions variability within fields brought the notion, in the early 1980s that variable management within fields by zones rather than whole fields (Site-Specific Crop Management, SSCM) would increase profitability by doing the right thing at the right place in the right way at the right time (4Rs). This innovative and futuristic concept of SSCM is often referred to by several other buzz words such as “Farming by Soils”, “Prescription Farming”, “Farming by the Foot”, “Farming by Soils, not Fields”, “Environmentally Friendly Production”, and recently, “Precision Agriculture, PA”. At the same time, microcomputers became available and made possible the acquisition, processing, and use of spatial field data as well as the development of a new kind of machinery with computerized controllers and sensors.

Precision agriculture (PA) is a farming management strategy based on observing, measuring and responding to temporal and spatial variability to improve agricultural production sustainability[2]. It is used in both crop and livestock production[3]. Precision agriculture often employs technologies to automate agricultural operations, improving their diagnosis, decision-making or performance[4][5]. The goal of precision agriculture research is to define a decision support system for whole farm management with the goal of optimizing returns on inputs while preserving resources[6][7].

Among these many approaches is a phytogeomorphological approach which ties multi-year crop growth stability/characteristics to topological terrain attributes. The interest in the phytogeomorphological approach stems from the fact that the geomorphology component typically dictates the hydrology of the farm field[8][9].

The practice of precision agriculture has been enabled by the advent of GPS and GNSS. The farmer's and/or researcher's ability to locate their precise position in a field allows for the creation of maps of the spatial variability of as many variables as can be measured (e.g. crop yield, terrain features/topography, organic matter content, moisture levels, nitrogen levels, pH, EC, Mg, K, and others)[10]. Similar data is collected by sensor arrays mounted on GPS-equipped combine harvesters. These arrays consist of real-time sensors that measure everything from chlorophyll levels to plant water status, along with multispectral imagery[11]. This data is used in conjunction with satellite imagery by variable rate technology (VRT) including seeders, sprayers, etc. to optimally distribute resources. However, recent technological advances have enabled the use of real-time sensors directly in soil, which can wirelessly transmit data without the need of human presence[12][13][14].

Precision agriculture has also been enabled by unmanned aerial vehicles that are relatively inexpensive and can be operated by novice pilots. These agricultural drones[15] can be equipped with multispectral or RGB cameras to capture many images of a field that can be stitched together using photogrammetric methods to create orthophotos. These multispectral images contain multiple values per pixel in addition to the traditional red, green blue values such as near infrared and red-edge spectrum values used to process and analyze vegetative indexes such as NDVI maps[16]. These drones are capable of capturing imagery and providing additional geographical references such as elevation, which allows software to perform map algebra functions to build precise topography maps. These topographic maps can be used to correlate crop health with topography, the results of which can be used to optimize crop inputs such as water, fertilizer or chemicals such as herbicides and growth regulators through variable rate applications.

2. HISTORY

Precision agriculture is a key component of the third wave of modern agricultural revolution. The first agricultural revolution was the increase of mechanized agriculture, from 1900 to 1930. Each farmer produced enough food to feed about 26 people during this time[17]. The 1960s prompted the Green Revolution with new methods of genetic modification, which led to each farmer feeding about 156 people[[17]. It is expected that by 2050, the global population will reach about 9.6 billion, and food production must effectively double from current levels in order to feed every mouth. With new technological advancements in the agricultural revolution of precision farming, each farmer will be able to feed 265 people on the same acreage[17].

3. OVERVIEW

The first wave of the precision agricultural revolution came in the forms of satellite and aerial imagery, weather prediction, variable rate fertilizer application, and crop health indicators[18]. The second wave aggregates the machine data for even more precise planting, topographical mapping, and soil data[19].

Precision agriculture aims to optimize field-level management with regard to:

- crop science: by matching farming practices more closely to crop needs (e.g. fertilizer inputs);
- environmental protection: by reducing environmental risks and footprint of farming (e.g. limiting leaching of nitrogen);
- economics: by boosting competitiveness through more efficient practices (e.g. improved management of fertilizer usage and other inputs).

Precision agriculture also provides farmers with a wealth of information to:

- build up a record of their farm
- improve decision-making
- foster greater traceability
- enhance marketing of farm products
- improve lease arrangements and relationship with landlords
- enhance the inherent quality of farm products (e.g. protein level in bread-flour wheat)

3.1 Prescriptive planting

Prescriptive planting is a type of farming system that delivers data-driven planting advice that can determine variable planting rates to accommodate varying conditions across a single field, in order to maximize yield. It has been described as "Big Data on the farm." Monsanto, DuPont and others are launching this technology in the US[20][21].

4. PRINCIPLES

Precision agriculture uses many tools but here are some of the basics: tractors, combines, sprayers, planters, diggers, which are all considered auto-guidance systems. The small devices on the equipment that uses GIS (geographic information system) are what makes precision agriculture what it is. You can think of the GIS system as the “brain.” To be able to use precision agriculture the equipment needs to be wired with the right technology and data systems. More tools include Variable rate technology (VRT), Global positioning system and Geographical information system, Grid sampling, and remote sensors[22].

4.1 Geolocating

Geolocating a field enables the farmer to overlay information gathered from analysis of soils and residual nitrogen, and information on previous crops and soil resistivity. Geolocation is done in two ways

- The field is delineated using an in-vehicle GPS receiver as the farmer drives a tractor around the field.

- The field is delineated on a basemap derived from aerial or satellite imagery. The base images must have the right level of resolution and geometric quality to ensure that geolocation is sufficiently accurate.

4.2 Variables

Intra and inter-field variability may result from a number of factors. These include climatic conditions (hail, drought, rain, etc.), soils (texture, depth, nitrogen levels), cropping practices (no-till farming), weeds and disease. Permanent indicators—chiefly soil indicators—provide farmers with information about the main environmental constants. Point indicators allow them to track a crop's status, i.e., to see whether diseases are developing, if the crop is suffering from water stress, nitrogen stress, or lodging, whether it has been damaged by ice and so on. This information may come from weather stations and other sensors (soil electrical resistivity, detection with the naked eye, satellite imagery, etc.). Soil resistivity measurements combined with soil analysis make it possible to measure moisture content. Soil resistivity is also a relatively simple and cheap measurement[23].

4.3 Strategies

Using soil maps, farmers can pursue two strategies to adjust field inputs:

- Predictive approach: based on analysis of static indicators (soil, resistivity, field history, etc.) during the crop cycle.
- Control approach: information from static indicators is regularly updated during the crop cycle by:

A better understanding of soil and crop conditions variability within fields brought the notion, in the early 1980s that variable management within fields by zones rather than whole fields (Site-Specific Crop Management, SSCM) would increase profitability by doing the right thing at the right place in the right way at the right time (4Rs). This innovative and futuristic concept of SSCM is often referred to by several other buzz words such as "Farming by Soils", "Prescription Farming", "Farming by the Foot", "Farming by Soils, not Fields", "Environmental Friendly Production", and recently, "Precision Agriculture, PA". At the same time, microcomputers became available and made possible the acquisition, processing, and use of spatial field data as well as the development of a new kind of machinery with computerized controllers and sensors.

- sampling: weighing biomass, measuring leaf chlorophyll content, weighing fruit, etc.
- remote sensing: measuring parameters like temperature (air/soil), humidity (air/soil/leaf), wind or stem diameter is possible thanks to Wireless Sensor Networks[24] and Internet of things (IoT)
- proxy-detection: in-vehicle sensors measure leaf status; this requires the farmer to drive around the entire field.

- aerial or satellite remote sensing: multispectral imagery is acquired and processed to derive maps of crop biophysical parameters, including indicators of disease[25]. Airborne instruments are able to measure the amount of plant cover and to distinguish between crops and weeds[26].

Decisions may be based on decision-support models (crop simulation models and recommendation models) based on big data, but in the final analysis it is up to the farmer to decide in terms of business value and impacts on the environment- a role being takenover by artificial intelligence (AI) systems based on machine learning and artificial neural networks.

It is important to realize why PA technology is or is not adopted, "for PA technology adoption to occur the farmer has to perceive the technology as useful and easy to use. It might be insufficient to have positive outside data on the economic benefits of PA technology as perceptions of farmers have to reflect these economic considerations[27].

4.4 Implementing practices

New information and communication technologies make field level crop management more operational and easier to achieve for farmers. Application of crop management decisions calls for agricultural equipment that supports variable-rate technology (VRT), for example varying seed density along with variable-rate application (VRA) of nitrogen and phytosanitary products[28].

Precision agriculture uses technology on agricultural equipment (e.g. tractors, sprayers, harvesters, etc.):

- positioning system (e.g. GPS receivers that use satellite signals to precisely determine a position on the globe);
- geographic information systems (GIS), i.e., software that makes sense of all the available data;
- variable-rate farming equipment (seeder, spreader).

5. USAGE AROUND THE WORLD

The concept of precision agriculture first emerged in the United States in the early 1980s. In 1985, researchers at the University of Minnesota varied lime inputs in crop fields. It was also at this time that the practice of grid sampling appeared (applying a fixed grid of one sample per hectare). Towards the end of the 1980s, this technique was used to derive the first input recommendation maps for fertilizers and pH corrections. The use of yield sensors developed from new technologies, combined with the advent of GPS receivers, has been gaining ground ever since. Today, such systems cover several million hectares.

In the American Midwest (US), it is associated not with sustainable agriculture but with mainstream farmers who are trying to maximize profits by spending money only in areas that require fertilizer. This practice allows the farmer to vary the rate of fertilizer across the field according to the need identified by GPS guided Grid or Zone Sampling. Fertilizer that would have been spread in areas that don't need it can be placed in areas that do, thereby optimizing its use.

Around the world, precision agriculture developed at a varying pace. Precursor nations were the United States, Canada and Australia. In Europe, the United Kingdom was the first to go down this path, followed closely by France, where it first appeared in 1997–1998. In Latin America the leading country is Argentina, where it was introduced in the middle 1990s with the support of the National Agricultural Technology Institute. Brazil established a state-owned enterprise, Embrapa, to research and develop sustainable agriculture. The development of GPS and variable-rate spreading techniques helped to anchor precision farming[29] management practices. Today, less than 10% of France's farmers are equipped with variable-rate systems. Uptake of GPS is more widespread, but this hasn't stopped them using precision agriculture services, which supplies field-level recommendation maps[30].

While digital technologies can transform the landscape of agricultural machinery, making mechanization both more precise and more accessible, non-mechanized production is still dominant in many low- and middle-income countries, especially in sub-Saharan Africa[4][5]. Research on precision agriculture for non-mechanized production is increasing and so is its adoption[31][32][33]. Examples include the AgroCares hand-held soil scanner, uncrewed aerial vehicle (UAV) services (also known as drones), and GNSS to map field boundaries and establish land tenure[34]. However, it is not clear how many agricultural producers actually use digital technologies[34][35].

Precision livestock farming supports farmers in real-time by continuously monitoring and controlling animal productivity, environmental impacts, and health and welfare parameters[36]. Sensors attached to animals or to barn equipment operate climate control and monitor animals' health status, movement and needs. For example, cows can be tagged with the electronic identification (EID) that allows a milking robot to access a database of udder coordinates for specific cows[37]. Global automatic milking system sales have increased over recent years[38], but adoption is likely mostly in Northern Europe[39], and likely almost absent in low- and middle-income countries[40]. Automated feeding machines for both cows and poultry also exist, but data and evidence regarding their adoption trends and drivers is likewise scarce[4][5].

The economic and environmental benefits of precision agriculture have also been confirmed in China, but China is lagging behind countries such as Europe and the United States because the Chinese agricultural system is characterized by small-scale family-run farms, which makes the adoption rate of precision agriculture lower than other countries. Therefore, China is trying to better introduce precision agriculture technology into its own country and reduce some risks, paving the way for China's technology to develop precision agriculture in the future[41].

In December 2014, the Russian President made an address to the Russian Parliament where he called for a National Technology Initiative (NTI). It is divided into subcomponents such as the FoodNet initiative. The FoodNet initiative contains a set of declared priorities, such as precision agriculture. This field is of special interest to Russia as an important tool in developing elements of the bioeconomy in Russia[42][43].

6. ECONOMIC AND ENVIRONMENTAL IMPACTS

Precision agriculture, as the name implies, means application of precise and correct amount of inputs like water, fertilizer, pesticides etc. at the correct time to the crop for increasing its productivity and maximizing its yields. Precision agriculture management practices can significantly reduce the amount of nutrient and other crop inputs used while boosting yields[44]. Farmers thus obtain a return on their investment by saving on water, pesticide, and fertilizer costs.

The second, larger-scale benefit of targeting inputs concerns environmental impacts. Applying the right amount of chemicals in the right place and at the right time benefits crops, soils and groundwater, and thus the entire crop cycle[45] . Consequently, precision agriculture has become a cornerstone of sustainable agriculture, since it respects crops, soils and farmers. Sustainable agriculture seeks to assure a continued supply of food within the ecological, economic and social limits required to sustain production in the long term.

A 2013 article tried to show that precision agriculture can help farmers in developing countries like India[46].

Precision agriculture reduces the pressure of agriculture on the environment by increasing the efficiency of machinery and putting it into use. For example, the use of remote management devices such as GPS reduces fuel consumption for agriculture, while variable rate application of nutrients or pesticides can potentially reduce the use of these inputs, thereby saving costs and reducing harmful runoff into the waterways[47].

GPS also reduces the amount of compaction to the ground by following previously made guidance lines. This will also allow for less time in the field and reduce the environmental impact of the equipment and chemicals.

Precision agriculture produces large quantities of varied sensing data which creates an opportunity to adapt and reuse such data for archaeology and heritage work, enhancing understanding of archaeology in contemporary agricultural landscapes[48].

7. EMERGING TECHNOLOGIES

Precision agriculture is an application of breakthrough digital farming technologies. Over $4.6 billion has been invested in agriculture tech companies—sometimes called agtech[17].

7.1 Robots

Self-steering tractors have existed for some time now, as John Deere equipment works like a plane on autopilot. The tractor does most of the work, with the farmer stepping in for emergencies[45]. Technology is advancing towards driverless machinery programmed by GPS to spread fertilizer or plow land. Autonomy of technology is driven by the demanding need of diagnoses, often difficult to accomplish solely by hands-on farmer-operated machinery. In many instances of high rates of production, manual adjustments cannot sustain[49]. Other innovations include, partly solar powered, machines/robots that identify weeds and precisely kill them with a dose of a herbicide or lasers[45][50][51].

Agricultural robots, also known as AgBots, already exist, but advanced harvesting robots are being developed to identify ripe fruits, adjust to their shape and size, and carefully pluck them from branches[52].

7.1.1 Drones and satellite imagery

Drone and satellite technology are used in precision farming. This often occurs when drones take high quality images while satellites capture the bigger picture. Aerial photography from light aircraft can be combined with data from satellite records to predict future yields based on the current level of field biomass. Aggregated images can create contour maps to track where water flows, determine variable-rate seeding, and create yield maps of areas that were more or less productive[45].

7.1.2 The Internet of things

The Internet of things is the network of physical objects outfitted with electronics that enable data collection and aggregation. IoT comes into play with the development of sensors[53] and farm-management software. For example, farmers can spectroscopically measure nitrogen, phosphorus, and potassium in liquid manure, which is notoriously inconsistent[45]. They can then scan the ground to see where cows have already urinated and apply fertilizer to only the spots that need it. This cuts fertilizer use by up to 30%[52]. Moisture sensors[54] in the soil determine the best times to remotely water plants. The irrigation systems can be programmed to switch which side of tree trunk they water based on the plant's need and rainfall[45].

Innovations are not just limited to plants—they can be used for the welfare of animals. Cattle can be outfitted with internal sensors to keep track of stomach acidity and digestive problems. External sensors track movement patterns to determine the cow's health and fitness, sense physical injuries, and identify the optimal times for breeding[45]. All this data from sensors can be aggregated and analyzed to detect trends and patterns.

As another example, monitoring technology can be used to make beekeeping more efficient. Honeybees are of significant economic value and provide a vital service to agriculture by pollinating a variety of crops. Monitoring of a honeybee colony's health via wireless temperature, humidity and CO2 sensors helps to improve the productivity of bees, and to read early warnings in the data that might threaten the very survival of an entire hive[55].

7.2 Smartphone applications

A possible configuration of a smartphone-integrated precision agriculture system

Smartphone and tablet applications are becoming increasingly popular in precision agriculture. Smartphones come with many useful applications already installed, including the camera, microphone, GPS, and accelerometer. There are also applications made dedicated to various agriculture applications such as field mapping, tracking animals, obtaining weather and crop information, and more. They are easily portable, affordable, and have high computing power[56].

7.3 Machine learning

Machine learning is commonly used in conjunction with drones, robots, and internet of things devices. It allows for the input of data from each of these sources. The computer then processes this information and sends the appropriate actions back to these devices. This allows for robots to deliver the perfect amount of fertilizer or for IoT devices to provide the perfect quantity of water directly to the soil[57]. Machine learning may also provide predictions to farmers at the point of need, such as the contents of plant-available nitrogen in soil, to guide fertilization planning[58]. As more agriculture becomes ever more digital, machine learning will underpin efficient and precise farming with less manual labour.

8. PRECISION AGRICULTURE IN NIGERIA

I have used the preceding paragraphs to attempt to introduce a research area that has been around for upwards of four decades in many parts of the world. But as usual, Nigeria is only waiting for results. A few Nigerian agricultural engineers have, however, attempted to bring PA research to the front burner (Yisa, 2000; Alonge, 2009 and Yisa, 2014). Our farmers continue to practice the old systems of input application of constant rate across the field causing severe and consistent damage not only to the environment, but also to human health. The present research is to characterize the Nigerian agriculture soils towards effective application and management of precision agriculture. In order to achieve this aim, the following specific objectives will be addressed;

1. Conduct a comprehensive fertility mapping of Nigeria
2. Develop sensors for soil characterization, yield mapping of common crops in Nigeria, weed mapping of crops,etc
3. Develop agricultural machinery for variable rate application.
4. Use (1), (2) and (3) above to recommend appropriate PA for different regions of the country
5. Plan an education programme for PA (workshops, lectures and seminars)

9. CONCLUSION

Much research and development are in progress in Universities, government agencies and industries across the world on precision Agriculture, but Nigeria. There are still important needs in engineering technology, management, understanding of natural condition variability, profitability, environmental protection, technology transfer.

Most frequent research needs are classified and ranked as;

1. Development of real-time sensors for soil and plant characterization
2. Remote sensing techniques for soil and crop condition detection, and management
3. Quantification of PA impacts on the environment
4. Development of protocols for sampling procedures
5. Economics of PA
6. Quantification of spatial and temporal natural resources variability
7. Development of practical crop models for PA management
8. Development of improved spatial data analysis methods
9. Methodologies for developing soil and crop site-specific prescriptions
10. Development of educational programmes

    Etc.

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CLIMATE CHANGE RESILIENCE AND SUSTAINABILITY: THE WATER CONSERVATION AND IRRIGATION MANAGEMENT NEXUS*

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ABSTRACT

Climate change presents significant challenges to agriculture and the environment in Nigeria, with impacts such as reduced crop yields, increased floods, droughts, and environmental degradation. This paper explores the nexus between water conservation and irrigation management as crucial elements in building resilience and ensuring sustainability in the face of climate change. It reviews mitigation and adaptation strategies, emphasizing climate-smart agriculture, ecosystem management, and crosscutting approaches that enhance agricultural resilience. Practical interventions such as conservation tillage, mulching, and agroforestry are evaluated for their effectiveness in improving water use efficiency and mitigating the adverse effects of climate change. The study highlights the need for integrated approaches that combine both natural resource-based and civil-engineering strategies to address climate vulnerabilities in Nigeria's agricultural sector. The paper concludes by advocating for strong policy frameworks, capacity building, and international cooperation to bolster climate resilience and sustainable livelihoods.

KEYWORDS: Climate change resilience, sustainability, water conservation, irrigation management, climate-smart agriculture, ecosystem management, Nigeria, soil and water conservation

1. BACKGROUND

Climate change or global warming is a long-term natural or anthropogenic phenomenon that bring about changes in average air temperatures near the surface of the earth (Mann, 2024), due to the emission and accumulation of Green House Gases, GHG, in the atmosphere. The emissions continue to increase over time, as a result of the unsustainable land use practices and other human activities. (Mann, 2024). While climate change is a global issue, it is felt on a local scale (NASA, 2024), and that every region in the world is projected to face further increases in climate hazards (IPCC, 2023).

Adegoke, *et al* (2015) observed that Nigeria have already experienced the impact of climate change. These impacts include accentuated droughts, severe floods and increased occurrence and intensity of storm surges, with concomitant flooding, coastal erosion, the salinization of fresh water aquifers, and variability in the availability of fisheries resources, and that without any adaptive measures, climate change could cause losses of between 6% to 30 % of Nigeria's GDP by 2050.

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2. IMPACTS AND VULNERABILITIES DUE TO CLIMATE CHANGE

The climate change phenomenon has led to widespread adverse impacts and related losses and damages to nature and people. The impacts and vulnerabilities associated with global climate change are generally linked to the agricultural, environmental, and socioeconomic sectors.

Impacts on Agriculture

Agriculture is the most vulnerable to temperature and variable rainfall patterns. In Nigeria, climate change poses a severe threat to agriculture through reduced crops yields and livestock productivity. Dependence on rain-fed agricultural practices has exacerbated water stress and yield decreases leading to food insecurity. A study published in the journal of Environmental Research Letters found that maize production in Nigeria could decline by 20 % by 2050 due to climate change. Similarly, rice production may drop by 15% if current trends continue. In the same vein, livestock productivity is also at risk, as higher temperature and reduced water availability affect pasture quality and animal health. The food and Agriculture Organization, FAO, reports that livestock productivity in Nigeria could decline by 30% in the coming decades due to climate stress.

Impact on Environment

On the other hand, more intense rainfall may bring about the incidence of erosion and floods leading to the destruction of livelihoods, farms and farm infrastructures. The 2022 floods in Nigeria affected many parts of the country, rendered over 1.4 million people homeless, killed over 603 people, and injured more than 2,400 persons. About 82,035 houses had been damaged, and 332,327 hectares of land had also been affected. Oguntola, (2022).

People walk through floodwaters after heavy rainfall in Hadeja, Nigeria, Monday, Sept 19, 2022. -

In a recent study on the impact of flood, recovery and mitigation assessment in Nigeria, NBS in collaboration with NEMA and the UNDP (2023), identified key mitigation strategies including the Development of a flood management scheme involving comprehensive risk assessment and analysis to identify vulnerabilities, exposure and elements at risk and an Early Warning Systems coupled with Community Engagement and Education. Other strategies recommended included designing and building of critical Infrastructure to withstand potential floods disasters, Land Use Planning and Ecosystem Conservation as well as the mainstreaming flood risk management into policy, budgeting, investment and development decisions.

The impact of climate change on the environment is manifested in form of agricultural droughts, land degradation, poor ecosystem biodiversity and reduced water resources availability.

Climate induced land degradation as a result of deforestation and bush burning/forest fires has brought about ecological droughts and desertification. Nigeria is faced with rapid desert encroachment affecting fifteen northernmost states from moderate to severe rate. Out of the 909,890 km^2 of the country's land area, about 580,841 km^2 accounting for 63.83% of total land is impinged on by desertification, Olagunju (2015).

Environmental degradation is responsible for rural-urban migration and movement of herders to the southern parts of the country. This rural-urban migration contributes to the rapid urbanization of cities, leading to overcrowding, inadequate infrastructure, and increased poverty levels.

Impact on public health

One of the reported impacts of climate change is on pubic health. Changing temperatures and rainfall patterns have created conducive environments for vector-borne diseases such as malaria. The World Health Organization, WHO, has reported an increase in malaria incidence in Nigeria, partly attributed to climate variability. Similarly, the Nigeria Institute of Medical Research indicates that heatwaves could increase mortality rates by up to 10% in major cities like Lagos and Kano.

Impact on Water Resources

Changes in precipitation patterns has tremendous impact on water resources availability. Nigeria is vastly endowed with surface and ground water resources, but is under immense pressure. The USAID Sustainable Water Partnership reports that Nigeria's freshwater resources stands at about 286,200 million m^3 per year. Nigeria's 2013 National Water Resources Master plan also projects that total surface water demand of 12,470 million m^3 per year will more than triple by 2030. More than half of all freshwater abstractions are from groundwater, mostly for irrigation and domestic use. Groundwater levels in northern and northeastern Nigeria are declining from over-abstraction and insufficient recharge attributed to urbanization and wetland degradation.

Available water resources support agricultural domestic and industrial activities. climate change may affect its availability due to changes in rainfall patterns leading drought or flood and rising temperature which increases the demand.

Socioeconomic impacts

The socioeconomic impacts of climate change in Nigeria is more severe in rural communities that rely on agriculture. The impacts on agriculture has affected livelihoods, food security, and economic stability of these communities. The Nigerian Bureau of Statistics(NBS) reports that poverty rates in Nigeria are highest in rural areas, with over 70% of the rural population living below the poverty line. Climate change exacerbates this poverty by reducing agricultural productivity and increasing the cost of living.

The impacts of the changes in temperature and rainfall pattern are further complicated by the ecosystem variability across the country. Nigeria has seven distinct agro-ecological zones from the Sahel in the extreme north to the rain forest in the south. Each zone is impacted differently by climate change, thus making the country’s vulnerability more complex.

UNDP (2006) further reports that these impacts are further compounded by poverty, illiteracy and lack of skills, weak institutions, limited infrastructure, lack of technology and information, low levels of primary education and health care, poor access to resources, low management capabilities and armed conflicts. The over-exploitation of land resources including forest, increases in population, desertification and land degradation pose additional threats.

3. CLIMATE CHANGE MITIGATION AND ADAPTATION OPTIONS

In order to reduce these vulnerabilities or avoid the impacts of climate change, a combination of strategic mitigation and adaptation options must be methodically and systematically implemented.

Climate change ***mitigation*** refers to any action taken to reduce rise by preventing the emission or removal of greenhouse gases, from the atmosphere while adaptation refers to a wide range of measures to reduce vulnerability to climate change impacts, UNDP (2024).

Mitigating temperature rise can be achieved by regulating the earth’s energy balance through the large scale manipulation of a specific process central to controlling earth’s climate (Boyd, 2024) or switching to renewable sources of energy (such as solar and wind energy), reduction in the use of fossil fuels (such as use of electrically driven vehicles and industrial machines), use energy efficient appliances; carbon capture and storage (tree planting and adoption of climate smart agricultural practices, Herring, (2020). The Nigerian government has set a target to increase the share of renewable energy in the national energy mix to 30% by 2030. Initiatives such the Nigeria Electrification Project aim to provide off-grid solar solutions to rural communities, improving access to clean energy.

The mitigation of green house gas emissions through advanced geoengineering techniques such as ocean fertilization, increasing surface reflectivity, altering the amount or characteristics of clouds or carbon capture such as carbon burial, biochar production and carbon sequestration (long term storage of carbon in plants, soils, geologic formations and oceans), though relatively new, are gaining attention among researchers.

On the other hand, climate change adaptation strategies employ the natural-resource-based or structural or civil-works-based techniques to reduce vulnerability to the impact on livelihoods. The natural resources based strategies cover areas in the agricultural production practices including conservation tillage systems, sustainable land and water resources management practices etc. In the same vein, the civil-works-based techniques involve the use of engineering or vegetative structures to control erosion, conserve soil moisture and improve on water resources availability.

Building climate change resilience and sustainability requires the integration of strategic mitigation and adaptation on approaches. The IPCC has identified key barriers to mitigation and adaptation that included limited resources, lack of private sector and citizen engagement, insufficient mobilization of finance (including for research), low climate literacy, lack of political commitment, limited research and/or slow uptake of adaptation science, and low sense of urgency.

4. BUILDING RESILIENCE AND SUSTAINABILITY

Climate change resilience and sustainability connote the capacity of an individual, a community, region, nation or systems to beneficially adjust, cope, modify, moderate, respond, ameliorate or recover from any existing or anticipated negative climate change impact, without jeopardizing future benefits. Nigeria's vulnerabilities to climate change are aggravated by its reliance on subsistence agriculture, diverse agro-climatic zones across the nation which pose varying challenges, inconsistent policy development and implementation, low awareness of the impact of climate change on the environment, inadequate climate change related innovations and infrastructures etc.

The agricultural sector is one of the sectors that is most affected by climate change. Fortunately, it has the capacity to provide maximum benefits from a variety of climate mitigation and adaptation options. Adegoke, et al (2015), opined that resilient agriculture creates agricultural growth out of knowledge, investment and innovation, while simultaneously building the capacity of farmers, particularly smallholder farmers to counter environmental degradation and climate change. Promoting climate-smart agriculture and sustainable land use and management are crucial for enhancing food security and building resilience to climate change.

Ecosystem-based adaptation approaches such as reforestation, afforestation, urban greening, sustainable land and water resources management are pertinent in building climate change resilience and sustainability.

Other crosscutting adaptation and mitigation options such as weather forecasting and early warning systems, disaster risk management, climate services and social safety nets have broad applicability across multiple sectors. IPCC, 2023.

5. WATER CONSERVATION AND CLIMATE RESILENCE AND SUSTAINABILITY

Resilience to climate change through water conservation aims at improving water use efficiency by either increasing supply or reducing demand. Agricultural production utilizes the interplay between tillage systems and soil and water resources management and conservation. Climate change alters these interactions either negatively or positively. Reduction in water availability results in ecological droughts, with negative consequences on crop yields. Heavy precipitation could lead to floods that destroy farms and farm infrastructure. Land use changes due agricultural expansion and deforestation promote soil erosion and loss of productivity. Studies have shown that climate change can increase potential erosion rates, which can lower agricultural productivity by 10% to 20% Ravi, et al. (2013).

A variety of water conservation strategies are available to reverse the impacts of climate change. These strategies border on the adoption of climate smart agriculture, sustainable land and water resources management at watershed, river basin and national levels. Evaluate Climate-smart agriculture (CSA) (or climate resilient agriculture) is a set of agricultural practices and technologies which simultaneously boost productivity, enhance resilience and reduce GHG emissions. World Bank (2024). At the field or farm level, the objective is to make soil moisture available for crop growth and development. Adapting *Conservation tillage,* a technique that entails preparing the land with the presence of residue mulch or *zero-tillage* where mechanical seedbed preparation is eliminated, conserves soil and water for increased crop yield and reduces carbon dioxide emissions by minimizing tractor use, with enhanced soil organic carbon sequestration.

Mulching - a layer of any material placed over the soil surface as cover against the impact of atmospheric elements. The material can be residues from the previous crop, brought-in grasses, perennial shrubs or other inorganic materials and synthetic products. Mulching reduces soil loss and enhances soil productivity and crop yields and can be easily integrated into the existing farming systems of smallholders. The effectiveness of mulches can adversely be reduced by bush fire, termites or removal from the field for alternate uses as fodder, firewood, or construction material.

Crop management strategies such as cover cropping, multiple cropping and high density planting improves the physical, chemical, and biological soil properties. Multiple and high density cropping act as insurance to crop failure, though intensive growth of several cover crop species might result in competition with food crops for growth factors.

At the farm level, the structural or civil-works-based soil and water conservation techniques utilized the construction of bunds, terraces, waterways, and other structures to slow down runoff.

Agroforestry, a form of land use system in which woody perennials are integrated with crops and/or animals on the same land management unit creates more diverse, productive, profitable, healthy and sustainable land-use systems with great potential to help reduce climate change.

In addition to increasing water supply as a conservation measure, reducing demand is also plays a ley role. The techniques and methods associated with this approach can be adapted the farm level, regional or national levels. At the field or farm level, crop selection and changes in crop calendars and cropping patterns will help farmers adapt to new temperatures and rainfall variability. Crops with short growing periods are preferred in areas experiencing dry spells. It is preferable to use crop varieties that are more resilient to dry spells (Ziadat, 2024), early maturing and disease resistant.

Controlled Environment Agriculture (CEA), hydroponics or green house techniques are promising solutions for mitigating the adverse impacts of climate change on agricultural production, Howden et al., (2007). CEA can also contribute to climate change adaptation by optimizing resource utilization, minimize carbon footprint, minimizing land requirements and reducing the need for pesticides and herbicides, Omoniyi et al., (2014).

At the Regional or national levels, water resources can be conserved trough an integrated approach to watershed management involving the sustainable use of all the land, vegetation, water resources of a watershed, river basin. Avoiding land management practices that degrade soils such as some conventional tillage-based crop production systems; improper application of fertilizers, overstocking, overgrazing and burning of range lands; inefficient grazing methods; and the over-exploitation or clearance of wooded and forest lands.

Proper hydrologic monitoring and improved weather forecasting would enable the efficient management of the incidence of floods and/or droughts. Similarly, controlling runoff and floods would enhance groundwater recharge, Grassland or pasture farming enhance the rehabilitation of degraded lands.

Structural or civil-works-based soil and water conservation techniques utilize the construction of structures to slow down or impound runoff, encourage infiltration and storage of water. The approaches depend upon manipulating the surface topography of the land as well as the installation and maintenance is usually labour-intensive bunds and terraces.

The building of some engineering infrastructure for gully erosion control, flood water diversions, ponds, reservoirs, embankments even dams contribute immensely to the conservation of water resources in a given region. These structures however, are largely ineffective on their own because they cannot prevent detachment of soil particles, but supplement the agronomic measures.

6. IRRIGATION MANAGEMENT FOR RESILIENCE AND SUSTAINABILITY

Irrigation - the artificial supply of water fro crop production; it is on the increase world wide. In Nigeria, the Federal Ministry of Water Resources (FMWR) estimated a total irrigation potential of about 3.14 million ha made up of 1.10 million ha for public large-scale irrigation projects and 2.04 million ha of formal irrigation projects operated by ADPs in the States. The RBDAs have planned to irrigate an area of 320,000ha out of which only about 70,000ha, have downstream irrigation facilities of which only 50,000ha are actually cultivated. An estimated area of 186,000ha is put under cultivation by the small farmer-owned and managed irrigation (*Fadama*). Less than 0.5% of the 72 million ha available agricultural land is under irrigation.

The largest single consumer of water is agriculture (Kipkorir, 2017), with irrigation accounting for 85 - 90%, Rosa, (2022). Water is lost as it is distributed to farmers and applied to crops. Thus, even modest improvements in agricultural efficiency could free up large quantities of water. Kipkorir (2017) enumerated the possible interventions aimed at preventing, mitigating, or reversing soil and water degradation at various levels within irrigated agriculture in Table 1.

Table 1. Possible interventions for mitigating soil and water degradation in irrigation systems
Source: Kipkorir (2017)

Policy Interventions	Engineering interventions
1. Introduce water and power pricing that better represents the market value of water; 2. Introduce transferable water entitlements; 3. Set limits for allowable groundwater recharge (amount and quality) and introduce penalties for exceeding these limits; 4. Provide incentives for land reclamation; 5. Require exhaustive environmental impact assessment for new irrigation projects; and 6. Provide incentives for monitoring and reduction of the environmental impact of existing irrigation projects.	1. Incorporate environmental impact considerations in the design, construction, and operation of new irrigation projects; 2. Improve maintenance of irrigation infrastructure; 3. Construct drainage facilities; 4. Improve maintenance of existing drains; 5. Reuse waste and drain water, and find alternative ways to dispose drainage effluent; and 6. Prevent or reduce canal seepage, i.e., through lining.
System management interventions	Irrigation/agronomic practices interventions
1. Improve the operation of existing irrigation and drainage infrastructure through introduction of management information systems, etc; 2. Enhance farmers' involvement in management and maintenance of irrigation and drainage facilities; and 3. Evaluate the feasibility of implementing on-demand water delivery to farms.	1. Minimize water losses in the on-farm distribution system; 2. Improve irrigation systems performance to minimize deep percolation and surface runoff; 3. On-farm watercourse improvement and precision land leveling; 4. Implement more efficient irrigation methods (e.g. drip instead of surface irrigation); 5. Minimize sediment concentration in runoff water; 6. Grow different crops or introduce different crop rotations (i.e., less-water demanding crops, more drought- and salt-tolerant crops); 7. Irrigate according to reliable crop water requirement estimates and leaching requirement calculations; 8. Manage fertilizer programs so as to minimize nutrients available for detachment and transport; and 9. Apply soil amendments and reclamation practices

Table 1 provides several policy and system management options coupled with diverse engineering and irrigation agronomic interventions that if appropriately chosen and applied would act as a catalyst to achieving sustainable irrigation. The irrigation sub-sector has the potential to reduce the effect of rainfall variability and other extreme weather events, thereby enhancing community resilience to climate change. (Musa, 2023).

Proper management of irrigation has the potential to boost agricultural production, reduce water pollution through wastewater re-use, mitigate the impacts of flood, drought, and desertification, thereby building climate resilience and sustainability. Adapting supplementary or deficit irrigation as a management option has the capacity to mitigate the impacts of rainfall variability, irrigating marginal lands for pasture or at critical crop growth stages, thereby boosting productivity, reduce poverty and improve food security.

Field irrigation management strategies that fortuitously contribute to climate adaptation and building resilience include the improvement of the capacity of the soil to store more water through on-farm water harvesting, enhancement of the soil moisture holding capacity using sustainable water conservation options. (Ziadat, 2024). Managing irrigation systems for improved water use efficiency at the field and project level reduces irrigation water demand, thus promoting resilience and sustainability.

7. THE WAY FORWARD

Recipe for success in mainstreaming the mitigation and adaptation strategies to address the negative impacts of climate change is to focus on resilience building. Governments at all levels must initiate, develop and provide conducive environment for implementation of relevant policies and programmes at the community, regional and national levels. Policies such as the National Digital Agricultural Strategy, National Agricultural Resilience Framework and the Nationally Determined Contributions and the Nigeria National Climate Change Policy aim to reduce greenhouse gas emissions, enhance energy efficiency and promote renewable energy sources. The country is committed to achieving a 20% reduction in emissions by 2030, as outlined in its Nationally Determined Contributions (NDCs) under the Paris Agreement.

Policies and programmes in the area of Climate Smart Agriculture has the greatest potential to bring about the building of resilience and sustainability. Thus, policies such as the National Policy on Water Resources, National Agriculture Policy, the Nigeria Erosion and Watershed Management Project. NEWMAP and the Agro-Climatic Resilience in Semi-Arid Landscapes, ACReSAL are typical multi-sector policies and projects that will help states and the federal government implement sustainable dry land management solutions, erosion control, afforestation, dune stabilization, and water storage. It will also support adaptation of agriculture and natural resources management practices at the community level to strengthen the climate resilience of rural communities. it will also support the establishment of capacities for national and state dry lands management programmes. World Bank (2021).

Developing the requisite synergies between strong research institutions, private sector organizations and professional bodies would scale up the creation and management of knowledge and inculcate the right skills and attitudes towards climate change issues through advocacy.

The need for international cooperation and support in water conservation and irrigation management are essential for Nigeria to navigate the complexities of climate change and secure a sustainable future for its people. Regional bodies such as Lake Chad Basin Commission, Niger Basin Authority and development Partners such as the World Bank, UNDP and FAO can tremendously contribute in the area of policy advocacy, technical, financial and institutional support.

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AGRO-ECOLOGICAL PRINCIPLES IN TILLAGE SYSTEMS

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ABSTRACT
This paper discusses the application of agro-ecological principles in tillage systems, focusing on sustainable agricultural practices that balance productivity, environmental conservation, and climate resilience. Agro-ecology integrates ecological processes with farming, enhancing soil health, biodiversity, and water management while reducing dependency on chemical inputs and heavy machinery. It emphasizes minimal soil disturbance, organic matter enhancement, crop diversity, and the integration of natural processes to create resilient agroecosystems. The adoption of agro-ecological practices in various countries has demonstrated improvements in soil fertility, crop yields, and environmental sustainability. In Nigeria and across West Africa, these practices offer significant potential to mitigate the impacts of climate change, reduce soil degradation, and improve food security. The study explores global and local case studies of agro-ecological tillage systems, highlighting their economic, environmental, and social benefits. Challenges such as weed management, knowledge gaps, and policy barriers are addressed, emphasizing the need for capacity building and supportive policies for widespread adoption.

KEYWORDS: Agro-ecology, Tillage systems, Soil health, Climate resilience, Sustainable agriculture, Crop diversity, Natural processes, Nigeria, Soil conservation.

1. INTRODUCTION

It gives me a great pleasure and a rare privilege to stand before this august assembly of erudite scholars, captains of industry and respected professionals in Agricultural Engineering to present a Lead Paper. I thank the organisers of this Symposium for their thoughtfulness in selecting such a relevant topic and for considering me worthy of this honour to address you. I fully intend to utilize the opportunity to share my thoughts on a number of contemporary issues that I hope will stimulate further insightful discussions, public policy intervention and corporate action for an overall meaningful and positive impact on our economy. The theme of ISTRO-NIGERIA 2024 Symposium on Resilience and Sustainability of Tillage Systems in Nigeria: Mitigating and Adapting to Climate Change is apt and timely at this period of our collective drive to advance as a nation and uplift the living standards of our people.

Tillage systems that improve soil quality are needed to maintain agricultural productivity. An important soil management is the proper amount and type of tillage system in use by the farmer, because the potential for erosion either by water or wind of a specific soil type depends largely on soil types, and the number and types of tillage operations. Conventional tillage methods often lead to soil degradation, loss of biodiversity, increased greenhouse gas emissions, and reduced soil fertility (Yusuf et al., 2001; Yusuf 2006). In response to these challenges, agro-ecological approaches to tillage systems have emerged as a promising alternative. Agroecology promotes sustainable interactions between plants, animals, humans, and the environment, emphasizing the importance of ecological processes in agricultural production. Applying agro-ecological principles to tillage systems aims to mitigate environmental impacts while enhancing farm productivity and resilience. Ladies and gentlemen, the global economic meltdown and mounting unemployment necessitate the adoption of appropriate strategies. This is to stimulate economic growth and develop human capital especially in the area of agricultural sector, and address the national problem of inadequate utilization of agro-ecological principles in tillage systems and achieve global competitiveness.

2 AGRO-ECOLOGICAL PRINCIPLES

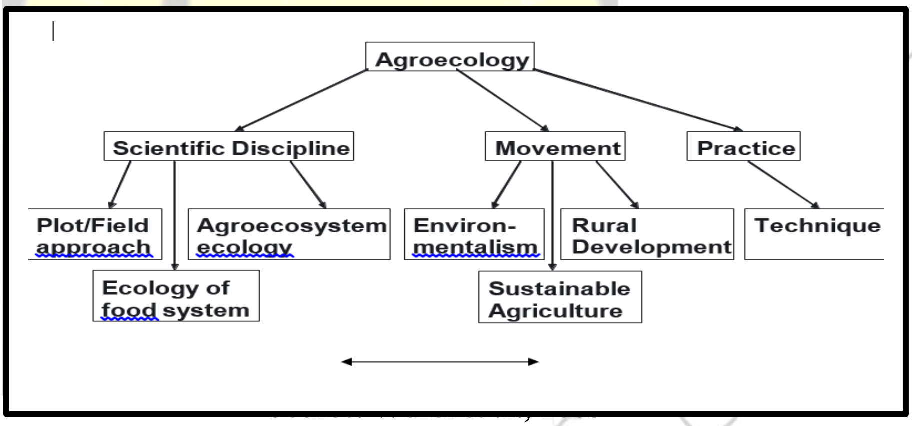
Food security is important and Nigeria has immense agricultural potential. The world's population is expected to grow to almost 10 billion by 2050, boosting agricultural demand (FAO, 2017) and according to the population division of the United Nations Department of Economic and Social Affairs in 2024, the total population of Nigeria is 229,277,728. With Nigeria's population growing at more than 3% a year, by 2050, Nigeria is forecast to have 400m people (United Nations Population Estimates (2019) meaning it will overtake the United States as the world's third-most – populous country (Table 1) with intensified pressure on arable land, leading to its overuse, and the cultivation of onto marginal lands. Food production must necessarily keep pace with population growth. Ensuring the access of peasants to land, seeds, water, credit and local markets through the creation of supportive economic policies, financial incentives, and market opportunities; as well as the scaling up of agro-ecological technologies is crucial since over 80% of the population, especially living in rural areas, derive their livelihoods mainly from agricultural related activities. To stimulate economic growth and launching the Nigeria onto a path of sustained and rapid socio-economic development, and industrialization, an agricultural revolution through the concept of nature - inclusive agriculture (NIA) should be the catalyst.

Table 1: Total population (in thousands) of the 5 most populous countries in 2050.

Rank	Country	Region	2050	2075	2100
1	India	Central and Southern Asia	1 639 176	1 609 041	1 450 421
2	China	Eastern Asia	1 402 405	1 221 580	1 064 993
3	Nigeria	Western Africa	401 315	586 203	732 942
4	United States of America	Northern America	379 419	409 993	433 854
5	Pakistan	Central and Southern Asia	338 013	394 265	403 103

Source: United Nations Population Estimates (2019).

Agroecology is the application of ecological concepts and principals in farming. It utilizes the natural interactions between plants, animals, humans and the environment to support sustainable food production, whilst restoring ecosystem services and building resilience to climate change. Agroecology targets the diversification in agricultural approaches, offering great potential to support the sustainability of the transition of agriculture towards prosperity as shown by Wezel et al.,(2009). Agroecology is deeply rooted in the ecological rationale of traditional small-scale agriculture, characterized by diversity of domesticated crop and animal species maintained (Fig. 1). Concerning agroecology as a scientific discipline. Gliessman (2007) noted that through the 1960s and 1970s, there was a gradual increase in applying ecology to agriculture, partially in response to the Green Revolution that created greater intensification and specialization. An important influence is also derived from research on traditional farming systems in tropical and subtropical developing countries (Janzen, 1973). When designed and managed with agro-ecological principles, farming systems will have the potential to address diversity, resilience, productivity, and ensures efficient use of resources through recycling, biodiversity, and fosters the multi-functionality of farming such as its nutritional, economic,



social, and cultural role. In addition, soil and water conservation practices, use of animal manure, and biocontrol methods to mitigate chemical pesticide use are encouraged.

Gliessman (2007) identified five different levels in agro-ecological transitions and FAO (2018) presented a broader, more principles-based approach, prioritizing democratic methods of governance and knowledge exchange, economic diversification and solidarity relations, and respect for diverse cultures and traditions (Fig .2). HLPE (2019) noted that agroecology can provide possible transition pathways towards more sustainable farming and food systems. A consolidated set of 13 principles on agroecology as manifest as a science, a set of practices and a social movement (HLPE, 2019) were found to be well aligned and complementary to the 10 elements of agroecology developed by FAO (2018). The left hand side shows the transitions, but the right hand side shows the consolidated set of 13 agro-ecological principles with the 10 elements of agro-ecological principles. The agro-ecological principles 1-7at the lower right hand side relate to ally with agroecosystem scale but 9-13 at the upper right hand side connect with the food system. The process allows the small holder farmers to have access to farm inputs through effective economic policies and financial assistance.

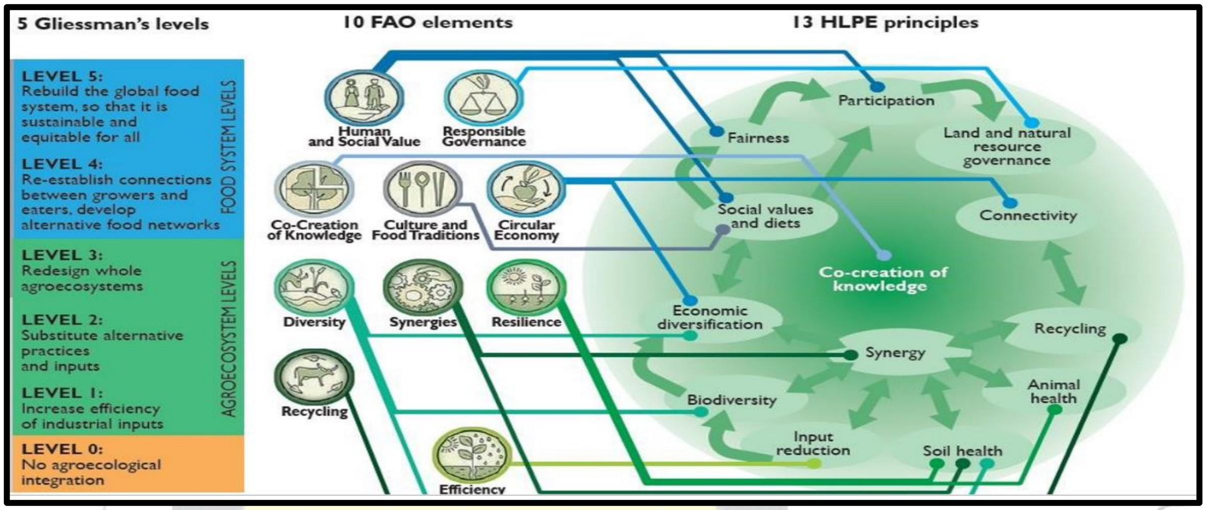


Figure 2: Linking FAO's 10 elements, Gliesmann's 5 levels of food system transformation and the 13 HLPE principles (Atta-Krah et al., 2021)

3 AGRO-ECOLOGICAL APPROACHES TO TILLAGE SYSTEMS

Tillage has been an integral component of crop production system since the beginning of agriculture influencing soil health, crop productivity, and environmental sustainability, but aimed at optimizing soil conditions for seed germination, seedling emergence and crop growth, and enhanced crop yield. Farming systems that are adaptable to local conditions, have helped small farmers to sustainably manage their farms and meet their subsistence needs without depending on mechanization, chemical fertilizers and pesticides, or other modern agricultural technologies.

Since tillage fractures the soil, it disrupts soil structure, accelerating surface runoff and soil erosion. Removal of topsoil by erosion contributes to a loss of inherent soil fertility levels (Yusuf, 1998, and Yusuf, 2001). Conventional tillage system has been widely reported to negatively affect soil physical, chemical and biological properties (Uri, 2000, Yusuf, 2003, Moussa-Machraoui et al., 2010; Yusuf and Yusuf, 2023). Moreover, by mixing soil layers, tillage alters the soil microbial dynamics by reducing the activity of microorganisms. Any method adopted must ensure the long - term productivity of soil, environmentally friendly and profitable. Recently, many developing countries have introduced tractors and various implements into agriculture in attempts to increase food production. The general lesson learnt in most such countries is that often the machinery chosen has not been matched to the various agro-ecological zones and soil types. Furthermore, the typical peasant farmer in tropical Africa does not think that the size of his farm justifies the cost of owing tractor (Yusuf, 1996) and the technicians engaged in the tillage operations were not properly trained. This has resulted in widespread of soil degradation and loss in soil productivity. Mechanical tillage and the use of heavy farm equipment have caused both soil compaction and soil erosion where they are not managed effectively. Soil compaction is caused by heavy farm machinery use and tilling when soils are too wet; compaction has become an increasing problem as farm equipment has gotten increasingly heavier (Mogdoff and Harold, 2021) resulting in poor water absorption and poor aeration which further lead to stunted root growth in plants and smaller yields. (Yusuf and Asota, 1998, Yiljep and Yusuf, 2000, Kawuyo et al., 2017; Mogdoff and Harold, 2021). Consequently, many land managers want to move away from tillage as a control option as it can reduce the soil quality, disturb beneficial soil biota (such as worms), and can resurface deeper buried viable weed seeds (Bhowmilk and Bekech, 1993). The appropriate technology would be the one which not only increase productivity, but also appeals to the farmers and is economical. Thus, a long-term solution requires developing a resilient and regenerative agricultural cropping system, and sustainable farming approach that can be managed by the farmers themselves. Agro-ecological principles in tillage systems is a holistic approach to changing the agri-food system, to create sustainable, resilient agroecosystems, and conserving biodiversity, while ensuring sustainable locally-based food systems. It encompasses reduced tillage, natural pest control, and use of biodiversity-based solutions – to enhance food production.

4 ADOPTIONS OF AGRO-ECOLOGICAL PRINCIPLES TO TILLAGE SYETEMS IN WEST AFRICA

There is potential of agro-ecological practices to promote sustainable agrifood systems. Agro-ecological practices seem to be mainly disseminated by local associations or NGOs, which promote and lead several development projects in agroecology as shown in some West Africa countries such as:

i Senegal: Agroecology has an encouraging potential to improve food security in Senegal by increasing yields and soil fertility. Some practices, such as agroforestry, crop mixtures of cereal and legume, residue mulching and compost use, are studied in Senegal and results indicated that they can improve soil properties and therefore productivity at lower costs, ensure stable prices to farmers and sell sufficient volumes (Ba Bah 2016).

ii Mali: In Mali, agroecology is supported by some associations and NGOs, such as Agroecology and Solidarity with the Sahelian People, and the Union for a Future Ecological and Solidarity (UAVES). Cooperation between farmers at the community level appears to be fundamental for the diffusion of new practices and some agro-ecological practices, such as agroforestry, present considerable potential at the economic, environmental and food security levels.

iii Burkina Faso: Agroecology is promoted by local or regional union of producers, Non-Governmental Organizations (NGOs) such as Fert, Accir, Gret and sometimes in collaboration with ministries or research institutions, by implementing on farm plots to diffuse innovations to producers and train them (Morin-Kasprzyk et al., 2015). They reported some positive contributions of agroecology especially in terms of food security and environmental impacts.

iv Nigeria: Nigerian government was highly supportive in the scaling-out of FMNR practices. Farmers organizations were key in the promotion of village and regional scale initiatives centred around agro-ecological practices. Most support for agroecology was provided by international development agencies and research efforts focus mainly on productivity and/or economic benefits of certain practices. The adoption of agro-ecological practices led to a significant improvement in farmers' net revenue and yield (Obakeng et al., 2024).

v Ghana: In Ghana, the promotion of agroecology has been done by local and traditional authorities and some extension officers. In some instances, national organizations like the Ministry of Food and Agriculture (MOFA) and other public institutions have been involved. Nevertheless, some NGOs and private organizations have promoted agroecology. In the orange-fleshed sweet potato research, agroecology was promoted by the TRAX Program Support and Self Help Africa, United Kingdom (Venhoeven 2014) by teaching farmers about compost pits; including how to construct these pits, how to improve animal pens for effective dropping collection, and providing financial assistance to farmers during the training programme.

iv Togo: In Togo, there is no regional or national policies supporting agroecology have been recorded in Togo, except the National Institute of Technical support and Advisory (ICAT) in partnership with Agronomes et Vétérinaires Sans Frontières (AVSF) in northern Togo. However, the promotion of agroecology and diffusion of agro-ecological practices were initiated by various organization from the civil society: local NGOs RAFIA, CARTO and international NGOs, such as AVSF and INADES. Crop diversification and rotation as well as various fertilisation practices have been shown to increase food availability, yield and income.

5 EMPHASISE OF AGRO-ECOLOGICALMPRINCIPLES IN TILLAGE SYSTEMS

The adoption of agro-ecological principles in tillage systems represents a paradigm shift towards soil management and conservation in increasing crop yields and soil productivity on a sustainable basis as a more sustainable agricultural practices. The major principles are minimal disturbance, soil organic matter enhancement, crop diversity, and integration of natural processes (Fig, 3).

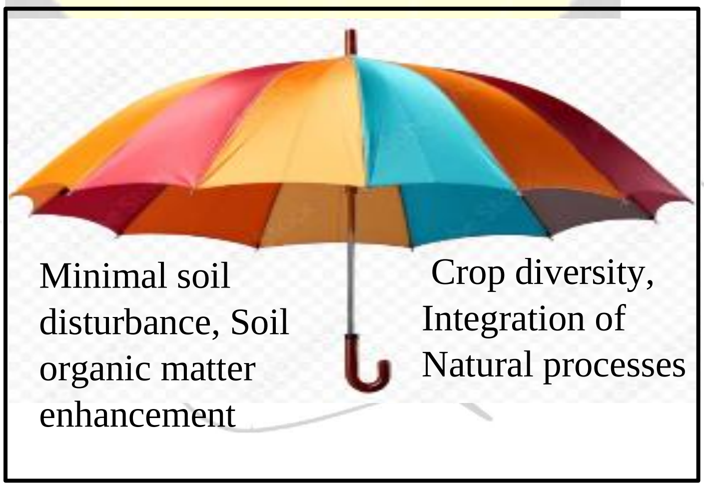


Fig. 3 : Emphasis of agro-ecological principles in tillage systems

i Minimal Soil Disturbance: Minimizing soil disturbance is an essential foundation of agro-ecological tillage systems. Reduced or no-till practices help reduce fuel usage, improve water penetration, enhance soil health, maintain soil structure, prevent erosion, and preserve soil organic matter. The widely adopted resource conserving technology (RCT) in the Indo-Gangetic Plains (IGP) has been zero-tillage (ZT) for wheat after rice, particularly in India (Vjay, 2007). By leaving crop residues on the soil surface, these practices improve water infiltration, reduce runoff, and enhance soil moisture retention. Crops can be sown almost immediately the previous crop has been harvested and is suited to areas where two or more crops are rotated on the same land within the year. Hobbs et al., (1997) reported that yield in wheat reduces rapidly as sowing time is delayed beyond the optimum date. Minimum tillage in addition to shortening turn-around time between crops can be much cheaper than conventional tillage (Yusuf, 1996).

ii Soil Organic Matter Enhancement: Agro-ecological tillage systems focus on building soil organic matter through cover cropping, use of crop rotation, minimizing tillage operations, and reducing losses of organic matter and application of organic amendments (Gebreves, 2019). Soil organic matter, sometimes a measure of a soil's fertility, and even a soil's resilience, enhances soil fertility, nutrient cycling, and microbial diversity, promoting healthier soil ecosystems, improving beneficial organisms living in the soil and enhance long-term productivity of the soil.

iii Crop Diversity: Crop diversity is a fundamental aspect of agriculture that encompasses the vast array of plant species cultivated for human consumption. It serves as the foundation of food security, resilience against environmental stresses, and sustainable agricultural practices. Crop rotations and intercropping are integral to agro-ecological tillage systems, fostering biological diversity and optimizing resource utilization which leads to a range of ecosystem improvements—while also maintaining or improving yields. Crop diversification is recognized as one of the most feasible and cost-effective ways of developing a resilient and regenerative agricultural cropping system. The maintenance of agrobiodiversity in situ, i.e., in nature and agricultural practice, remains indispensable, and is a task for protected areas and on-farm conservation efforts (Vincent et al. 2019). Crop diversity may mitigate some food production biodiversity trade-offs (Redlich et al., 2018) and reduce some of the environmental impacts associated with the conventional tillage as related to fertiliser and pesticide use and high-input intensification of agricultural land that can cause decrease in biodiversity (Newbold et al., 2015).

iv. Integration of Natural Processes: Agro-ecological tillage systems integrate natural ecological processes such as biological nitrogen fixation, nutrient cycling, and pest predation. Integrated farming is a holistic, biologically integrated system, which integrates natural resources in a regulated mechanism into farming activities to achieve maximum replacement of off-farm inputs and sustain farm income (Walia et al., 2019). It seeks to reinforce the positive influences of agricultural production while mitigating its negative impacts (Walia et al., 2019). By mimicking natural ecosystems, these systems reduce the need for external inputs, promote ecological balance, and support sustainable agricultural intensification. By recognizing the intricate interconnections within ecosystems, resource integration, and harnessing the natural processes that sustain life, agro-ecological tillage systems provide optimum production in cropping patterns and ensuring optimal resource utilization. The main idea is to improve biological diversity by reducing competition for water, nutrients, and space, as well as implementing ecologically friendly practices (Scavo and Mauromicale, 2020). Overall, it connects subsystems with all the components working together mutually to develop a resilient and regenerative agricultural cropping system.

6 CASE STUDIES AND EMPERICAL EVIDENCE OF APPLICATION OF AGRO-ECOLOGICAL PRINCPLES TO TILLAGE SYSTEMS

i Conservation Agriculture in South America: Adoption of no-till and direct-seeding techniques in Brazil and Argentina has led to significant improvements in conservation agriculture, soil health, water conservation, and crop yields while reducing greenhouse gas emissions, producing high crop yields while reducing production costs, maintaining the soil fertility and conserving water. The global empirical evidence shows that farmer-led transformation of agricultural production systems based on Conservation Agriculture (CA) principles is already occurring and gathering momentum worldwide as a new paradigm for the 21st century (Theodor, 2012) **.** Conservation agriculture has three basic principles such as: minimum disturbance of soil, rational organic soil cover and the adoption of innovative and economically viable cropping systems possible,

In South America, the area under no-tillage has been growing steadily. South America represents 47% of the total global area under no-till (Kassam *et al*., 2009). In 1987, there were only 670,000 hectares of no-till in the MERCOSUR countries (Brazil, Argentina, Paraguay, and Uruguay), but by the year 2002 the technology had grown to over 30 million hectares and no-till adoption in terms of percent of total cropland was reported by Derpsch and Friedrich (2009) as follows: Argentina (80%), Brazil (50%), Paraguay (90%), and Uruguay (82%). In southern Brazil, adoption of no-till exceeds 80% (Bolliger *et al*., 2006) and Brazil cultivates about 33.5 million hectares through no-tillage. Brazil is the only country in the world where zero tillage has been successfully adopted by a large proportion of smallholder farmers with 90% of the land cropped by smallholders is under no-till. No-tillage is defined as the planting of crops in previously unprepared soil by opening a narrow slot, trench or band only of sufficient width and depth for proper seed coverage (Fig. 4) and no other soil preparation. Before planting, it is necessary to kill the weeds in the field and no-till is dependent on herbicides because of the elimination of tillage for control of weeds (Ribeiro, 2007). The most important factor in no-till adoption in South America was to educate and convince farmers that there was a new way to farm land without tillage, and increased crop yields, with cut in tractor use, resulting in big savings in fuel and production costs (Kassam *et al*., 2009). Labor reductions in Brazil as a result of no-till were 10% for soya and 51-55% for maize (Pieri *et al*., 2002). In Paraguay, no-till led to a reduction of 12% in labor requirements and an increase of 77% in net farm income (Pieri *et al*., 2002). The cumulative benefits to Argentinean farmers of the adoption of no-till from 1991-2008 is estimated at $12.0 billion in increased gross income and $4.7 billion in decreased production costs (Trigo *et al*., 2009).

Fig. 4: Big farm seeder for direct seeding in crop residues, Floresta, State of Parana, Brazil.

Source: Speratt et al.,(2015).

ii Agroforestry Systems in Sub-Saharan Africa: Agro-ecological practices of combining tree planting with minimal tillage have enhanced soil fertility, biodiversity, and resilience to climate variability in regions such as Kenya and Tanzania. It is now widely promoted in Sub-Saharan Africa as it provides low-input, resource-conserving farming approaches that are socially relevant and relate well to livelihood and ecosystem functions (Carsan et al. 2014). The practice involves growing of woody perennials in association with food crops and pastures (Shem et al., (2019) as shown in Fig. 5. Humans have significantly modified the landscapes of Sub-Saharan Africa in efforts to improve welfare and the majority of livelihoods are directly derived from natural resources, particularly from no- or low-input agriculture and pastoralism (Alliance for a Green Revolution in Africa, 2017). Agroforestry involves the management of trees with crops and livestock to alter microclimates, hydrology, and biodiversity to yield multiple ecosystem goods and services. Agroforestry seems to be a major solution for reversing the processes of deforestation and soil degradation in Africa. Hence, attention has been focused on the role of trees in agriculture in restoring soil fertility by combining trees with crops and livestock in integrated farming systems. The development paradigms including "nature-based solutions," "climate-smart agriculture," "agroecology," "sustainable intensification," and "ecosystem-based adaptation" all promote agroforestry (Pretty, 2018).

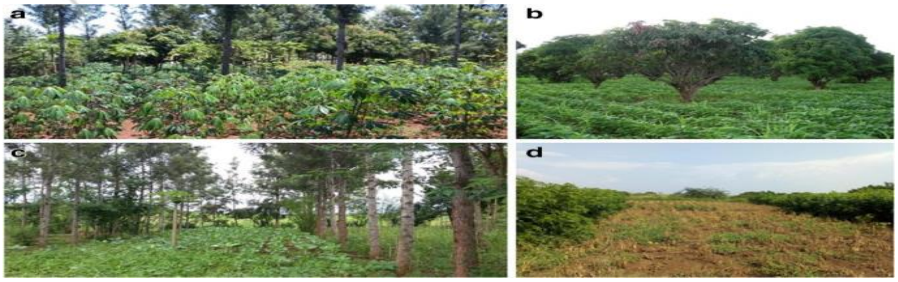


Fig. 5: Agroforestry practices common in sub-Saharan Africa. **a** Homegarden (a mosaic landscape with cassava, pawpaw, *Mangifera indica* L. and *Grevillea robusta,* in Uganda). **b** Dispersed intercropping (in maize-bean intercrop in Malawi). **c** Intercropping with annual crops between widely spaced rows of trees (collard intercropped with *G. robusta*). **d** Alley cropping (climbing beans planted between hedges of *Gliricidia sepium* in Rwanda), Source: Shem et al., (2019).

iii Cover Cropping in North America: Integration of cover crops in maize and soybean rotations in the United States has improved soil structure, reduced erosion, and provided additional income through livestock forage and nitrogen fixation. Cover crops are established on fields that may otherwise be left bare during a fallow period after the cash crop has been harvested and may also filter water, improve water quality, improve soil quality, and help retain nutrients (Figure 6). Cover crops act as green manures when they are turned into the soil to provide organic matter and nutrients and the decomposing cover crop residues release nutrients to support subsequent cash crops. In New Mexico, grazing cover crops could be a sustainable way to improve soil health (Fig. 7). Cover crops have been identified as a promising approach for reducing greenhouse gas emissions by decreasing soil nitrate concentrations during the non-growing season (Chahal et al., 2021). Up to 11 Mg ha^{-1} $year^{-1}$ of topsoil are estimated to be lost through wind erosion in the Great Lakes Region of North America (OMAFRA, 2018); particularly on sandy and organic or muck soils. Cover crops decrease the risk of wind erosion primarily by protecting the soil surface, improving soil structure, and increasing SOC levels (Blanco-Canqui et al., 2015). The ability of cover crops to reduce wind erosion is largely dependent on the amount of cover crop above-ground biomass, which varies among cover crop species, climatic conditions, and soil types.

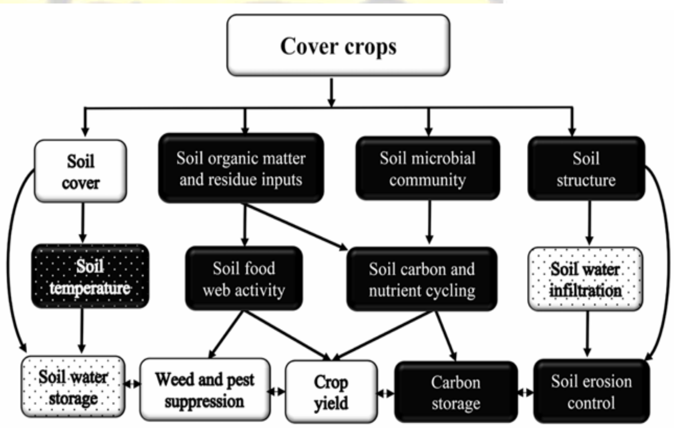


Fig. 6: Cover crops provide multiple benefits including soil water storage, weed and pest suppression, and enhanced soil microbial communities. Source: Rajan, et al (2022).

Fig. 7: Multispecies cover crops demonstration at NMSU's Agricultural Science Center at Clovis, New Mexico. Source: Rajan et al., (2022).

7 BENEFITS OF AGRO- ECOLOGICAL PRINCIPLES IN TILLAGE STSTEMS

i Improved Soil Health: Agro-ecological practices enhance soil structure, increase organic matter content, and foster beneficial microbial activity. Healthy soils are more resilient to erosion, drought, and nutrient loss. Reduced mechanical disturbance results in less destruction of soil organisms and their habitat with robust biological activity. Yusuf (2006) found higher values of organic matter, nitrogen, phosphorus, potassium, calcium and magnesium in cropping systems that utilize conservation tillage systems rather than conventional tillage systems.

ii Enhanced Biodiversity: Diverse cropping systems and reduced chemical inputs promote biodiversity above and below ground. Beneficial insects, pollinators, and soil organisms thrive in agro-ecological environments, contributing to pest control and nutrient cycling. Organic matter in the soil and at the soil surface provides nourishment for soil organisms that are part of the foundation of the food web. Soils in conservation tillage systems have a greater abundance of earthworms, microorganisms, and fungi.

iii Water Management: Practices like no-till and cover cropping provide environmental benefits by improving water infiltration and reduce runoff, thereby conserving water resources and mitigating soil moisture variability. Conservation tillage, including crop-residue management, conserves soil and water on southeastern soils (Langdale et al., 1992) and improves soil productivity by improving organic matter and soil structure.

iv Climate Resilience: Agro-ecological systems can sequester carbon in soils and biomass, mitigating greenhouse gas emissions. Reduced tillage practices also decrease fuel and associated emissions from farm machinery. As we confront pressing global challenges such as climate change, and food insecurity, the principles of agroecology in tillage systems offer a beacon of hope to embark on a journey towards a future where agriculture thrives in harmony with the natural world, ensuring the well-being of present and future generations.

v Economic and Societal Benefits: Agro-ecological systems improve quality of life (reduced labor, greater flexibility in planting); and improve profitability (reduces wear and tear on equipment, saves fertilizer, and improve productivity).

vi Improved Wildlife Habitat: Wildlif**e** require nutritious food, clean water and adequate shelter. Hence, management of agricultural land has vital implications for wildlife. Conservation tillage provides food opportunities and shelter for small mammals and birds (Basore et al., 1987) such as mice, rabbits, bobwhite or quail. Coven (1982) and Martin and Forsyth (2003) have reported higher nest densities and nest success in conservation tillage fields as compared to conventional tillage fields.

vii Improved Crop Yields: Cover crops to conservation tillage systems often results in increased crop yield and net returns compared to conservation systems without cover crops. Bergtold et al.(2005) reported that net returns for cotton with a rye/black oat cover crop mixture increased 10–37 percent over the conventional tillage treatment.

8 CHALLENGES

i Transition Period: Switching from conventional to agro-ecological practices may require initial investments in equipment, knowledge, and adaptation to new management techniques.

ii Weed Management: No-till systems, in particular, may require adjustments in weed management strategies, such as cover cropping or targeted herbicide se. **G**lyphosate (herbicide) resistance is becoming an issue of increasing concern where the agro-ecological principles in tillage systems have relied on this herbicide, and resistant *Erigeron* species biotypes are now globally widespread (Heap, 2017), and is currently one of the widest spread glyphosate-resistant weeds. In addition to glyphosate resistance, *Erigeron* species have also adapted resistance to at least 20 other widely used herbicides (Heap, 2017).

iii Knowledge and Education: Farmer education and access to information about agro-ecological principles in tillage systems are crucial for successful adoption and adaptation to local conditions.

iv Climate and Soil: Tillage requirement is influenced by climate and extrinsic factors such as site drainage and soil moisture class. No-tillage is generally difficult to use in wet soils. Soils with an imbalance in particle size distribution (i.e., high clay or sand content) and/or those with poor permeability tend to have a high tillage requirement and are more difficult to manage when tillage is reduced.

v. Policy and Regulatory Barriers: The widespread adoption of agro-ecology principles in tillage systems faces challenges, including policy and regulatory barriers, and knowledge and training gaps. Supportive policies, incentives, and subsidies can facilitate the adoption of agro-ecological practices and encourage long-term sustainability in agriculture. There is need for a collaborative effort involving governments, farmers, researchers, consumers, and civil society organizations. The core principle of co-creation of knowledge requires that farmers and stakeholders are at the centre of defining research questions and developing solutions alongside scientists. Enabling integration across sectors and scales necessary to foster holistic, rather than fragmented, implementation of policy is crucial. Advocating for supportive policies, investing in knowledge dissemination and capacity building on the agro-ecological principles in tillage systems, can accelerate the transition towards sustainable food systems, contribute to food security, resilience to climate change, and the conservation of natural resources.

9 CONCLUSIONS

Agro-ecological principles offer a promising pathway towards sustainable agriculture by transforming conventional tillage systems into more resilient and environmentally-friendly practices. It is important to make sure farming stays sustainable.The integration the of agro-ecological principles into tillage systems through minimal soil disturbance, soil organic matter enhancement, crop diversity, and natural process integration not only improves soil health and productivity but also enhances ecosystem services, and mitigates climate change impacts. Crop diversity is essential for global food security, resilience against climate change, and sustainable agriculture, offering a promising path towards sustainable food production and environmental stewardship. Importantly, agro-ecology principles in tillage systems is not merely a set of techniques but a holistic approach that emphasizes the interconnectedness of social, ecological, and economic systems. It is essential to have continued research, policy support, and farmer education for scaling up agro-ecological tillage systems globally, ensuring food security while safeguarding natural resources for future generations.

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FRAMEWORK FOR CLIMATIC RESILIENCE AND SUITABLE TILLAGE SYSTEMS

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ABSTRACT

This paper presents a framework for developing climate-resilient tillage systems in response to the increasing impacts of climate change on agriculture. The framework integrates strategies for mitigating and adapting to climate variability while promoting sustainable tillage practices. It emphasizes conservation tillage, reduced greenhouse gas emissions, and soil carbon sequestration to enhance agricultural resilience. The study highlights the role of actors and enablers, such as government, technology, and policy, in driving change towards sustainable tillage systems. Additionally, the paper explores global frameworks like the Hyogo and Sendai frameworks and their applicability to Nigerian agriculture. Through a combination of conservation practices, agro-ecological principles, and sustainable development goals (SDGs), the framework aims to improve food security, soil health, and climate adaptation in agricultural systems, particularly in developing countries.

KEYWORDS: Climate resilience, Tillage systems, Sustainable agriculture, Conservation tillage, Climate adaptation, Greenhouse gas mitigation, Soil carbon sequestration, Nigerian agriculture, Sustainable development.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) refers climate change to any change in climate over time, whether due to natural variability or because of human activity (IPCC, 2001). Climate change is manifested by climate warming, abnormal precipitation, floods, droughts, windstorms, and other extreme weather, which cause several problems to agriculture, including disturbance to soil structure, loss of soil nutrients, decrease in biodiversity, plant diseases and pest outbreak, and low crop yield, thereby raising a series of issues associated with society, economy, and life safety (Chausson et al., 2020). Climate change threatens agricultural production and leads to an increasing contradiction between food supply and needs.

To reduce the risk of climate change on agriculture, governments and international organizations have developed various countermeasures from both mitigation and adaptation perspectives. Mitigating the effects of climate change is crucial for minimizing the occurrence of hazards associated with climate change. Adaptation is a process by which strategies to moderate, cope with, and take advantage of the consequences of climatic events are enhanced, developed, and implemented for the continued existence of life on planet earth (Tunji-Olayeni et al., 2019). Measures to mitigate climate change are defined as any human (anthropogenic) intervention that can either reduce the sources of greenhouse gas (GHG) emissions (abatement) or enhance their sinks (sequestration). Increased C is beneficial for some soil structures and functions, improving the use of water and in turn the crop adaptation (Montanaro et al., 2018).

According to Zong et al. (2022) climate change mitigation action would significantly reduce the severity of impacts, while climate change adaptation action will reduce them and will then enhance the resilience of ecosystems to climate change. Climate change and weather variability are negatively impacting crop yields in many parts of the world leading to an increase in the number of people migrating from the countryside into cities (Lohano et al., 2016; Shammin et al., 2022). This climate-change-induced migration impacts agricultural production and leads to an increasing contradiction between food supply and needs, thereby challenging agriculture to feed increasing numbers of people – most of whom are in developing countries (Tubiello, 2012).

2. CLIMATE CHANGE IMPACTS

The societal response to climate-change-induced impacts is biophysical – biological impacts and physical impacts. These impacts have "Actors" and "Enablers" which facilitate them with mediating factors given as responses, shown in Fig.1.

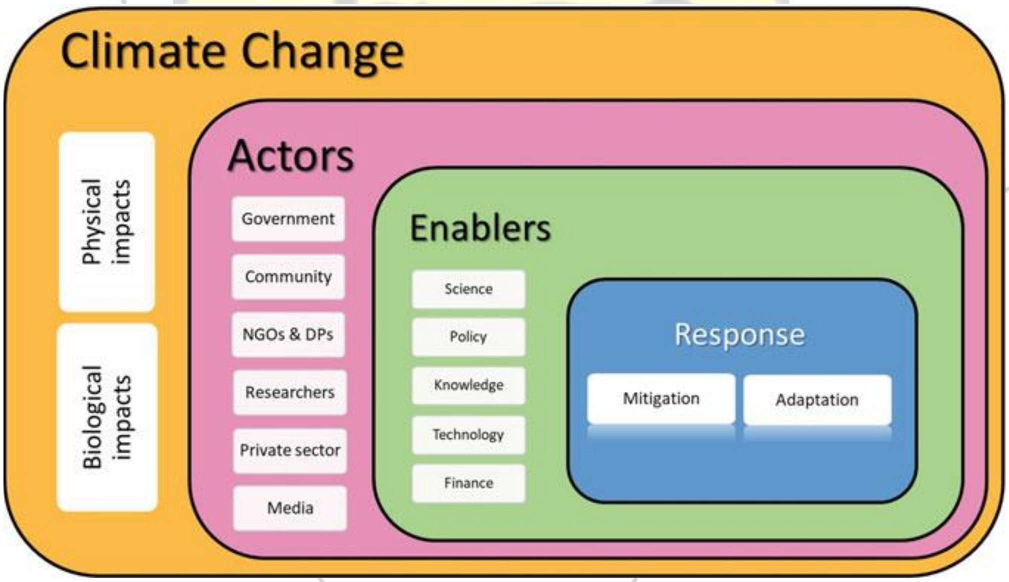

Fig. 1. Anatomy of climate change response to induced impacts (Shammin et al., 2022)

The mediating factors play an important role in determining their collective ability to anticipate, prepare for, and respond to the present and future threats of climate change.

2.1 Actors

Climate change actors, which include Government, Community, NGOs & DPs, Researchers, Private sector, and Media, experience the biophysical impacts as institutions and individuals. On the other hand, they are also the drivers of change. These actors interact and cooperate with each other within the given socioeconomic and political contexts, to identify and prioritize key concerns, develop strategies, collaborate with internal and external stakeholders, mobilize resources, and ultimately design and implement the climate response programs to achieve better outcomes. Climate change governance requires governments to deploy an active mitigation and adaptation policy regime focusing on building coalitions for change at every level of decision making so that systemic weaknesses can be reversed (Meadowcroft, 2010).

2.2 Enablers

Climate change enablers (Science, Policy, Knowledge, Technology and Finance) are factors that influence the quality of response when the actors finally agree on the threat and are willing to act. With climate science providing information on the cause and extent of climate change, future scenarios are generated that inform evidence-based policy development including sector-specific goals for climate response. Importantly, climate policy should be closely aligned, and preferably well integrated, with other key sectoral policies related to energy, infrastructure, industry, agriculture, natural resources, health, and the environment. This policy alignment is crucial in disaster risk reduction.

2.3 Climatic resilience

In physics or engineering, resilience refers to the ability of a material or building to resist stress and disruption and its ability to recover after deformation (Smith et al., 2017). Climatic resilience is the ability to recover from, or mitigate vulnerability to, climate-related shocks such as floods and droughts. When it comes to climate change, the IPCC (Field et al., 2012) integrated different concepts and defined climate resilience as the ability of social, economic, and environmental systems to cope with hazardous climate change disturbances or challenges in a manner that maintains their essential structure, characteristics, and functions while maintaining an integrated capacity to adapt, learn and transform (UNISDR, 2009; Denton et al., 2014; IPCC, 2014c). In agricultural systems, resilience refers to the capacity of the systems to respond to social, economic, and environmental changes via structural reorganization (El Chami et al., 2020), to ensure the continuity of the agricultural systems to maintain agriculture's core functions while mitigating the impacts of climate change (Deng et al., 2022). (Ayeb-Karlsson et al., 2015) posits that the concept of resilience provides one of the most promising approaches to poverty reduction, development, growth, and sustainability. So, climate resilient development has become a new paradigm for sustainable development.

3. SUSTAINABLE DEVELOPMENT

Sustainable development was defined by IPCC as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987; IPCC, 2014c). Climate change shifts the sustainability challenge from conservation to adaptation bringing in a new discipline, and transitions toward sustainability (Werners et al., 2013; Caniglia et al., 2017). This has gravitated **sustainability science**, which evolves using interdisciplinary research involving scientists and social actors to produce knowledge that supports and informs solutions, transformations towards implementation of the Sustainable Development Goals (SDGs) that addresses poverty alleviation, through agriculture and food security, while tackling climate change and safeguarding the environment. Indeed, successful adaptation and mitigation responses in agriculture can only be achieved within the MDGs and the UNFCCC (Tubiello, 2012). However, the overall challenge of climate policy will be to find the efficient mix of mitigation and adaptation solutions, including many existing mutually re-enforcing synergies, as enunciated in the SDGs. The SDGs shown in Fig. 2 build on more than two decades of global endeavors to operationalize sustainable development. These goals provide a detailed, practical, and comprehensive deconstruction of the concepts of sustainability and sustainable development that captures the spirits of economic advancements, environmental responsibility, and social justice. These SDGs provide a new framework to consider climate action within the multiple dimensions of sustainability (IPCC, 2018).

4. FRAMEWORKS

A climate framework helps organizations become more sustainable from an environmental perspective through green alternatives and lowered emissions. Resilience to climate change, if applied through a framework, could mean any resilience subsystems that challenge any kind of general system level resilience (Elmqvist et al., 2019).

Fig. 2 Sustainable development goals (UN, 2015)

a. **The Hyogo Framework** for Action specifically identifies the need to "promote the integration of risk reduction associated with existing climate variability and future climate change into strategies for the reduction of disaster risk and adaptation to climate change" (UNISDR, 2005).
b. **The Sendai Framework** on Disaster Risk Reduction has one of the guiding principles as "The development, strengthening and implementation of relevant policies, plans, practices and mechanisms aimed at coherence, as appropriate, across sustainable development and growth, food security, health and safety, climate change and variability, environmental management and disaster risk reduction agendas" (UNDRR, 2015). It includes understanding of disaster risks, strengthening disaster management governance, investing in risk reduction, and resilience building.

c. **The Paris Agreement** affirms a global aim of strengthening the response to the threats of climate change by striving to keep the global temperature rise this century well below 2.0 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. The 2015 Paris Agreement includes provisions for developed countries to mobilize financial support to assist developing country parties with climate change mitigation and adaptation efforts (Lattanzio, 2017).

5. AGRICULTURE

Agriculture sustains the food and nutrition necessary for human life and plays a pivotal role in socioeconomic development (Latruffe et al., 2016). Agricultural production is strongly influenced by weather/climate, and its instability and vulnerability will increase with climate warming (Liu et al., 2010; Zhang et al., 2017). Extreme weather events, such as droughts, heatwaves, and floods, directly threaten food production and security, agricultural revenues, and the capacity of the poor to overcome poverty, especially in rural communities with high populations of small-scale producers who are highly dependent on rain-fed agriculture for their livelihoods and food (Acevedo et al., 2020), impacting the entire food systems (Olsson et al., 2014; Porter et al., 2014).

5.1 Agriculture contribution to emissions

Agriculture impacts on global warming through the production of 'greenhouse gases' (Fig. 3), such as CO_2 (Robertson *et al*., 2000), contributing about 13 – 15% of global greenhouse gas (GHG) emissions (Poore and Nemecek, 2018) with increases in temperature (Smith, 2004; Baker et al., 2007; Lybbert and Sumner, 2010; Baye et al. (2019). The agricultural sector can be manipulated for the dual benefits of changing its role from CO_2 producer into CO_2 absorber (Smith, 2004; Reicosky and Saxton, 2007) reducing GHG emissions and acting as a sink by storing and sequestering CO_2 from the atmosphere in the form of soil carbon (Lal, 1999; FAOSTAT, 2006). Ammonium nitrate (NH_4NO_3) was beneficial in reducing the volatility of NH_3 and the emission of N_2O (Mc Taggart et al., 1994; Paustian et al., 2004). Any practice that conserves N within the system can also reduce N_2O.

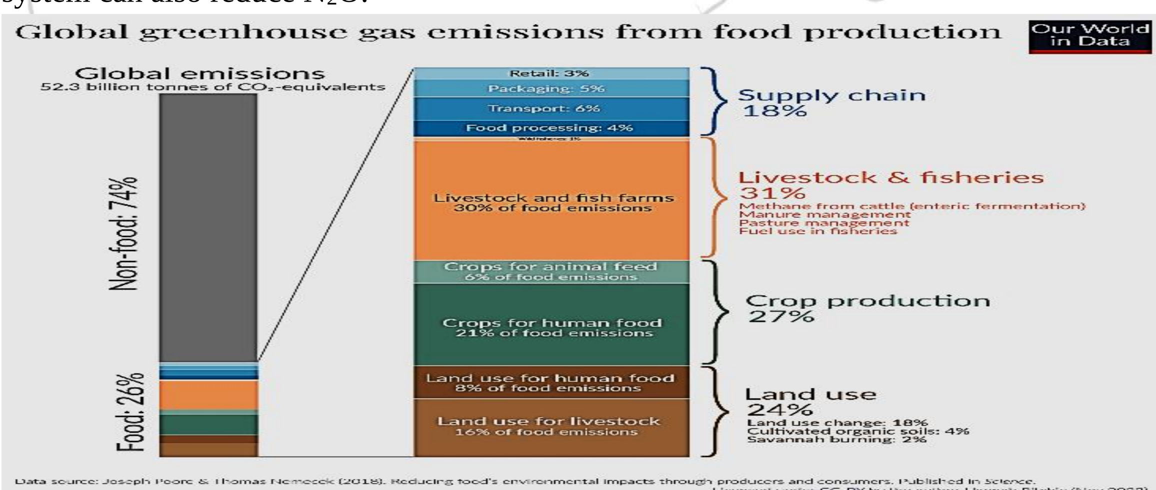

Fig. 3. Global greenhouse gas emissions from food production (Source: Poore and Nemecek, 2018).

The main GHG emissions from agriculture are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) (Fig. 4). Agricultural emissions account for 49% anthropogenic methane emissions (FAO, 2003), 66% of global anthropogenic N_2O emissions (Robertson and Grace, 2004) and 15% of anthropogenic CO_2 emissions (Janssens et al., 2003). Agriculture contributes nearly half of the CH_4 and N_2O emissions (Bhatia et al., 2004) and nutrient, water and tillage management can help to mitigate these GHGs.

6. MITIGATION MECHANISMS AND PRACTICES

According to Smith et al. (2007) opportunities for mitigating GHGs in agriculture fall into three broad categories, based on the underlying mechanism:

a. **Reducing emissions**: Agriculture releases to the atmosphere significant amounts of CO_2, CH_4, or N_2O (IPCC, 2001a; Paustian *et al.*, 2004). The fluxes of these gases can be reduced by more efficient management of carbon and nitrogen flows in agricultural ecosystems.

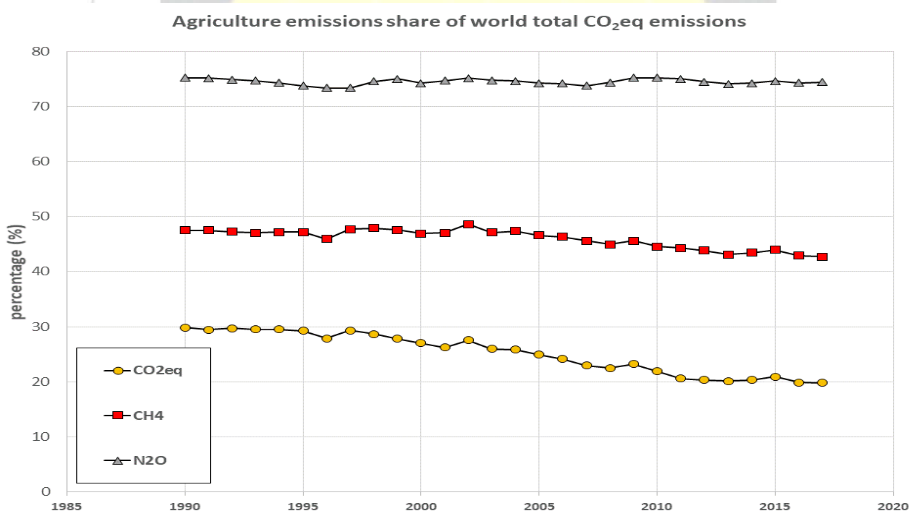

Fig. 4. Agriculture emissions share of world total CO_2eq emissions. (Source: FAOSTAT, 2020).

b. **Enhancing removals**: Agricultural ecosystems hold large carbon reserves (IPCC, 2001a), mostly in soil organic matter. Historically, these systems have lost more than 50% C (Paustian *et al.*, 1998; Lal, 2004a), but some of this carbon lost can be recovered through improved management (Smith and Conen, 2004). Agricultural lands also remove CH_4 from the atmosphere by oxidation (Tate et al., 2006).

c. **Avoiding (or displacing) emissions**: Crops and residues when used as a source of fuel, either directly (Foley et al., 2005) or after conversion to fuels such as ethanol or diesel (Schneider and McCarl, 2003; Cannell, 2003) which upon combustion, becomes of atmospheric origin (via photosynthesis), rather than from fossil carbon. (FAO, 2001; IPCC, 2007).

6.1 Sequestration

Carbon sequestration, a key sequestration pathway in agriculture, provides climate change mitigation benefits primarily through an offset strategy to the GHGs emission from agriculture through increase in C sink capacity (Schneider and Kumar, 2008). Soil C sequestration improves soil quality by changing soil bulk density (Lenka and Lal, 2013) and impacts positively in sustainable crop production. It may be stated that soil management (tillage systems and crop rotation) is the decisive factor for C stock or organic C sequestration (Lenka and Lenka, 2014).

7. ADAPTATION POLICY FRAMEWORK

Adaptation is a process by which strategies to moderate, cope with and take advantage of the consequences of climate events, including variability, are enhanced, developed and implemented (Ebi et al., 2004). This process should incorporate future climate risk into policymaking and make available a practical guidance on adaptation. Adaptation Policy Framework (APF) – is designed to link climate change adaptation to sustainable development and other global environmental issues offering a flexible approach for implementing responsive adaptation strategies, policies and measures. It consists of five basic Components (Lim et al., 2004):

Component 1: Scoping and designing an adaptation project involve ensuring that a project – whatever its scale or scope – is well-integrated into the national policy planning and development process for implementation (Ebi et al., 2004).

Component 2: Assessing current vulnerability answers questions, such as: Where does a society stand today with respect to vulnerability to climate risks? What factors determine a society's current vulnerability? How successful are the efforts to adapt to current climate risks? (Jones & Boer, 2004).

Component 3: A**ssessing future climate risks** focuses on the development of scenarios of future climate, vulnerability, and socio-economic and environmental trends as a basis for considering future climate risks (Jones & Mearns, 2004).

Component 4: Formulating an adaptation strategy in response to current vulnerability and future climate risks involves the identification and selection of a set of adaptation policy options and measures, and the formulation of these options into a cohesive, integrated strategy (Niang-Diop & Bosch, 2004).

Component 5: C**ontinuing the adaptation process** involves implementing, monitoring, evaluating, improving and sustaining the initiatives launched by the adaptation project (Perez & Yohe, 2004).

While adaptation strategies that minimize expected impacts on access, stability and utilization of food resources involve largely local-to regional-scale actions, safeguarding food availability also requires a global perspective, which climate-resilient agriculture (CRA)addresses.

8. SUITABLE TILLAGE SYSTEMS FOR CLIMATE-RESILIENT AGRICULTURE (CRA).

CRA is a new model of agricultural management that follows the concept of sustainable development, and it aims to address hunger and poverty under climate change (Gentle and Maraseni, 2012; Reddy, 2015; Acevedo et al., 2020). CRA practices can alter the current situation and sustain agricultural production from the local to the global level, especially in a sustainable manner (Reddy, 2015; Srinivasa Rao et al., 2019; Acevedo et al., 2020). One of the four principal issues of global concern with regards to agricultural production is the role of residue management and conservation tillage (CT) in carbon sequestration (Baye et al., 2019). Crops cannot be produced without disturbing the soil by either conservation tillage or conventional tillage (Koeller, 2003). Because tilling the soil stimulates microbial decomposition of soil organic matter, resulting in emissions of CO_2 to the atmosphere, crops grown with minimum tillage promotes sequestration of carbon in the soil (Smith et al., 2008). Sustainable soil management can be practiced through conservation tillage (including no-tillage), high crop residue return, and crop rotation (Crutzen et al., 2008; Amini and Asoodar, 2015). Agricultural management practices such as CT methods involving crop residue retention and incorporation, have been promoted due to their beneficial effects on soil properties, enhanced soil moisture retention which influences soil gas diffusion, better soil structure to promote nutrient cycling and aggregation and reduced soil erosion. These management practices, however, affect soil carbon and nitrogen contents as well as their distributions within the soil profile (Yamulki and Jarvis, 2002). Using cover crops to assist with controlling pest diseases is common in the context of climate change (Sharma and Prabhakar, 2014; Rosenzweig et al., 2001). Cover crops are essential to CT for weed management and soil nutrients (Büchi et al., 2018). Using crop rotation, along with CT, is a win-win crop management option (Sun et al., 2016; Madari et al., 2005). CT combined with the use of cover crops, can offset the adverse effect of conservation tillage and improve soil health to increase yield (Burayu et al., 2006).

8.1 Conservation tillage

Adoption of the best management practices (BMPs) contribute significantly to climate change mitigation through reduction in source and increase in sink of carbon. One of the measures recommended as the BMPs is conservation tillage (CT) (Singh et al., 2014). Lenka and Lenka (2014) stated that CT can mitigate climate change effects and ensure sustainable agriculture by promoting soil erosion reduction and improving soil organic matter content and water storage. Table 1 shows how different regions of the world conceptualize CT and it is not difficult to see that crop residue and no-tillage are the core technologies of CT practice. Conservation tillage (Fig. 5) may be defined as a tillage system in which at least 30% of crop residues are left in the field before after planting (Dinnes, 2004) and no tillage as the basic operation (Deng et al., 2022) to improve agricultural productivity and sustainability. It is an important conservation practice to mitigate the impacts of climate change (Madejon et al., 2007; **MDA, 2011**).

Table 1. Technical points of conservation tillage practice in different countries and regions (Deng et al., 2022).

Country/Region	Technical Points
China	residue incorporation, and no/reduced tillage
United States	resilience determines within a more than 30% crop residue
United Kingdom	not using cultivation machinery
European Union	leave at least 30% plant residue and do not invert soil
Sub-Saharan Africa	do not disturb the soil and allow retention of mulch

Fig. 5. Showing conservation tillage

The term "conservation tillage" broadly encompasses tillage practices that "reduce the volume of soil disturbed; preserve rather than incorporate surface residues; and result in the broad protection of soil resources while crops are grown" (Allmaras and Dowdy 1985). The general advantages and disadvantages of conservation tillage is given in Table 1, while different types of conservation tillage are shown in Table 2.

Table 1. The general advantages and disadvantages of conservation tillage

Advantages	Disadvantages
1. Increases the ability of soil to store or sequester carbon while simultaneously enriching the soil. 2. Improves soil water infiltration, thereby reducing erosion and water and nitrate runoff. 3. Improves the stabilisation of soil surface to wind erosion and the release of dust and other airborne particulates. 4. Reduces leaching of nutrients due to greater amounts of soil organic matter to provide binding sites. 5. Decreases evaporation and increases soil moisture retention, which can increase yields in drought years (Suddick et al., 2010). 6. Reduces the number of passages of equipment across the field, thereby reducing the cost of fossil fuel and the associated carbon emissions to the atmosphere. 7. Reduces the loss of pesticides and other applied chemicals. This is because higher infiltration rates with more surface residue results in less runoff moisture holding capacity due to higher soil organic matter that results in less leaching.	1. Adoption of reduced tillage in humid, cool soils would primarily affect the distribution of SOC in the profile, unless carbon inputs were increased (Lal et al., 1998). 2. Specialised, expensive equipment is required, or much hand labour in the case of very small-scale growers. 3. Requires more herbicides and pesticides than standard conventional practices to control weeds and other pests. 4. Due to the large size of the original soil carbon pools, the contribution of conservation tillage can appear to be small, and a significant amount of time is required to detect changes. 5. Sizable amounts of non-CO_2 greenhouse gases (N_2O and CH_4) can be emitted under conservation tillage compared to the amount of carbon stored, so that the benefits of conservation tillage in storing carbon can be outweighed by disadvantages from other GHG emissions.

8.2 Types of conservation tillage.

The types of CT aim to achieve little to no soil disturbance; promote crop rotations; provide permanent soil coverage; increase residues on the soil surface; reduce use of inputs; improve soil quality; control traffic (Derpsch, 2008); and minimize the impact of water and wind erosion (Bergtold et al., 2020). CT methods include zero-till (slot planting), strip-till (zonal), ridge-till, mulch-till and reduced-till (minimum) (Table 2 and Fig. 6). Table 3. Advantages and Disadvantages of Types of Conservation Tillage

Table 2. The different types of conservation tillage

No-Till (Zero-Till) = minimally disrupts the topsoil through single-pass seeding and fertilization, with only shallow seedbeds covered with mulch from plant residues.

Strip-Tillage (Zonal Tillage) involves tilling the soil mechanically only in narrow strips with the rest of the field left untilled (strip-till) (MDA, 2011), and treated it with cover crops. The principle's essence is to divide a field into two parts: seedling and soil management. Additionally, rows can be made for better water penetration.

Ridge-Till involves planting seeds in the valleys between carefully moulded ridges of soil. The previous crop's residue is cleared off ridge-tops into adjacent furrows to make way for the new crop being planted on ridges. Maintaining the ridges is essential and requires modified or specialised equipment (MDA, 2011).

Mulch-Till involves covering the ground with a layer of residues as mulch, which are cultivated with cultivators, sweeps, and chisels to mix with the soil partially. Such a practice is suitable for large and small farmers alike when growing both annual and perennial crops.

Reduced or Minimum Tillage is inherently like no-tillage. It aims to minimize damage to the topsoil. It includes the use of biological insecticides and fertilizers, mild chemicals, and reduced furrowing.

Ridge Tillage

Reduced/Minimum Tillage

Fig. 6. Types of conservation tillage

Table 3. Advantages and Disadvantages of Types of Conservation Tillage

Type	Major advantages	Major disadvantages
No-till or slot planting	Excellent erosion control. Soil moisture conservation. Minimum fuel and labour costs. Builds soil structure and health. The soil is left entirely undisturbed between harvesting and planting.	No incorporation. Increased dependence on herbicides. Slow soil warming on poorly drained soils. Residues may be caused by allelopathy (Butnariu, 2012; Bostan, et al., 2012) (a chemical process that a plant uses to keep other plants from growing too close to it) and high C:N ratios.
Mulch-Till	Tills the soil without turning it. It's a rough tilling method that leaves soil more intact and less prone to erosion. Incorporates last season's crop residues back into the soil, increasing nutrient content and humidity and reducing evaporation loss.	Soil temperatures under the stubble are cooler in the spring, potentially delaying maturity of warm season vegetables.
Strip-till	Clears residue from row area. Allows preplant soil warming and drying. Injection of nutrients into row area. Well suited for poorly drained soils. With residues incorporated, allelopathic substances (Butnariu, 2012) break down relatively quickly and are usually not a problem.	Cost of preplant operation. Strips may dry too much, crust, or erode without residue. Not suited for drilled crops. Potential for nitrogen fertilizer losses. Timeliness in wet falls.

Ridge Plant	Excellent for furrow irrigation or poorly drained soils. Ridges warm up and dry out quickly. Well suited for organic production. The seedbed is as a mound or ridge. Reduces runoff and increases soil temperature for the germinating seeds. Excellent erosion control if on contour. Low fuel and labour costs.	No incorporation. Must be annual row crops. Wheel spacing and other machinery modifications may be needed. Creating and maintaining ridges. No incorporation. Narrow row soybeans and small grains not well suited. No forage crops. Machinery modifications required.
Reduced or minimum	**Helps preserve the soil's natural structure. Makes soil more resistant to erosion.** Soil water–holding capacity and c**rop** use water increases. Runoff water losses and evaporation are reduced. Higher microbial activity, earthworm populations and higher total carbon found (Mihovsky and Pachev, 2012).	**Seed germination is slower. Tendency for insect populations increase.** Sowing operations are difficult with ordinary equipment. Continuous use of herbicides causes pollution and perennial weed problems. High inputs of fertilizers, pesticides as rate of decomposition of soil organic matter (SOM) is slow.

9. STRENGTHENING CLIMATIC RESILIENCE THROUGH CONSERVATION TILLAGE PRACTICES

Figure 7 will explain how conservation tillage can function to enhance climate resilience by improving soil health from the aspect of water dynamics, soil physicochemical properties, and the eco-environment and by reducing greenhouse gases to mitigate the negative impact of climate change

9.1 Improve the hydrologic function of soil:

Conservation tillage has positive effects on soil hydrologic function enhancing soil water storage, reducing soil evaporation and reducing evapotranspiration (Yang et al., 2018). Conservation tillage can enhance water infiltration and reduce water evaporation, thus increasing soil water storage and improving water use efficiency, which gives agriculture higher resilience to cope with climate change.

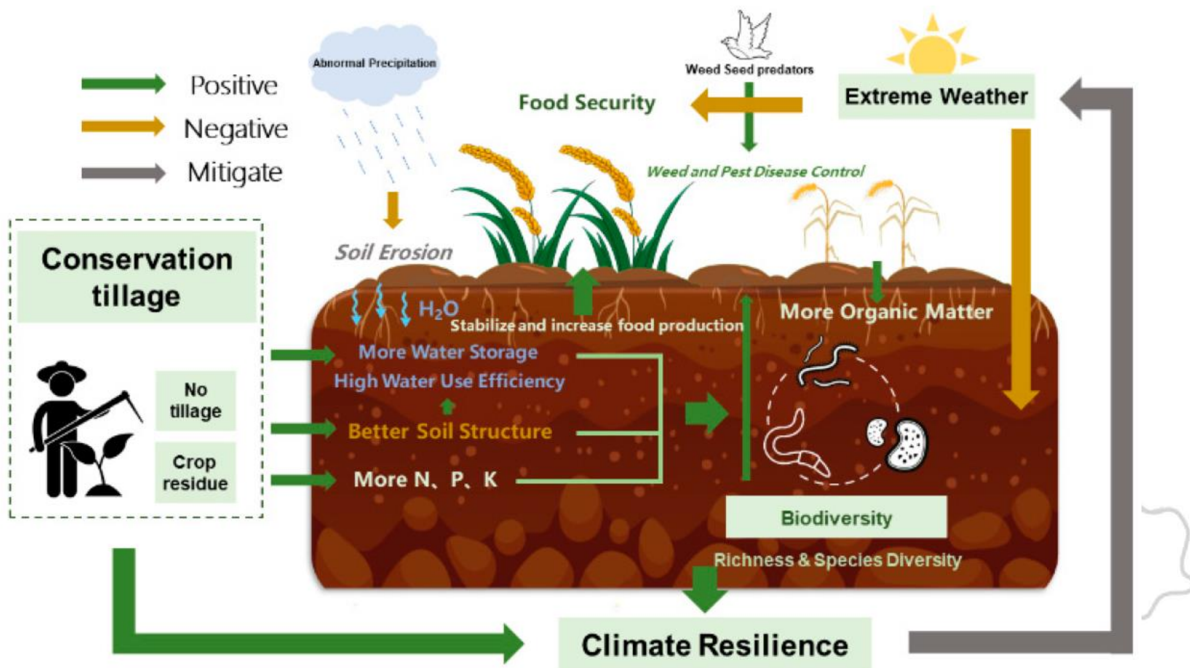

Fig. 7. How Conservation Tillage Enhances Climate Resilience in Agriculture (Deng et al., 2022)

9.2 Improve soil structure and increase soil nutrients:

The two practices with major impact on soil conservation are crop residue management and tillage. With windstorms and heavy rain eroding the topsoil and rob soil of nutrients, thereby reducing crop yield, CT can promote the increase in soil organic matter and total nitrogen content and can improve soil structure as well (Liu.et al., 2021) with high carbon sequestration and mitigate the devastation from climate change (Anikwe and Ubochi, 2007). No-tillage was able to decrease soil bulk density, increase soil aggregate stability, increase soil nutrients, increased soil organic carbon, increase soil total nitrogen and particulate organic matter, increase soil organic carbon content (Li et al. 2020; Islam and Reeder, 2014) and available phosphorus concentration (Kushwa et al., 2016) and potassium, A and D (Karathanasis and Wells, 1990). CT can increase soil nutrients through stubble mulching with improved infiltration, water-holding capacity (Schwab et al., 2002), fertility and disease resistance thereby mitigating the impact of climate change on agriculture and increasing climate resilience.

9.3 Reduce greenhouse gases to mitigate climate change:

Assessing strategies to help mitigate the rise in atmospheric CO_2 includes evaluation of management decisions concerning tillage practices that influence soil carbon loss by soil disturbance/residue mixing and time of tillage operations (Prior et al., 2004). Conservation systems are an effective way to increase soil organic matter, store soil carbon (ESA, 2000), and reduce greenhouse gases by reducing fossil fuel use (Archer et al., 2002; West and Marland, 2002). No-till has been reported to yield a carbon sequestration rate of 367–3667 kg CO_2 ha-1 year-1 (Lal et al., 2007; Tebrügge & Epperlein, 2011).) CT practices decreased the exposure of un-mineralized organic substances to the microbial processes, thus reducing SOM decomposition and CO_2 emission (Gambolati et al., 2005), and influenced other greenhouse gases (GHGs) notably, nitrous oxide (N_2O) (Kessavalou et al., 1998). and methane (NH_4) (Parkin and Kasper, 2006). Nitrous oxide from soils contributes 38% of the emissions to the atmosphere (Bellarby et al., 2008) while NH_4 is the most potential GHG after CO_2 (IPCC, 2001). Tilled soil aerates it with oxygen resulting in increased aerobic turnover in the soil and increased gaseous emissions (Skiba, et al., 2002). No-tillage can reduce 15.5% of CH emissions, which can reduce the global warming potential, under specific conditions (Huang et al., 2018). The benefits of conservation tillage in climate change mitigation primarily come from increased soil C sequestration (Smith *et al*., 2007; Lal, 2009).

9.4 Improve the Soil's Eco-Environment to Achieve Weed and Pest Control

Climate change creates a suitable and favourable environment for weed growth and pest diseases with abundance of soil organisms (fungi and nematodes), raising land-based temperature. CT improves on soil health, provides for soil bacterial richness and diversity (Wang et al., 2016; Cai et al., 2021) especially the natural enemies of pests, thereby achieving pests' control (Zhang et al., 2015; Jaques, 1983). Using crop rotation along with CT can increase biodiversity to achieve weed control (Yang et al., 2018; Yu et al., 2022).

9.5 Stabilize and Increase Yield, Enhance Food Security and Economic Benefits:

Conservation tillage improves farming conditions from the aspect of hydrologic function, water retention and soil health, soil physicochemical properties, and the eco-environment, which stabilize and increase crop yield, enhance agriculture's resistance to climate change, and maintain its core functions. The stable and increased crop yields ensure food security, provide raw materials for the industry, and help improve the economy (Li et al., 2020; Islam and Reeder, 2014). No-till farming with no repeated ploughing reduces fuel usage, equipment maintenance costs, and associated labour.

CONCLUSION

Climate change is manifested by climate warming, abnormal precipitation, floods, droughts, windstorms, and other extreme weather, which cause several problems to agriculture, including disturbance to soil structure, loss of soil nutrients, decrease in biodiversity, etc.

Climate change mitigation action would significantly reduce the severity of impacts, while climate change adaptation action will reduce them and will then enhance the resilience of ecosystems to climate change.

The societal response to climate-change-induced impacts is biophysical – biological impacts and physical impacts. These impacts have "Actors" and "Enablers" which facilitate them with mediating factors given as responses.

Climatic resilience is the ability to recover from, or mitigate vulnerability to, climate-related shocks such as floods and droughts, and has become a new paradigm for sustainable development.

Sustainability science, which evolves using interdisciplinary research involving scientists and social actors to produce knowledge that supports and informs solutions, transformations towards implementation of the Sustainable Development Goals (SDGs).

A climate framework helps organizations become more sustainable from an environmental perspective through green alternatives and lowered emissions e.g**.** The Hyogo Framework; The Sendai Framework; The Paris Agreement; etc.

The agricultural sector can be manipulated for the dual benefits of changing its role from CO_2 producer into CO_2 absorber reducing GHG emissions and acting as a sink by storing and sequestering CO_2 from the atmosphere in the form of soil carbon.

CT can result in an increase in greenhouse gases and can mitigate climate change because the quantity of additional organic carbon in soil under no-tillage is relatively small to improve resilience in response to climate change.

To achieve sustainable development of agriculture, regenerative agriculture which includes not only the use of CT, but also crop rotation, cover crops, and holistic grazing can be used to achieve sustainable agriculture development maximizing the benefits of CT is advocated.

Using cover crops, crop rotation, along with CT, is a win-win crop management option to offset the adverse effect of CT, improve soil health, weed management, soil nutrients enhancement, control pest diseases, to increase yield and mitigate climate change by reducing greenhouse gases

As agriculture faces more and more severe climate change challenges, Nigeria should develop frameworks based on CT to improve climate resilience. In the future, CT can be better implemented to achieve climate resilience under different conditions across Nigeria.

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CAPACITY BUILDING AND EXTENSION SERVICES IN RELATION TO TILLAGE SYSTEMS

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ABSTRACT

This paper discusses the importance of capacity building and extension services in promoting sustainable tillage systems, particularly in the context of mitigating climate change impacts. Tillage systems play a critical role in agricultural productivity, and with climate change posing significant threats, adopting sustainable practices is essential. The study highlights the various tillage systems—conventional, reduced, and no-till—and their respective advantages and challenges. It further emphasizes the role of capacity building in equipping farmers, extension agents, and agricultural stakeholders with knowledge and skills to adopt best practices in tillage. Extension services are highlighted as a vital link between research and farmers, ensuring the dissemination of information, technologies, and practices. The integration of capacity building and extension services enhances knowledge transfer, increases adoption of sustainable practices, and ultimately improves agricultural productivity and resilience in the face of climate change.

KEYWORDS: Capacity building, Extension services, Tillage systems, Sustainable agriculture, Climate change, Agricultural productivity, Knowledge transfer, Soil conservation, Nigeria.

INTRODUCTION

Background and Importance of Tillage Systems

Tillage systems play a critical role in agricultural practices, influencing soil health, crop productivity, and overall farm management. Tillage has been a fundamental aspect of farming, evolving from the use of simple hand tools to sophisticated machinery for soil preparation and crop production. Tillage refers to the mechanical manipulation of soil to prepare seedbeds, control weeds, and incorporate organic matter and fertilizers (Smith, 2016; Feng & Balkcom, 2017; Lal, 2020).

In the face of escalating climate change, the resilience and sustainability of tillage systems to increasing agricultural productivity are paramount. This is because climate change poses significant threats to agricultural productivity, affecting food security, livelihoods, and overall economic stability. Hence, tillage systems must evolve to mitigate and adapt to these environmental changes. To adequately mitigate and adapt to these changes, there must be enhancement of knowledge and tools necessary for sustainable tillage practices. These enhancements of knowledge and techniques are therefore dependent on capacity building and extension services to empower farmers and other stakeholders.

The choice of tillage practices within the discourse of climate change must recognize mitigation and adaptation strategies to combat environmental menace. These choices of tillage systems range from the traditional or conventional tillage, reduced tillage, to the no-till systems. The conventional or traditional tillage involves intensive soil disturbance, typically using plows, harrows, and other implements to turn and break the soil. This tillage practice can lead to soil erosion, loss of organic matter, and decreased soil fertility. In the case of reduced tillage, also known as the conservation tillage method, there is minimized soil disturbance while preparing the seedbed. The reduced tillage is carried out as either no-till or reduced tillage. The use of any reduced form of tillage practices have been shown to enhance soil structure, and improve water infiltration, preserve soil structure, minimize erosion, better aeration, improved soil health and fertility, better weed control by disrupting their growth cycles and burying the weed seeds,

incorporation of crop residues into the soil, enhancing organic matter and nutrient cycling, reduction in exposure of crops to pest, diseases, soil-borne pathogens and contribute less to environmental changes (Altieri & Nicholls, 2003; Derpsch et al., 2010; Mitchell, et al., 2012; Lal, 1991; Giller et al., 2009).

Despite these aforementioned benefits, tillage systems pose negative impacts, such as soil erosion, loss of organic matter, disruption of soil biota, among others. Hence, the need to address climate change adaptation and soil health management will further enhance the sustainability and resilience of tillage sytems (Altieri, 2002; Franzluebbers, 2005). Therefore, understanding and implementing appropriate tillage system is crucial to adequately mitigate and adapt to the pressure of climate change. The question then is, where is the place of capacity building and extension services in order to ensure the resilience and sustainability of tillage systems?

Objectives of the Presentation

The objectives of this presentation include, to:

1. provide an understanding the different types of tillage practices and their applications in modern agriculture.
2. highlight the the role of capacity building in enhancing the knowledge and skills of farmers and agricultural stakeholders regarding tillage practices.
3. examine the role of extension services to effectively disseminate information and best practices related to tillage systems to farmers.
4. integrate capacity building and extension services as two critical elements to promote sustainable tillage practices.
5. discuss challenges and opportunities in the adoption of sustainable tillage systems.

OVERVIEW OF TILLAGE SYSTEMS

Definition and Types of Tillage Systems

Tillage refers to the mechanical manipulation of soil to prepare seedbeds, control weeds, incorporate organic matter and fertilizers, and manage crop residues. The main goal of tillage is to create a favorable soil environment for seed germination and crop growth. Tillage systems can be broadly categorized into three types:

1. **Conventional/Traditional Tillage**: This system involves intensive soil disturbance using implements such as plows, harrows, and cultivators. The soil is turned over, creating a fine seedbed but often leading to soil erosion and loss of organic matter.
2. **Reduced Tillage**: This system minimizes soil disturbance while still preparing the seedbed. Techniques include strip-till and ridge-till, where only a portion of the soil is tilled, leaving the rest undisturbed.
3. **No-Till**: Here, seeds are planted directly into undisturbed soil, maintaining soil structure and minimizing erosion. Crop residues are left on the soil surface, enhancing organic matter and soil moisture conservation.

Historical Perspective

The practice of tillage dates back thousands of years, with early farmers using simple hand tools like digging sticks, cutlass and hoes. The advent of the plow around 3000 BCE marked a significant advancement, allowing for more efficient soil preparation. Over centuries, tillage tools evolved from wooden to iron and steel implements, improving durability and effectiveness during soil preparation.

The Industrial Revolution in the 18th and 19th centuries brought about mechanization in agriculture, with the development of animal-drawn and later tractor-drawn plows and harrows. This period saw a dramatic increase in agricultural productivity, but also led to widespread soil degradation and erosion due to intensive tillage practices.

In the mid-20th century, concerns about soil conservation and sustainability led to the development and adoption of reduced tillage and no-till systems. These practices aimed to mitigate the negative impacts of conventional tillage by preserving soil structure, reducing erosion, and enhancing soil health.

In recent years are more advancements in technology and growing emphasis on sustainable agriculture, these have driven innovations in tillage systems.

Some of these notable trends and innovations include:

1. **Precision Agriculture**: This is the use of GPS and GIS technologies to optimize tillage operations, reducing overlap and minimizing soil disturbance. Precision tillage

equipment allows for targeted soil management, improving efficiency and reducing environmental impact.

2. **Conservation Tillage**: Integration of conservation practices such as cover cropping and crop rotation with reduced tillage and no-till systems. These practices enhance soil health, increase biodiversity, and improve water management.

3. **Biological Tillage**: Utilization of plant roots and soil organisms to naturally aerate and structure the soil. Cover crops with deep root systems, such as radishes and legumes, can break up compacted soil layers and improve soil fertility.

4. **Advanced Machinery**: Development of innovative tillage implements, such as vertical tillage tools and strip-till machines, that minimize soil disturbance while maintaining crop productivity. Robotics and automation in tillage operations are emerging, allowing for more precise and labor-efficient soil management

These trends reflect a shift towards more sustainable and efficient tillage practices, aiming to balance productivity with environmental conservation (Braun et al., 2006; Davis, 2006; Anderson & Feder, 2004; Lal, 1991; Johnson & Huggins, 1999; Gebbers, & Adamchuk, 2010; Swanson & Rajalahti, 2010; Kassam, Friedrich, & Derpsch, 2019; Shaktawat & Swaymprava, 2024).

CAPACITY BUILDING IN TILLAGE SYSTEMS

Importance of Capacity Building

Capacity building in tillage systems is essential for enhancing the knowledge, skills, and competencies of farmers, extension agents, engineers and other agricultural stakeholders. Effective capacity building ensures that these stakeholders can adopt, implement, and sustain improved tillage practices, leading to increased agricultural productivity, environmental sustainability, and resilience to climate change.

Capacity building is vital for these key reasons:

1. **Enhancing Knowledge and Skills**: Capacity building provides farmers and stakeholders with up-to-date information on best practices, new technologies, and sustainable tillage methods. Empowers individuals to make informed decisions regarding soil management and crop production.

2. **Promoting Sustainable Agriculture**: Encourages the adoption of conservation tillage practices that reduce soil erosion, improve soil health, and enhance biodiversity. Supports the transition to more sustainable and environmentally friendly farming systems.

3. **Improving Economic Outcomes**: Increases crop yields and farm profitability by optimizing tillage practices and reducing input costs. Enhances market access and competitiveness for smallholder farmers.

4. **Building Resilience to Climate Change**: Equips farmers with strategies to adapt to changing climatic conditions, such as improved water management and soil conservation techniques. Reduces vulnerability to extreme weather events and other climate-related risks.

Key Stakeholders and Their Roles

Effective capacity building in tillage systems involves the collaboration of various stakeholders, each playing a crucial role:

1. **Farmers**: These are the primary beneficiaries of capacity-building initiatives and they actively participate in training programs, adopt new practices, and share knowledge with peers.

2. **Extension Agents**: Serve as information intermediaries between research institutions and farmers and also provide training, and support to farmers in knowledge exposure on improved tillage practices.

3. **Engineers and Technical Experts:** Serve as technical intermediaries between research institutions and farmers. Provide technical assistance, training, and support to farmers in implementing improved tillage practices.

4. **Research Institutions**: The research institutions develop and disseminate new knowledge and technologies related to tillage systems. Conduct field trials, demonstrations, and impact assessments to validate and promote best practices.

5. **Government Agencies**: Formulate and implement policies that support capacity-building efforts and sustainable agriculture. Provide funding, infrastructure, and resources for training programs and extension services.

6. **Non-Governmental Organizations (NGOs)**: Facilitate community-based training and capacity-building initiatives. Mobilize resources and advocate for sustainable agricultural practices.

7. **Private Sector**: Develop and supply innovative tillage equipment and technologies. Partner with other stakeholders to deliver training and support services to farmers.

Approaches and Strategies for Capacity Building

To carry out effective capacity building in tillage systems, a combination of approaches and strategies tailored towards the needs of different stakeholders must be established. These approaches and strategies, are to effectively build the capacity of stakeholders in tillage systems, leading to more sustainable and productive agricultural practices. According to FAO (2016), some of these approaches and strategies include the use of:

1. **Training and Workshops**: Conduct hands-on training sessions, field demonstrations, and workshops to teach farmers and extension agents about improved tillage practices. Focus on practical skills, such as equipment operation, soil health management, and conservation techniques.
2. **Farmer Field Schools (FFS)**: Establish participatory learning platforms where farmers can learn from each other and experiment with new tillage methods. Promote experiential learning and peer-to-peer knowledge exchange.
3. **Extension Services and Advisory Support**: Provide continuous knowledge assistance and advisory services through extension agents. Utilize mobile technology, helplines, and digital platforms to reach a wider audience.
4. **Engineering and Technical Support:** Provide continuous technical assistance and advisory services. Utilize their technical knowledge to provide know-how.
5. **Capacity Building for Extension Agents and Technical Staff**: Train extension agents and Technical Staff on the latest tillage technologies and sustainable practices. Enhance their skills in communication, facilitation, and participatory approaches.
6. **Collaborative Research and Development**: Foster partnerships between research institutions, government agencies, NGOs, and the private sector to develop and disseminate new tillage technologies. Engage farmers in participatory research to ensure relevance and applicability of innovations.
7. **Monitoring and Evaluation (M&E)**: Implement robust M&E systems to assess the effectiveness of capacity-building initiatives. Use feedback from stakeholders to continuously improve training programs and strategies.

Use of Capacity Building in Agricultural Tillage Systems in Nigeria

Capacity building is a crucial strategy for enhancing the skills, knowledge, and competencies of individuals and organizations involved in agriculture. In Nigeria, capacity building efforts in agricultural tillage systems are essential for promoting sustainable farming practices, improving soil health, and increasing crop productivity (Nwaneri et al., 2022).

Tillage systems, which involve the preparation of soil for planting through mechanical agitation, have significant impacts on soil structure, fertility, and erosion. Effective capacity building programs can educate farmers on the best tillage practices, leading to improved agricultural outcomes and environmental sustainability (Sennuga, & Oyewole, 2020).

Recent studies indicate that capacity building initiatives have had a positive impact on agricultural tillage systems in Nigeria. Some of these studies include:

a) **Adoption Rates**: Training programs have significantly increased the adoption of conservation tillage practices among Nigerian farmers. A study by Akinbile & Odebode, (2002) found that farmers who participated in capacity building workshops were 40% more likely to adopt no-till and reduced tillage practices compared to those who did not receive training.

b) **Soil Health**: Improved tillage practices resulting from capacity building efforts have led to better soil health. According to research by Junge et al., (2008), areas where farmers received training on sustainable tillage practices reported a 25% reduction in soil erosion and a 15% increase in soil organic matter within two years.

c) **Crop Yields**: Capacity building in tillage systems has also contributed to higher crop yields. Data from the Federal Ministry of Agriculture and Rural Development (FMARD) shows that farmers who adopted improved tillage practices through capacity building programs experienced an average yield increase of 20% for major crops such as maize and rice (FMARD, 2021).

Specific Case Studies and Success Stories

1. **The Kano Agricultural Development Project (KADP)**: The KADP has been instrumental in building the capacity of farmers in northern Nigeria. Through series of workshops and field demonstrations, the project has trained several farmers and improved methods of crop production through sustainable practices ranked first among the expectations of farmers from extension services (Ammani et. al., 2011).

2. **The Oyo State Agricultural Initiative**: This state-run program focuses on training young farmers in modern tillage techniques. The initiative has successfully trained 5,000 young farmers, resulting in increased adoption of no-till farming and a reduction in land degradation (Harry & Abudu, 2022).

Despite the successes, some challenges hinder the effectiveness of capacity building in tillage systems in Nigeria:

1. **Limited Resources**: Many capacity building programs lack adequate funding and resources, which affects their reach and quality (Camillone et al., 2020).

2. **Access to Training**: Geographic and infrastructural barriers often limit farmers' access to training programs, particularly in remote areas (Lahai, Goldey & Jones, 1999).

EXTENSION SERVICES IN TILLAGE SYSTEMS

Role of Extension Services

Extension services play a pivotal role in bridging the gap between research and practice in agriculture. They serve as the conduit through which scientific knowledge, innovations, and best practices are transferred to farmers. In Nigeria, where agriculture remains a significant part of the economy, extension services are vital for promoting sustainable agricultural practices, improving crop yields, and enhancing food security (Noah & Abidoye, 2019; Ekong, 2020).

According to the Federal Ministry of Agriculture and Rural Development (FMARD), Nigeria has approximately 14,000 extension agents serving millions of smallholder farmers across the country (FMARD, 2021). Despite this number, the extension agent-to-farmer ratio remains inadequate, with one agent for every 2,500 farmers, far below the recommended ratio of 1:500 (Etuk, Okoro & Tombere, 2023).

Specifically, in the context of tillage systems, extension services carry out these roles:

i. **Disseminate Information**: Provide farmers with up-to-date information on the benefits, techniques, and technologies related to various tillage systems

ii. **Facilitate Adoption of Best Practices**: Encourage the adoption of sustainable tillage practices by demonstrating their benefits and providing hands-on training.

iii. **Support Decision-Making**: Help farmers make informed decisions about soil management, crop production, and resource utilization.

iv. **Enhance Capacity**: Build the technical skills and knowledge of farmers and other agricultural stakeholders through training and continuous education (Swanson & Rajalahti, 2010; Noah & Abidoye, 2019; Ekong, 2020).

However, recent data highlights several challenges faced by extension services in Nigeria:

1. **Inadequate Funding**: Many extension programs suffer from limited financial support, which affects the availability of resources and the quality of services provided (Harry, A. T., & Abudu, S. (2022) & Idowu, 2018).
2. **Insufficient Training**: Extension agents often lack up-to-date training, which hampers their ability to effectively transfer knowledge and skills to farmers (Sanni et al., 2008).
3. **Logistical Constraints**: Poor infrastructure and transportation issues make it difficult for extension agents to reach remote farming communities (Ezima et al., 2023).

Despite these challenges, extension services have had a positive impact on Nigerian agriculture. Studies have shown that farmers who regularly interact with extension agents tend to adopt improved farming practices more readily, leading to higher productivity and income levels (Agbamu, 2005). The adoption of improved seed varieties and modern farming techniques has been significantly higher among farmers with access to extension services (Oyetunde-Usman, Olagunju & Ogunpaimo, 2021).

A notable example of extension services is in the Agricultural Transformation Agenda (ATA) and afterwards the Agricultural Transformation Agenda Support Programme (ATASP-1). These initiatives focused on enhancing the capacity of extension agents and improving their reach to farmers. As a result, there was a marked increase in the adoption of new technologies and farming practices, leading to improved agricultural output in several regions (FMARD, 2021).

Models of Extension Services

There are different models of extension services that can be employed to effectively reach and support farmers. These models include:

1. **Traditional Public Extension**: Here, the extension service is fully government-funded. The extension services are provided through a network of extension officers who visit farms, conduct demonstrations, and offer advice (Anderson & Feder, 2004).
2. **Private Sector Extension**: Private companies offer extension services, often linked to the sale of agricultural inputs and equipment. This model can be highly effective but may focus more on profit-driven advice.
3. **Farmer Field Schools (FFS)**: A participatory approach where farmers learn by doing. FFS involves groups of farmers who meet regularly to learn about and experiment with new farming techniques, including tillage practices (Braun et al., 2006).
4. **Digital and ICT-Based Extension**: Use of mobile phones, apps, and online platforms to deliver extension services. This model can reach a large number of farmers quickly and cost-effectively, especially in remote areas (Aker, 2011).
5. **Community-Based Extension**: Local community organizations and cooperatives provide extension services tailored to the specific needs of their members. This model fosters local ownership and sustainability.

Effective Communication and Outreach Techniques

Effective communication and outreach are crucial for the success of extension services. These communication techniques are ways used to properly disseminate trainings and information to the stakeholders. Key techniques include:

1. **Demonstration Plots**: Setting up demonstration plots to showcase the benefits of different tillage systems in a real-world context. Farmers can observe the results and learn practical applications (Franzel & Wambugu, 2007).
2. **Field Days and Workshops**: Organizing field days and workshops where farmers can interact with extension agents, researchers, and fellow farmers to discuss and learn about tillage practices (Davis & Place, 2003).
3. **Use of Mass Media**: Leveraging radio, television, and print media to reach a broad audience with information on tillage systems. These channels can be particularly effective in areas with high media penetration (Chapman et al., 2003).

4. **Farmer-to-Farmer Extension**: Encouraging successful farmers to share their experiences and knowledge with peers. This peer learning approach can be highly persuasive and relatable (Lukuyu et al., 2012).

5. **Digital Platforms**: Utilizing mobile apps, SMS services, and online portals to provide timely and relevant information to farmers. Digital platforms can facilitate two-way communication and instant feedback (Aker, 2011).

Training and Development Programs for Farmers

Training and development programs are essential components of extension services. These programs should be designed to address the specific needs and challenges faced by farmers:

1. **Hands-On Training**: Practical, hands-on training sessions where farmers can learn by doing. Topics might include soil health management, operation and maintenance of tillage equipment, and conservation practices.

2. **Workshops and Seminars**: Interactive workshops and seminars conducted by experts in tillage systems. These events provide opportunities for farmers to gain in-depth knowledge and ask questions.

3. **Continuous Education Programs**: Ongoing education programs that keep farmers updated on the latest developments in tillage technology and practices. This could involve regular newsletters, online courses, and refresher training sessions.

4. **Capacity Building for Extension Agents**: Training programs for extension agents to ensure they have the latest knowledge and skills to effectively support farmers. This includes training on new tillage technologies, communication skills, and participatory approaches (Swanson & Rajalahti, 2010).

5. **Peer Learning Groups**: Formation of peer learning groups where farmers can share experiences, discuss challenges, and collectively find solutions. This fosters a collaborative learning environment and strengthens community ties (Lukuyu et al., 2012).

INTEGRATING CAPACITY BUILDING AND EXTENSION SERVICES

Synergies between Capacity Building and Extension Services

The integration of capacity building and extension services can create powerful synergies that enhance the effectiveness of agricultural interventions and hence better tillage practices. According to Anderson & Feder, (2004), Swanson & Rajalahti, (2010), capacity building and extension services play a pivotal role in disseminating knowledge, skills, and technologies to farmers as both components play complementary roles in promoting sustainable farming practices, enhancing productivity, and ensuring food security.

Capacity building focuses on developing skills and knowledge, while extension services aim to disseminate this knowledge to farmers and support its practical application (Aker, 2011). Hence, the integration of capacity building and extension services can lead to a more efficient and effective agricultural system. By aligning these two components, the transfer of knowledge and skills becomes more seamless, fostering an environment where farmers are better equipped to adopt and implement sustainable agricultural practices (Adesoji & Tunde, 2012).

The integration of capacity building and extension services promote the adoption of sustainable tillage systems through the following ways:

1. **Enhanced Knowledge Transfer**: Capacity building programs equip farmers with essential knowledge and skills, while extension services provide ongoing support and reinforcement, ensuring that new practices are effectively implemented and sustained (Swanson & Rajalahti, 2010).
2. **Increased Adoption of Innovations**: Combining capacity building with extension services fosters a conducive environment for the adoption of innovative tillage practices. Extension agents can tailor their support to the specific needs and contexts of farmers, making it easier for them to adopt and adapt new techniques (Anderson & Feder, 2004).
3. **Improved Problem-Solving**: Capacity building initiatives develop critical thinking and problem-solving skills among farmers. Extension services can then provide targeted assistance and facilitate peer learning, helping farmers address challenges collaboratively (Lukuyu et al., 2012).
4. **Strengthened Community Engagement**: Integrating these two components fosters stronger community ties and collective action. Farmers who have undergone capacity building are more likely to engage in community-based extension activities, sharing their knowledge and experiences with others (Braun et al., 2006).

Some empirical findings that highlight the positive impact of integrated capacity building and extension services on Nigerian agriculture include:

5. **Adoption of Improved Practices**: Farmers who received both capacity building training and regular extension support were 50% more likely to adopt improved agricultural practices compared to those who only received one form of support (Junge et al., 2021).
6. **Increased Productivity**: The Federal Ministry of Agriculture and Rural Development (FMARD) indicated that integrated capacity building and extension programs have led to a 30% increase in crop yields among participating farmers (FMARD, 2021).
7. **Enhanced Farmer Knowledge**: Integrated programs significantly improved farmers' understanding of sustainable farming techniques, resulting in better soil management and crop diversification (Issa, Auta, & Jaji, 2010).

Success Stories of Integrated Capacity Building and Extension Services

1. **The FADAMA III Project**: This World Bank-funded project has been successful in integrating capacity building and extension services across the 36 States of Nigeria. By providing training on modern farming techniques and offering regular extension support, the project has improved agricultural productivity and livelihoods for over 2 million farmers (Iortyom, Abawua, & Shabu, 2020).

2. **The Agricultural Transformation Agenda (ATA) and by extension, the Agricultural Transformation Agenda Support Program (ATASP)**: Launched to promote sustainable agriculture in Nigeria, ATA focuses on integrating capacity building with

   extension services. The program has trained thousands of extension agents and farmers, leading to widespread adoption of improved agricultural practices (FMARD, 2021).

However, despite the successes, several challenges hinder the full integration of capacity building and extension services in Nigeria. Some of the identified challenges include:

1. **Funding Constraints**: Limited financial resources affect the sustainability and reach of integrated programs (Camillone et al., 2020).
2. **Infrastructure Deficits**: Poor infrastructure, particularly in rural areas, hampers the delivery of extension services and capacity building initiatives (Lahai, Goldey & Jones, 1999).
3. **Coordination Issues**: Lack of coordination between government agencies, non-governmental organizations, and the private sector can lead to fragmented efforts (Nwaneri et al., 2021).

To address these challenges, the following recommendations are proposed:

1. **Increased Investment**: Allocate more funding to integrated programs to enhance their scope and sustainability.
2. **Infrastructure Development**: Improve rural infrastructure to facilitate better delivery of services.
3. **Stakeholder Collaboration**: Foster partnerships among government, NGOs, and the private sector to ensure cohesive and coordinated efforts.
4. **Monitoring and Evaluation**: Implement robust monitoring and evaluation frameworks to assess the impact of integrated programs and identify areas for improvement.

Frameworks for Integrated Approaches

Effective integration of capacity building and extension services requires well-designed frameworks that align objectives, resources, and activities. Key components of such frameworks include:

1. **Participatory Approaches**: Engage farmers and other stakeholders in the design, implementation, and evaluation of capacity building and extension programs. This ensures that the programs are relevant, context-specific, and address the actual needs of the farming community (Davis & Place, 2003).

2. **Multi-Stakeholder Collaboration**: Foster partnerships among government agencies, research institutions, NGOs, and the private sector. Collaborative efforts can pool resources, expertise, and knowledge, enhancing the reach and impact of integrated programs (Swanson & Rajalahti, 2010).

3. **Holistic Training Programs**: Develop comprehensive training programs that combine theoretical knowledge with practical skills. Training should cover a wide range of topics, from technical aspects of tillage to business management and environmental sustainability (Leeuwis & Van den Ban, 2004).

4. **Extension Agent Capacity Building**: Invest in the continuous professional development of extension agents. Ensure they are equipped with the latest knowledge, communication skills, and participatory techniques to effectively support farmers (Anderson & Feder, 2004).

5. **Monitoring and Evaluation (M&E)**: Implement robust M&E systems to track progress, measure outcomes, and gather feedback. Use this data to continuously improve and adapt capacity building and extension strategies (Swanson & Rajalahti, 2010).

Measuring the Effectiveness of Capacity Building and Extension Services

Impact assessment is crucial for understanding the effectiveness of capacity building and extension services in tillage systems. It helps to evaluate whether the initiatives are achieving their intended goals, identify areas for improvement, and ensure accountability. The key aspects of measuring effectiveness include:

1. **Outcome Evaluation**: According to Davis (2006) surveys and interviews can capture these changes in indices over time. It could involve assessing changes in farmers' knowledge, attitudes, and practices (KAP) related to tillage systems.

2. **Behavioral Change**: Evaluating the adoption rates of improved tillage practices among farmers. High adoption rates indicate successful capacity building and extension efforts (Anderson & Feder, 2004).

3. **Productivity and Sustainability**: Measuring improvements in crop yields, soil health, and environmental sustainability as a result of adopting new tillage practices. These indicators reflect the long-term impact of the interventions (Pretty, 2008).

4. **Economic Benefits**: Analyzing the economic impact on farmers, such as increased income, reduced costs, and improved market access. Economic benefits are strong indicators of the viability and attractiveness of the practices promoted (Birkhaeuser, Evenson, & Feder, 1991).

Tools and Techniques for Impact Assessment

Various tools and techniques can be employed to assess the impact of capacity building and extension services:

1. **Surveys and Questionnaires**: Structured surveys and questionnaires are commonly used to collect quantitative data on farmers' KAP, adoption rates, and economic benefits. They provide a broad overview of the impact across a large population (Davis, 2006).

2. **Interviews and Focus Groups**: In-depth interviews and focus group discussions provide qualitative insights into farmers' experiences, challenges, and perceptions. These methods help to understand the context and reasons behind the observed changes (Krueger, 2014).

3. **Field Observations**: Direct observations in the field allow for the assessment of actual practices and conditions. Observers can document the implementation of tillage practices and their effects on soil and crop health (Pretty, 2008).

4. **Experimental and Quasi-Experimental Designs**: Controlled experiments and quasi-experimental designs, such as randomized controlled trials (RCTs) and before-and-after studies, provide robust evidence of causal impacts. These methods help to isolate the effects of the interventions from other factors (Glennerster & Takavarasha, 2014).

5. **Case Studies**: Detailed case studies of specific communities or projects offer comprehensive insights into the processes and outcomes of capacity building and extension services. They highlight best practices and lessons learned.

Data Collection and Analysis for Impact Assessment

Effective data collection and analysis are critical for accurate and reliable impact assessment. Key steps include:

1. **Baseline Data Collection**: Collecting baseline data before the implementation of capacity building and extension activities. This provides a reference point for measuring changes and impacts over time (Glennerster & Takavarasha, 2014).

2. **Monitoring and Continuous Data Collection**: Implementing ongoing monitoring systems to track progress and gather data throughout the project. Regular data collection helps to identify trends and make timely adjustments (Davis, 2006).

3. **Data Triangulation**: Using multiple data sources and methods to validate findings and ensure accuracy. Triangulation enhances the credibility of the impact assessment results (Krueger, 2014).

4. **Quantitative Analysis**: Applying statistical techniques to analyze survey and experimental data. Descriptive statistics, inferential statistics, and econometric models are commonly used to assess changes and identify determinants of impact (Glennerster & Takavarasha, 2014).

5. **Qualitative Analysis**: Analyzing qualitative data from interviews, focus groups, and case studies using content analysis, thematic analysis, or narrative analysis. These techniques help to identify patterns, themes, and insights (Yin, 2009).

6. **Reporting and Dissemination**: Presenting the findings in clear, concise reports that communicate the impact and lessons learned to stakeholders. Effective dissemination ensures that the results inform future capacity building and extension efforts (Pretty, 2008).

CHALLENGES AND OPPORTUNITIES

Common Challenges in Capacity Building and Extension Services

Despite the significant benefits of capacity building and extension services, several challenges hinder their effectiveness:

1. **Limited Resources**: Funding constraints often limit the scope and reach of extension programs. Insufficient financial resources can result in inadequate training, low extension agent-to-farmer ratios, and poor infrastructure (Anderson & Feder, 2004).

2. **Fragmented Services**: Lack of coordination among different agencies and stakeholders can lead to fragmented and inconsistent services. This can confuse farmers and reduce the overall impact of capacity-building initiatives (Swanson & Rajalahti, 2010).

3. **Inadequate Training for Extension Agents**: Extension agents may lack the necessary training and skills to effectively deliver services. Continuous professional development is often neglected, leading to outdated knowledge and techniques (Rivera & Alex, 2004).

4. **Resistance to Change**: Farmers may be resistant to adopting new practices due to cultural beliefs, fear of failure, or satisfaction with traditional methods. Overcoming

this resistance requires sustained effort and persuasive communication (Leeuwis & Van den Ban, 2004).

5. **Information Gaps and Accessibility**: Limited access to timely and relevant information can impede the effectiveness of extension services. In remote areas, poor communication infrastructure exacerbates this problem (Aker, 2011).

6. **Gender Inequality**: Gender disparities can limit women's access to capacity-building and extension services. Cultural norms and biases may prevent women from participating fully in training programs and decision-making processes (Doss, 2014).

Opportunities for Improvement and Innovation

Addressing these challenges presents numerous opportunities for enhancing capacity building and extension services:

1. **Leveraging Digital Technology**: Digital platforms, mobile apps, and online resources can revolutionize extension services by providing real-time information, training modules, and decision-support tools to farmers. Technologies such as SMS-based advisory services can reach remote and underserved areas (Aker, 2011).

2. **Strengthening Partnerships**: Enhancing collaboration among government agencies, NGOs, research institutions, and the private sector can lead to more coordinated and comprehensive services. Public-private partnerships can also mobilize additional resources and expertise (Swanson & Rajalahti, 2010).

3. **Fostering Participatory Approaches**: Engaging farmers in the design and implementation of capacity-building programs ensures that services are tailored to their needs. Participatory approaches, such as Farmer Field Schools, encourage peer learning and collective problem- solving (Braun et al., 2006).

4. **Enhancing Training Programs**: Investing in the continuous professional development of extension agents is crucial. Training programs should focus on both technical skills and soft skills, such as communication and facilitation (Rivera & Alex, 2004).

5. **Promoting Gender Inclusivity**: Ensuring that capacity-building and extension services are inclusive and accessible to women is essential. Tailored programs that address the specific needs and constraints of women farmers can enhance their participation and impact (Doss, 2014).

6. **Innovative Funding Models**: Exploring innovative funding mechanisms, such as blended finance, crowd-funding, and impact investments, can supplement traditional funding sources. These models can provide sustainable financing for extension services.

Policy Recommendations

To create an enabling environment for effective capacity building and extension services, several policy recommendations can be made:

1. **Increase Investment in Extension Services**: Governments should allocate more resources to agricultural extension services. Increased funding can improve infrastructure, expand outreach, and enhance the quality of training programs (Anderson & Feder, 2004).
2. **Promote Integrated Approaches**: Policies should encourage the integration of capacity building and extension services. Coordinated efforts among different stakeholders can lead to more effective and comprehensive services (Swanson & Rajalahti, 2010).
3. **Support Digital Agriculture**: Governments and development agencies should invest in digital infrastructure and promote the use of digital tools in agriculture. Policies that support internet connectivity, mobile networks, and digital literacy are essential (Aker, 2011).
4. **Enhance Extension Agent Training**: Establish Farmer Field Schools (FFS), national standards for the training and certification of extension agents. Continuous professional development should be mandated and supported through training institutes and on-the-job learning opportunities (Rivera & Alex, 2004).
5. **Promote Gender Equality**: Policies should aim to eliminate gender disparities in access to extension services. This includes targeted programs for women farmers, gender-sensitive training materials, and inclusive decision-making processes (Doss, 2014).
6. **Foster Public-Private Partnerships**: Encourage the private sector to play a more active role in extension services through incentives and collaborative frameworks. Public-private partnerships can leverage additional resources and innovation.

International Case Studies and Best Practices

Some countries outside the shored of Nigeria have recorded ways capacity building and extension services have been used to enhance the tillage systems. Some of these examples include;

Kenya: Farmer Field Schools (FFS) Approach

The Farmer Field Schools (FFS) approach in Kenya has been instrumental in promoting sustainable tillage practices. Through FFS, farmers learn by doing, engaging in hands-on activities that demonstrate the benefits of improved tillage systems. This participatory approach has led to higher adoption rates and improved crop yields (Braun et al., 2006).

India: Digital Green Initiative

Digital Green, an initiative in India, uses digital technology to amplify the reach of agricultural extension services. Farmers watch short, locally produced videos on best practices, including tillage systems. The use of community videos has proven effective in increasing knowledge retention and adoption of new techniques (Gandhi et al., 2007).

Brazil: Zero Tillage System

The Zero Tillage System (ZTS) in Brazil has revolutionized soil management practices. By minimizing soil disturbance, ZTS enhances soil health and reduces erosion. Extension services have played a critical role in disseminating knowledge about ZTS, leading to widespread adoption among Brazilian farmers (Derpsch et al., 2010).

Ethiopia: Integrated Watershed Management

In Ethiopia, integrated watershed management projects have successfully combined capacity building and extension services to promote sustainable land management practices. These projects have improved soil fertility, water retention, and agricultural productivity, demonstrating the effectiveness of integrated approaches (Bewket, 2003).

Emerging Trends in Tillage Systems

Advancements in tillage systems are shaping the future of agriculture, focusing on sustainability, efficiency, and resilience:

1. **Conservation Tillage**: Conservation tillage practices, such as no-till and reduced tillage, are gaining popularity due to their benefits in soil health, moisture retention, and erosion control (Derpsch et al., 2010).
2. **Precision Agriculture**: Precision agriculture techniques, including GPS-guided machinery and variable rate technology, optimize tillage operations by minimizing inputs and maximizing yields. These technologies enable farmers to tailor practices to specific soil and crop conditions (Lal, 1991).
3. **Agroecological Approaches**: Agroecological principles emphasize the integration of ecological processes in farming systems. Agroforestry, cover cropping, and crop rotation enhance soil fertility and biodiversity while reducing reliance on external inputs (Altieri, 2002).

Future Research Areas

To address current challenges and leverage emerging opportunities, future research in tillage systems should focus on:

1. **Climate Change Adaptation**: Developing tillage systems resilient to climate variability and extreme weather events. Research on climate-smart practices, such as drought-resistant crops and adaptive soil management, is critical.

2. **Soil Health and Carbon Sequestration**: Investigating the impacts of tillage practices on soil carbon dynamics and nutrient cycling. Enhancing soil organic matter through improved tillage techniques contributes to climate change mitigation and sustainable agriculture.

3. **Economic Viability**: Assessing the economic benefits and trade-offs of different tillage systems. Research should explore the cost-effectiveness of adopting conservation practices and the potential for market-based incentives.

4. **Integrated Pest Management**: Integrating tillage practices with pest and disease management strategies. Research on biological control, crop diversification, and integrated pest management systems can reduce reliance on pesticides.

Role of Technology and Innovation

Technology and innovation will play a crucial role in shaping the future of tillage systems (Six et al., 1998; Franzluebbers, A. J. (2005) & Lindstrom, 2011; Pannell et al., 2006; Altieri & Nicholls, 2003). Some of the roles of technology and innovation are evident in:

1. **Digital Agriculture**: Digital tools, such as precision agriculture technologies and farm management software, will continue to improve efficiency and decision-making in tillage operations (Shaktawat & Swaymprava, 2024).

2. **Robotics and Automation**: Robotics and automation in tillage machinery offer opportunities for precise and autonomous field operations. Autonomous tractors and robotic weeders can reduce labor costs and environmental impact (Bechar & Vigneault, 2016).

3. **Big Data and Analytics**: Harnessing big data analytics to optimize tillage practices. Data-driven insights on soil health, weather patterns, and crop performance enable farmers to make informed decisions and improve productivity (Johnson, G. A., & Huggins, D. R. (1999) et al., 2009).

4. **Biotechnology and Genetics**: Advances in biotechnology, such as genetically modified crops with improved stress tolerance and nutrient uptake, can enhance the resilience and productivity of tillage systems (Tester & Langridge, 2010).

Recommendations for Stakeholders

The following recommendations are proposed for stakeholders involved in promoting sustainable tillage systems:

1. **Governments and Policy Makers**: Increase investment in agricultural extension services and capacity-building programs. Develop policies that support sustainable farming practices and provide incentives for adopting conservation tillage methods.

2. **Extension Service Providers**: Strengthen extension service delivery through improved training for extension agents, enhanced use of digital technologies, and tailored

communication approaches. Foster partnerships with research institutions and private sector entities to leverage expertise and resources.

3. **Farmers and Farmer Organizations**: Embrace participatory approaches and peer-to-peer learning platforms, such as Farmer Field Schools and community-based networks. Implement sustainable tillage practices tailored to local agroecological conditions and actively participate in decision-making processes.

4. **Research Institutions and Academia**: Conduct interdisciplinary research to address emerging challenges in tillage systems, including climate change adaptation, soil health management, and socio-economic impacts. Translate research findings into practical recommendations and technologies accessible to farmers.

Final Thoughts

The future of tillage systems lies in sustainable practices, technological innovations, and interdisciplinary research collaborations. By embracing emerging trends, exploring new research frontiers, and harnessing the power of technology, agriculture can achieve greater productivity while safeguarding natural resources for future generations.

Capacity building is a vital component in the promotion of sustainable agricultural tillage systems in Nigeria. By empowering farmers with the knowledge and skills to adopt best practices, capacity building initiatives can significantly improve soil health, increase crop yields, and contribute to the overall sustainability of Nigerian agriculture.

Extension agents are indispensable in the quest for agricultural development in Nigeria. Strengthening extension services through increased funding, better training, and improved infrastructure is essential for achieving sustainable agricultural growth and food security in the country. Addressing these challenges will enable extension agents to more effectively support farmers and foster a more productive agricultural sector.

The integration of effective capacity building and extension services is essential for promoting sustainable tillage systems and ensuring food security in a changing climate. By addressing challenges, seizing opportunities, and embracing technological innovations, stakeholders can collectively contribute to enhancing agricultural productivity, conserving natural resources, and improving livelihoods. The future of tillage systems lies in embracing emerging trends such as digital agriculture, precision technologies, and climate-smart practices.

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GENDER PERSPECTIVE IN TILLAGE SYSTEMS

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ABSTRACT

This paper examines the gender perspective in tillage systems, focusing on the challenges and opportunities faced by women in agriculture, particularly in developing countries like Nigeria. Tillage systems, essential for soil preparation and crop production, are dominated by men due to the physical demands and access to resources such as equipment. Women, who constitute a significant portion of the agricultural labor force, face barriers in accessing tillage technologies and resources, leading to gender inequality in productivity and income. The study emphasizes the importance of addressing these gender disparities by implementing gender-sensitive technologies, policies, and training to promote equal participation in tillage systems. This would improve food security, sustainability, and economic development in agriculture. Recommendations include increasing awareness, advocating for policy changes, and adopting affirmative action to empower women in tillage operations.

KEYWORDS: Gender perspective**,** Tillage systems**,** Agricultural, labor, Gender inequality, Conservation tillage, Sustainable, Women's empowerment, Agricultural technology, Food security

1.0. INTRODUCTION

Globally, tillage systems have been the general solution to the crop production methods that invert the soil and destroy its structure. Tillage has been practiced by many farmers worldwide as a means to improve soil fertility and reduce energy requirements. The advantages are numerous and have been realized in agricultural production with the tillage concept, which have greatly increased productivity. Hence, in the past decade witnessed a significant advancement in how gender dynamics are considered in research related to tillage systems. Focus shifted away from mere advocating for women's participation in these systems to understanding and implementing effective strategies to bring improvements. The utilization of tillage systems in developing human and material resources can be dramatically enhanced when women are included, since they are responsible for 50 - 60% percent of agricultural production and most domestic tasks.

In tillage system research and development, there is increasing recognition that addressing gender equality involves correcting power imbalances in gender relations rather than 'fixing' women. The intersection of gender and agriculture, particularly in tillage systems, offers fertile ground for exploring the dynamics of the division of labour, resource access, economic impact, cultural influences, and sustainability practices.

This paper delves into these critical areas, providing comprehensive understanding of how gender perspectives shape tillage systems. A probing of how sustainable food systems can be fostered through resolving the challenges of gender-based discrimination in tillage practices. Inclusive approaches, voices and shared lived experiences of the female folks who constitute approximately 50 percent of farming population have to be mainstreamed for meaningful headwinds to development. Traditional gender roles dictate division of labour, access to resources, and decision-making power in agricultural settings. Focusing on both the constraints and opportunities faced by men and women, and the huge significance of the 75% of the population involved in Agriculture in Nigeria, this paper highlights the importance of taking into account gender needs when designing tillage implements as men and women are physiologically different and their needs should be given their respective study and other development attention as a way for food sufficiency (Mohammed and Abdulquadri, 2012).

2.0. CONCEPTUAL CLARIFICATION

2.1. Gender

Gender refers to socially constructed roles, behaviours, identities of male and female members in society. It means assigned, ascribed and attributed roles and responsibilities based on whether individuals are male and female (Teklewold *et al*., 2013; Yahaya *et al*., 2018). According to the FAO, gender refers not only to women or men, but to the socially defined roles of each sex, as well as to the relation between them (FAO, 2011). The Oxford Learners Dictionary defines gender as the state of being male or female which is expressed in social or cultural terms, and not based on biological sex. Therefore, gender distinction accounts for differentiating agricultural labour in traditional settings.

Farming tasks of land preparation include clearing, tilling, and ridging especially where manual processes are entailed. Planting, weeding, and harvesting are also operations in agriculture where gender based delineation of agricultural labour subsist.

2.2. Tillage

Tillage is the agricultural process of preparing the soil for planting crops through mechanical agitation and consists a range of activities such as digging, stirring, and overturning the soil to improve its structure, manage weeds, and incorporate organic matter and nutrients. As well, Tillage is defined as the process of preparation of the soil to loosen it up for purposes of enhancing its readiness to support crop production. It is viewed as the manipulation of the soil into suitable state with the use of farming tools including machineries or manual labour. Common tillage methods include ploughing, harrowing, and rototilling. These practices permeate the soil to allow for aeration, germination of seeds, encouraging roots production and weeds control. Sequences of operations are involved to manipulate the soil in order to produce a crop.

2.3. Types of Tillage:

i. Conventional/ Traditional Tillage: Conventional tillage includes primary tillage, secondary tillage and special purpose. This is a way of soil preparation that involves intensive mechanical agitation to prepare the seedbed for planting as well as enhance the seedbed conditions and control weeds. This method typically includes ploughing, followed by harrowing and levelling the soil. Ploughing is an operation that involves turning over the top layer of soil to bury weeds and crop residues, which helps to loosen the soil and improve aeration. Harrowing further breaks down soil clods and smooth the surface. More so, lead to soil erosion, loss of organic matter, and disruption of soil structure over time

ii. **Conservation Tillage:** Conservation tillage includes no tillage and minimum tillage. This refers to a set of farming practices that aim to maintain long-term soil productivity, reduce environmental impacts, minimize soil disturbance and erosion as well as preserving soil health and fertility. It typically focus upon managing crop residues and leaving the previous year's crop residue (such as stalks, leaves, and roots) on the field before and after planting the next crop which helps to protect the soil from erosion by wind and water, improves water retention, reduces the need for irrigation, and enhances soil organic matter content. Conservation tillage can vary in intensity from no-tillage (where no soil is disturbed) to reduced tillage (minimal soil disturbance). Conservation tillage systems, thus, include soil cover management; weed management; soil and water conservation. Soil cover management involve operations such as mulching and planting cover crops: Weed management involves application and use of herbicides, mechanical weed control, agronomic crop management and hoeing while soil and water conservation activities involve physical, biological and agronomic measures.The systems classified as conservation tillage systems are no-tillage, ridge-tillage and mulch-tillage.

iii. No tillage: This is also known as zero tillage or direct drilling, is a farming technique where the soil is left undisturbed or minimally disturbed from harvest through planting. It requires specialized equipment that plants seeds directly into untilled soil, often through the residue of the previous crop.

iv. **Ridge tillage:** in stripe-tillage, the soil is also left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.

v. **Mulch tillage:** the soil is disturbed before planting. Tillage tools such as chisels, field cultivators, disks, sweeps or blades are used. Weed control is accomplished with herbicides and/or cultivation. Mulch-till is a category that includes all conservation tillage practices other than no-till and ridge-till. Some modern tillage implements are as shown below:

- **Plate 1: Plough**

Plate 2: Harrow

Plate 3: Plank (Floorboard) is done to crush the hard clods to smoothen the soil surface and to compact the soil lightly

2.4. Importance of Tillage systems and practices in agriculture

Specific benefits of tillage systems and practices in agriculture are as follows:

a. It improves soil condition, and sets the stage for increased crops yield
b. It reduces the occurrence of soil erosion
c. Tillage helps the process of weed management
d. It is vital to enhancement of crop growth
e. Utilizing tillage is critical to seed bed preparations
f. Enhance Soil Aeration

Generally therefore, tillage systems are critical operation in crop production processes that confers an advantage on the farmer who has the capability of carrying it out. It is on account of this that understanding the gender perspectives of tillage systems becomes paramount.

3.0. FORMS OF GENDER RELATED GAPS IN TILLAGE SYSTEMS

a. Gender and access to tillage assets

Applcation of tillage systems in production has strategic gender implications. The productivity of labour will be altered depending on accessibility of the tillage implements between men and women. In many small-holder farms, technology is mostly at the disposal of men, so when we talk of gender and tillage practices, the questions that arise are whether the systems are gender neutral or hindering of women participation or not addressing a gender concern.

Women are disproportionately disadvantaged in terms of access to agricultural assets generally. Invariably, women farmers and farm workers are unable to acquire tillage equipment, whether such are mechanized or automatically powered. A critical factor in accessing tillage assets is capital formation. This often reflects a pattern of wide exclusion and disadvantage against women. Perennially, women earn low income from farming, lack collaterals required to access credit, have less information to access grants and due to skills deficiency including communication skills are excluded from acquiring tillage assets especially tractors. Lacking adequate capital may also account for why a female farmer may not hire tillage assets for farming operations. Relying on crude means to till the soil for farming operations may increase the drudgery and burdensomeness involved in farming thereby constituting a major reason for high farming failure rates among women than men.

b. Gender dimension of the tillage labour force

Tillage labour force is subcategory of overall agricultural labour force. It is estimated that between 60 to 80 percent of workers in agriculture for the developing economies including Nigeria are female. However that the tillage labour force in Nigeria is male dominated is no brainer. The reasons for this is where tillage operation is done manually, there are indeed very few women who are physically capable of doing it because the development of these technologies is not based on a comprehensive analysis of gender roles and as a result they do not offer equal opportunities for women and men to participate and benefit. Secondly as mentioned earlier, owing to incapacity to form adequate capital, there are few women owners of tractors in the country. The absence of a critical mass of female involved in tillage operations of agricultural activities therefore creates a high degree of dependencies on male.

This low representation of female tillage labour force has serious implications on sustainable food production specifically by women. It is somewhat challenging for a female farm worker who may aspire to break through barriers such as misleading perceptions that roles such as tractor driving is not meant for a girl or woman. While boys gain head-start exposures through training and become future commercial farmers, the girl child raised to belief that she is meant to end up as a housewife is not supported to understand key tillage operations preparatory for possible future roles as successful farmers. The erroneous impression that roles are either masculine or feminine consigns the girls to grow lacking capacities to perform more financially rewarding tillage tasks.

c. Income disparity and Gender roles in tillage

Individuals who handle the most tedious tasks earn more than others. Gender roles are important in this form of disparity here referred to as income disparity. The international labour organization prescribes there should be equal pay for work of equal value. How a work is valued is a matter of what the end user of the service considers to be of importance. As earlier noted, without tillage of the soil, farming operations can go awry. For this reason end users of agricultural labour accord a higher value to workers who are involved in tilling than those who are engaged for planting, weeding and harvesting.

The wages earned by workers who till a certain parcel of land preparing it for cultivation would be much higher than what is paid to have seeds planted. The men who till therefore earn more than the female who do weeding of grasses. This implies also that tillage wage earners would receive most of their income from female farmers most of whom lack the muscular built to perform tillage of the soil.

d. Technology neutrality

Gender perspective to a large extent contribute to lack of neutrality in that, no account is taken of who participates in the production process and to what extent. Tillage practices, especially those pertaining to Soil and Water conservation, do not promote the fair participation of both women and men.

Development of technologies is not based on a complete analysis of gender roles and as a result they do not offer equal opportunities for women and men to participate and benefit. There is a clear need, therefore, to have an institutional framework that takes into account the aspect of gender within which the system the technology will be adopted.

4.0. PRAGMATIC APPROACHES TO SOLVING GENDER CHALLENGES OF TILLAGE SYSTEMS

The above referred gender based labour problems hamper every meaningful measures aimed at improving food security and sufficiency in our part of the world. Find wise and prudent ways to solve these issues and pragmatically applying the solutions is therefore essential to making progress generally. Some of the ways of overcoming the problems are identified below

a. **Awareness creation, advocacy and education**

It is said a problem which is known is half solved. Put in another way, what you cannot name, you cannot tame. While the above mentioned issues are well expressed and circulated among the enlightened few in the society, the majority of the population who matter the most to actively solving the problems live in denial or outright ignorance. Ignoring what gender is and how discrimination in tillage systems along gender line is a problem leaves us plagued with the problems. Launching campaigns, educating and advocating against gender discrimination in tillage practices has to be presented as critical to overcome food shortage and to defeat hunger.

b. **Implementing Gender-Sensitive Policies**

Policies must be developed to ensure equal access to resources, opportunities, and decision-making roles for both men and women in tillage systems. This would take the forms of outlawing denial of women from accessing credits, providing grants, training and other forms of supports to interested women. Empowering women to acquire skills and opportunities for them to practice tillage methods would gradually build their confidence. There has to be deliberateness in bringing young girls on board onto tillage practices.

c. Affirmative Action

This entails giving initial preference to women seekers of opportunities for employment or placements in positions for tillage practices. If for example five positions of tractor operators exist and 8 candidates qualify of whom 3 are female, affirmative action increases women in tillage by subjectively hiring all the three of them. It is also the practice of lowering the barrier which hitherto prevented women from gaining access to assets in tillage systems including financial resources. It recognizes that as more women become involved in tillage systems, food insecurity is reduced generally.

d. **Recognizing and Valuing Women's Contributions**

The contributions of women to tillage systems must be recognized and valued, ensuring that their efforts are visible and appreciated in the agricultural narrative.

e. Ensuring Equal Access to Technology and Training

Women must have equal access to modern tillage technologies and training programs to enhance their skills and productivity.

5.0. FUTURE PERSPECTIVES OF GENDER IN TILLAGE SYSTEMS

The future of gender in tillage systems envisions a more equitable and inclusive agricultural sector, where women have equal access to resources, opportunities, and decision-making roles. Efforts to mainstream gender in agricultural policies and practices are expected to continue, promoting a more balanced distribution of labour and responsibilities.

Some key drivers of the envisaged future state include the following

Gender-Sensitive Technologies

The development and implementation of gender-sensitive technologies and policies will be crucial in bridging the gender gap in tillage systems. Future innovations may include tools and machinery designed with women's needs in mind, as well as policies that ensure equal access to land, credit, and training for both men and women on the use of these technologies.

a. Sustainable and Inclusive Practices

The future of tillage systems will likely focus on sustainable and inclusive practices that recognizes and value the contributions of both men and women. Emphasis on collaborative and community-based approaches to farming can foster greater gender equality and enhance the overall resilience of agricultural systems.

Conclusion:

i. Incorporating gender perspectives in tillage systems is essential for achieving equitable and sustainable agricultural development.

ii. Labour Contributions: In conventional tillage systems, women often engage in labour-intensive activities such as seedbed preparation and weeding, while men handle ploughing and machinery. Reduced and no-tillage systems tend to redistribute labour more equitably, reducing the overall burden on women.

iii. Decision-Making Power: Men generally have more decision-making power regarding tillage practices, often due to their control over machinery and inputs. However, women's involvement increases in reduced and no-tillage systems as these practices become more widespread and accessible.

iv. Access to Resources: Women face significant barriers to accessing resources such as land, credit, and technology, which are crucial for adopting improved tillage practices. Gender-sensitive policies and programs are needed to address these disparities.

v. Perceived Benefits and Challenges: Women report benefits such as reduced labour and improved soil health with reduced and no-tillage practices. However, challenges include limited access to training and extension services tailored to their needs.

vi. Addressing the disparities in labour division, resource access, economic opportunities, and social norms can empower women and enhance the overall productivity and sustainability of our agricultural practices.

vii. Promoting gender equality in agriculture not only benefits women but also contributes to broader social and economic development goals.

viii. Government and research institutions should make special effort to assign monetary resources to more study of the problems relating to the influence of tillage systems on women and agricultural processes in which women along with men are direct beneficiaries.

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EFFECT OF BULK DENSITY INCREASE OCCASIONED BY TRAFFIC INTENSITY ON THE YIELD OF EGUSI-MELON IN SOUTHEAST NIGERIA

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ABSTRACT

Some research on the effect of wheel traffic on soil compaction has used bulk density as an indicator. Not much has been done on the effect of wheel traffic on the mechanical properties of soil as they affect egusi-melon yield. This paper reports the effect of an increase in dry bulk density (BD) caused by agricultural machinery traffic pass intensity (TP) on some yield indices (no. of fruits, NF; fruit weight, FW; dry seed weight, SW; and weight of 1000 seeds, WTS) of egusi-melon (*Colocynthis citrullus*) grown on a sandy loam soil of Southeastern Nigeria. The soil was compacted using a 58 kW, 3.15 t weight (2WD) wheel tractor. Experimental treatments consisted of 0, 1, 3, 5, and 10 passes (TP) (wheel-wheel) of the tractor on the same trafficked portion of the plot and were replicated three times in four growing seasons. The BD was analyzed from 10 random core samples (100 cm^3) taken from each plot at 0-5, 5-10, 10-15, and 15-20 cm depths. Three (3) egusi-melon seeds were manually planted into holes at 2x2 m spacing after each wheeling treatment and taking of soil samples at 5x100 cm within each treatment plot. While an increase in TP increased BD by about 10.6%, the individual fruit weight of egusi-melon decreased from 9 kg in the 0 and 1 pass treatments to 3.3 kg in the 10 passes treatment while dry seed weight/fruit decreased from 0.16 kg in the 0 pass to 0.10 kg in the 10 passes treatment due to increased BD. Relationships between some egusi-melon crop yield indices and BD as well as TP were established to provide valuable information on the effect of BD on the productivity of egusi-melon seeds in Southeastern Nigeria to guide farmers, policymakers, and practitioners toward informed decisions.

Keywords: Compaction, Tractor Intensity, Egusi-melon, Bulk Density; South- East Nigeria; Yield

1. INTRODUCTION

The soil is not just another component necessary for egusi-melon crop production but rather a complex, living, fragile medium that requires protection and nurturing to ensure sustained productivity, profitability, and stability (Renanold et al., 1990) and therefore, should not be compacted. Most farmers are not aware of the harmful effects of intensive agricultural practices and therefore, may be exposed to the use of unsustainable agricultural methods (Ojadi, 2024) such as excessive machinery trafficking. Traffic-induced soil compaction is known as the process induced by the wheeling of mobile farming units in which soil particles are spatially rearranged, which leads to increasing in soil bulk density (Hamza and Anderson, 2005). The bulk density is the most beneficial parameter of soil structure as it measures soil compaction or looseness. The bulk density of the soil demonstrates the relationship between its mass and the volume it occupies (Hernanz *et al.*, 2000). It affects rooting depth, infiltration, soil porosity, soil microorganism activity, plant nutrient availability, and available water capacity (Özdemir et al., 2022).

In modern cropping systems for increased food production to meet the increasing food demand for the rapidly increasing global population (Shaheb et al., 2021), numerous operations are based on the use of agricultural machinery. Agricultural machinery traffic is responsible for most of the soil compaction that impacts soil structure, decreasing overall crop growth and development, and yield (McKenzie, 2010). Twum and Nii-Annang (2015) posits that soil compaction caused by heavy machinery traffic on the field is known to result in increased soil BD (Hassan and Gregory, 1999; Batey, 2009). Increased soil BD due to mechanical compaction may alter root configuration and root-soil interactions (Lipiec and Stepniewski, 1995; Correa et al., 2019), increase resistance to root penetration, alter root development and proliferation (Olsson and Cockroft, 2002), and thereby affect root distribution and biomass within the soil profile that impinges on the development of the living roots in the soil and eventually affect plant growth (Radford et al., 2000).

However, there seems to be little information on the impact of soil compaction caused using heavy machinery traffic on the bulk density of egusi-melon (*Colocynthis citrullus*) yield. Egusi-melon is an oil seed of great economic importance in the tropics. Giwa and Akanbi (2020) stated that egusi-melon seed kernels are a good source of edible oil (31–59%), protein (19–37%), fibre (3–4%), and carbohydrate (8–20%). The seeds are used in soups and other delicacies such as "*ogbala ati*" (Ibo) (Asoegwu, 1992). The oil is edible (Egwim et al., 2015) and potentially useful for producing biofuel for automobiles (Aziz Hairuddin et al., 2019). Egusi-melon oil has higher density at 15°C (kg/m^3) and kinematic viscosity at 40°C (mm^2/s) of 905.3 and 6.58, respectively than diesel of 853.97 and 4.33, respectively; but a lower calorific value (MJ/kg) of 39.37 than 45.273 for diesel (Sahoo and Das, 2009; Benjumea et al., 2008). Oil from egusi-melon seeds can be extracted by simple means (Adebalugbe, 1986) and is suitable for biodiesel production (Okwundu et al., 2021) with fuel properties showing Cetane numbers (52.54 - 53.06), kinematic viscosities (@ 40°C of 2.53 - 3.00) mm^2/s, with very low pour and cloud points (Muhammad et al., 2013). Egusi based biodiesel shows a comparable engine performance to that of conventional diesel and B7 palm oil (Aziz Hairuddin et al., 2019).

An increase in the production of egusi melon seeds could be achieved by full mechanization of egusi-melon production (Asoegwu, 1992). Ogunsola et al. (2020) stated that Nigeria is the highest producer of melon in Africa, producing about 569, 398 tonnes over an area of 1,085,998 ha, with an average yield of 5,243 kg/ha, followed by the Democratic Republic of Congo (62,487 tonnes) and Cameroun (52, 940 tonnes) (FAO, 2016). However, Omale et al. (2022) posited that in 2018, egusi-melon production statistics ranked Nigeria as the highest producer with a production of 585,347 tons of the egusi-melon seeds which translates to 60% of the global egusi-melon seed production (FAOSTAT, 2018). Ibironke and Oyeleke (2014) established that egusi-melon production was profitable, and it contributed to rural farmers' household food security and livelihood sustainability. Egusi-melon is well known and widely cultivated in West Africa (Nigeria, Ghana, Togo, and Benin) and many other African Countries for the food in the seeds (Van der Vossen et al., 2004). It plays vital roles in the farming system and the well-being of West African rural farmers as a good source of energy, weed suppressants and for soil fertilization (Achigan-Dako et al., 2008). It is also used as mulch, leaving high residual nitrogen in the soil after harvesting as cover crop, weed suppressant and soil fertilization through the formation of root nodules that improves the nitrogen status of the soil (Abiola & Daniel, 2012). Egusi=melon is one of the most economically important vegetable crops worldwide and is grown in both temperate and tropical regions (Bisognin, 2002). The use of egusi-melon as local medicine is attributed to its biomedical properties and efficacy in the treatment of some ailments as marasmus (lack of calories), kwashiorkor (lack of protein), and other debilitations Gurudeeban *et al*. (2010).

Despite the socioeconomic, cultural, agronomic, medicinal, and culinary importance of egusi-melon, information is lacking on the debilitating effect of bulk density induced by machinery traffic on the soil as it affects the crop. The effects of soil compaction on crops and soil properties are complex (Bailey et al. 1986) and bulk density becomes the most frequently used parameter to characterize the state of soil compactness. The objective of this paper is to examine the effect of bulk density increase occasioned by traffic intensity on the yield of egusi-melon in south-east Nigeria. Relationships between some egusi-melon crop yield indices and BD as well as TP were established to provide valuable information on the effect of BD on the productivity of egusi-melon seeds in Southeastern Nigeria. The results obtained are important for guiding farmers policymakers, and practitioners toward informed decisions for sustainable agricultural practices in the region to enhance egusi melon crop yield and soil health, to improve crop productivity.

2. MATERIALS AND METHODS

On a 30x120 m^2 sandy loam well-drained Ultisol field at the Federal University of Technology, Owerri (FUTO - 5.3927°N and 6.9861°E), field experiments were conducted. The field was manually cleared with cutlass and divided into three blocks of four plots each. The size of each plot is 6x25 m^2 with a headland of 5m between plots. The soil was compacted using a 58 kW, 3.15 t weight (2WD) tractor. Rear Tire size – 16.9/14-30, 40 psi inflation pressure, and the tractor speed was 3.45 km/hr.

Experimental treatments consisted of 0, 1, 3, 5, and 10 passes (wheel-wheel) of the tractor (TP) on the same trafficked portion of the plot and were performed in a completely randomized block design (CRBD) with three replications in four growing seasons. Before and after each treatment, disturbed and undisturbed composite soil samples were collected, and the samples were put in thick polyethylene bags labeled and stored in a refrigerator at -5ºC. Soil physical property of dry bulk density (BD) was analyzed using standard laboratory methods from 10 random core samples (100 cm^3) taken from each plot at 0-5, 5-10, 10-15, and 15-20 cm depths at same depths at a spacing of 15x100 cm within each treatment plot near the core sample points. The plots were treated with paraquat (1-1' dimethyl-4, 4'-bipyridylium ion) at the rate of 0.5 kg a.i./ha for weed control one week prior to planting.

Egusi-melon seeds were planted manually after each wheeling and taking soil samples at three seeds per hill at a 2 m x 2 m spacing. Fertilizer use consisted of 50 kg/ha NPK: 15:15:15 applied at 4 weeks after planting (WAP). Additional weeding was done manually using the hoe at 30 and 60 days after planting (DAP) to avoid injury to the plants.

At harvest (85 – 90 days), fruits were manually gathered and traditionally processed for seed extraction (Osunde and Kwaya, 2012) and drying to 13% m.c. (w.b.). The number and weight of fruits, and dry seed weight per hectare were determined. The weight of 1000 seeds per hectare from each treatment was also taken. The treatment means were checked at the confidence level of 95% of probability. Relationships between some seed and soil dry bulk density were established.

3. RESULTS AND DISCUSSION

The interaction of BD as affected by tractor-wheel traffic passes (TP) from 0 to 10 showed that increased TP increased BD from 1.23, 1.26, 1.3, 1.34 to 1.36 Mg m^{-3}, respectively, an increase of about 10.6% as observed by Horn et al. (2001) and Abu-Hamdeh (2010). Seedling emergence, one WAP, decreased from about 93%, 97%, 91%, and 80%, to 2% in the 0, 1, 3, 5, and 10 passes (TP) treatment, respectively. Similar results were reported by Ahmadi and Ghaur (2015) for corn seedlings. TP inversely affected the emergence percentage of egusi-melon, which may be attributed to increased dry BD (Shaheb, 2020). Generally, egusi-melon crop yield decreased as follows: individual average FW decreased from 9 kg in the 0 and 1 TP treatments to 3.3 kg in the 10 TP treatment while average SW/fruit decreased from 0.16 kg in the 0 TP to 0.1 0 kg in the 10 TP treatment.

2.1 Tractor Passes on Bulk Density

Tractor passes (TP) had a significant effect on the soil bulk density as observed in Eqn. 1 as 2nd order polynomial regression equation (with R^2=0.9965) as observed by Dada et al. (2020). The mean soil BD for the whole field was 1.297 Mg m^{-3} but values ranged from 1.13 to 1.44 Mg m^{-3} within the treatment levels. The increasing number of TP caused an increase in BD overall (Allman et al., 2022) as shown in Fig. 1 with the highest BD (1.44 Mg m^{-3}) recorded at the 10-15 cm depth for the 10 TP treatment as also reported by Balbuena et al. (2000). However, Naghdi et al. (2010) in their work reported that maximum BD occurred between 7 and 12 TP. The average BD for the different depths 0-5, 5-10, 10-15, and 15-20 cm were 1.232, 1.32, 1.356 and 1.28 Mg m^{-3}, respectively, with the 10-15 cm depth having the highest BD which agrees with Picchio et al. (2012). These are shown in Fig. 2 and Eqns. 2 – 5 as 2nd order polynomial equations with R^2 > 0.98. Bulk density (BD) as affected by TP at 0-5 and 10-15 cm depths had R^2 > 0.99. From Fig. 2, after the 5th or 6th TP, the BD tends to decrease. The BD of the soil increase with the depth of the soil profile is partially attributed to the weight of the overlying soil, change of texture along the profile, and compaction caused by traffic during earlier field operation (Argaw et al., 2013).

$$BD = -0.0015(TP)^2 + 0.0272(TP) + 1.2336 \qquad R^2 = 0.9965 \qquad 1.$$

$$BD_{0-5} = -0.0029(TP)^2 + 0.0466(TP) + 1.1331 \qquad R^2 = 0.9981 \qquad 2.$$

$$BD_{5-10} = -0.0012(TP)^2 + 0.0192(TP) + 1.2798 \qquad R^2 = 0.9822 \qquad 3.$$

$$BD_{10-15} = -0.0002(TP)^2 + 0.016(TP) + 1.3007 \qquad R^2 = 0.9936 \qquad 4.$$

$$BD_{15-20} = -0.0016(TP)^2 + 0.0269(TP) + 1.2208 \qquad R^2 = 0.9898 \qquad 5.$$

It was observed that with the TP the BD increased by 2.4% with 1 TP, 5.3% with 3 TP, 8.3% with 5 TP, and 10.1% with 10 TP. However, with the depth of the soil profile, BD increased by 7.14% at 5-10 cm, 10.1% at 10-15 cm, and 3.9% at 15-20 cm, showing that the percent-increase in BD of the soil caused by the wheel traffic decreases as we go deeper into the soil profile (Argaw et al., 2013). Studies conducted by Etana and Håkansson (1994) and Arvidsson (2001) have confirmed that compaction by heavy machinery can lead to a compaction in the subsoil to a depth of at least 0.50 m. The results of this work seem to conform with the above assertion.

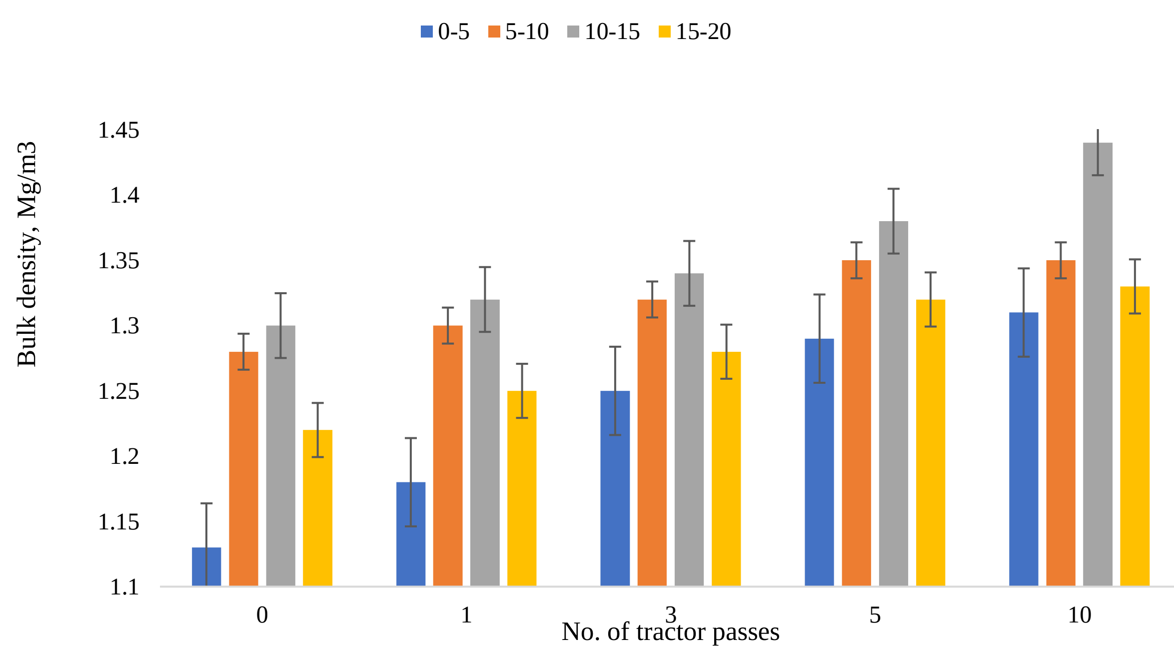

Fig. 1: Effect of tractor passes on bulk density at different depths.
Bars denote 0.95 confidence intervals.

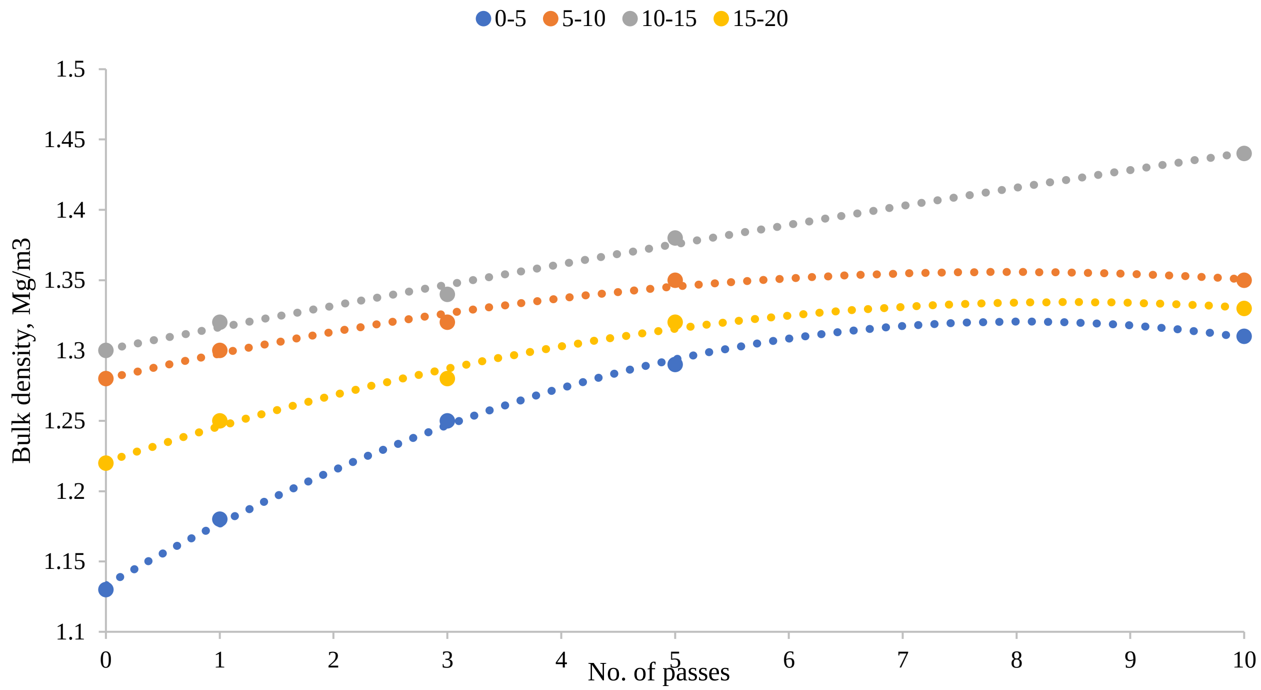

Fig. 2. Regression curves of the effect of no. of traffic passes on the bulk density of the soil at different depths

For all TP, the BD increased from 1.232 Mg m^{-3} at 0-5 cm depth to 1.356 Mg m^{-3} at 10-15 cm depth and dropped to 1.28 Mg m^{-3} at 15-20 cm depth. However, results show that the first three passes increased BD by 5% which agrees with Picchio et al. (2012), who reported that soil deformation resulting from multiple TP was greater for the first three runs than for the subsequent ones. Abich (2023) posited that the fact that bulk density increased as depth increased suggests that soil compaction is dynamic and is conveyed to lower depths via the soil matrix. These findings agreed with those of Agele et al. (2016), who found a strong correlation between an increase in bulk density and traffic intensity. Similar results were obtained from Gregorich et al. (2011) and Godwin et al. (2019).

2.2 Bulk Density and Egusi-melon Yield Parameters

Figure 2 shows that all egusi-melon yield parameters (NF, FW, SW & WTS) were significantly affected by BD. The highest yield components of egusi-melon were observed at the lowest BD (1.2325 Mg m^{-3}) while the lowest yields were found in the highest BD (1.3575 Mg m^{-3}) The results showed that increasing the soil BD with the soil depth, as observed by Hosea et al. (2018), decreased the egusi-melon yield parameters. The results affirm Obafemi and Yessoufou (2019)'s finding that increasing BD reduces yields. In many agronomic studies, soil BD is used as a measure of soil quality, with bulk densities of 1.2-1.4 Mg m^{-3} generally considered to be the desirable range for good crop production (McPhee et al. 2020).

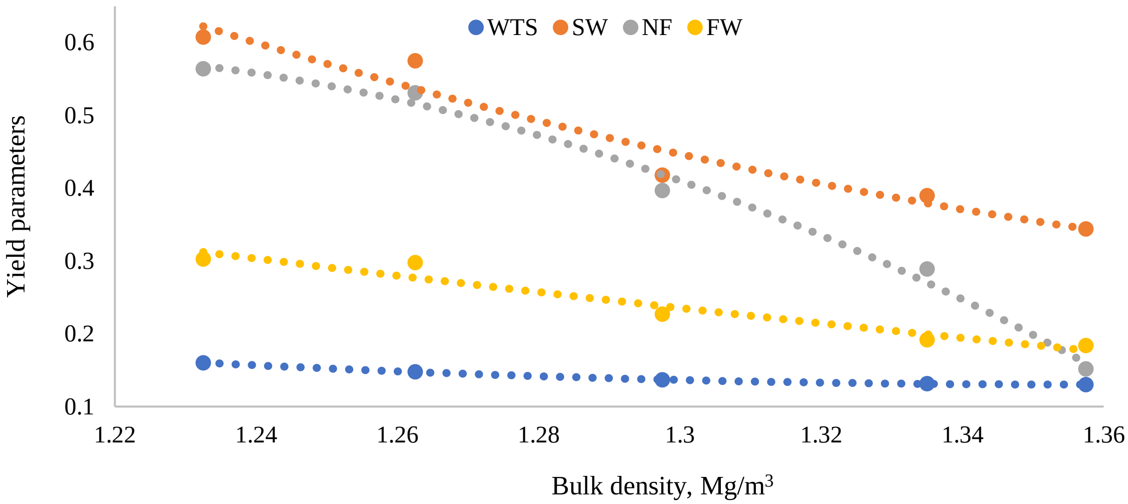

Fig. 2: Effect of bulk density on different egusi-melon yield parameters.

With increasing BD due to an increase in TP, as also reported by Ogunjirin and Kamal (1999) and Manuwa et al. (2011), the regression relationships between the yield parameters NF, FW, SW, and WTS and BD are given in Eqns. 6 to 9 as a 2nd order polynomial with a high R^2 of over 0.94.

$$NF = -16.202(BD)^2 + 38.694(BD) - 22.511 \qquad R^2 = 0.9905 \qquad 6.$$

$$FW = 1.0436(BD)^2 - 3.783(BD) + 3.3896 \qquad R^2 = 0.9421 \qquad 7.$$

$$SW = 6.5584(BD)^2 - 19.212(BD) + 14.339 \qquad R^2 = 0.9465 \qquad 8.$$

$$WTS = 1.9306(BD)^2 - 5.2401(BD) + 3.6861 \qquad R^2 = 0.9996 \qquad 9.$$

The reductions in yield (NF, FW, SW, and WTS) of egusi-melon as shown in Eqns. 2 to 5 above, arise from increased BD from 1.2325 - 1.3575 Mg m^{-3} because of soil compaction caused by TP (Odey, 2018; Sabir et al., 2021). The results are for NF, FW, SW, and WTS: 0.564 – 0.152 $x10^4$/ha; 0.303 - 0.184 $x10^2$ t/ha; 0.608 – 0.334 t/ha; and 0.1602 - 0.1301 $x10^3$ kg/ha; for BD 1.2325 – 1.3575 Mg m^{-3}, respectively. These reductions were -73%, -39.39%, -43.40%, and -18.80%, respectively, which by all indications are on the high side. Thus, it can be said that increased BD has a debilitating effect on the yield components of egusi-melon. Increasing bulk density (BD) decreases crop growth probably by (i) increasing mechanical impediment to root growth, (ii) hampering root architecture, and (iii) decreasing distribution and development of roots (Godwin et al., 2017; Godwin et al., 2019).

CONCLUSION

Machinery traffic damages soil structure by increasing BD which is critical for sustainable egusi-melon crop production, leading to reduced crop growth and yield. Increased wheel TP (0 to 10) increased BD, showing 2nd order polynomial relationships with TP of $R^2 > 0.99$. It was observed that one week after planting (WAP) about 93%, 97%, 91%, 80%, and 2% seedling emergence were recorded in the 0, 1, 3, 5, and 10 passes treatment, respectively. Again, with increased BD of 1.232 - 1.356 Mg m^{-3}, yield components of NF, FW, SW, and WTS were 0.564 – 0.152 x 10^4/ha; 0.303 -0.184 x 10^2 t/ha; 0.608 – 0.334 t/ha; and 0.1602 -0.1301 x 10^3 kg/ha, respectively. These reductions were -73%, -39.39%, -43.40%, and `-18.80%, respectively, this showed that compaction had more effect on NF followed by SW and FW, and least on WTS. Regression models were used to describe the trends in the results for the effect of BD on egusi-melon yield parameters. These results will help to better understand the effects of soil compaction arising from traffic intensity on dry bulk density, crop growth and development, and yield, of egusi-melon. They will also assist in an improved understanding of dry bulk density effects on egusi-melon production. and provide useful information to growers, researchers, and policymakers to support better decisions on reducing the impact of soil compaction in production of egusi-melon.

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MACHINERY ADAPTABLE FOR TILLAGE PRACTICES IN LOWLAND RICE FARMING IN NIGERIA

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ABSTRACT

The paper discusses machinery and tillage practices suitable for lowland rice farming in Nigeria. Lowland agriculture refers to farming in low-lying areas with fertile soil, abundant water, and favourable climate. Rice is a major crop grown in Nigeria's lowland ecology, which accounts for about 50% of the country's rice production. The power tiller is identified as the most appropriate and affordable agricultural machinery for lowland rice farming in Nigeria. Power tillers are versatile, able to perform operations like ploughing, puddling, bunding, levelling, smoothening, transplanting, harvesting, transporting, canal digging, and water pumping, when coupled to the appropriate implements. They are cheaper, easier to maintain and better suited for the soft, waterlogged soils of lowland areas compared to conventional tractors. However, several challenges in using machinery for lowland cultivation including heavy, smooth, and slippery soils, waterlogging, operator sinking, and the inability of power tillers to achieve desired bund height with improvised mouldboard plough implements are encountered. To address these issues, the paper suggests incorporating bund makers into power tillers using higher horsepower models and adding floater seats to improve operator stability. Overall, the paper emphasizes the importance of mechanization in boosting Nigeria's rice production, particularly, in the country's lowland ecologies, and provides practical recommendations to overcome the challenges faced by rice farmers.

Keywords: Power tiller, tillage, lowland, rice, mechanization.

1. INTRODUCTION

Lowland agriculture, according to https://www.quora.com/what-is-lowland-agriculture, refers to the practice of cultivating crops and raising of livestock in low-lying areas such as plains, valleys, and coastal regions. These areas are typically described by the presence of fertile soil, abundant water supply from rivers or groundwater and favourable climatic conditions for crop growth. The cultivation of a variety of crops such as rice, wheat, corn, soybeans, sugarcane and various fruits and vegetables are often involved in lowland agriculture. The availability of water for irrigation is a key factor that makes lowland areas suitable for intensive agriculture. Farmers in lowland areas may utilize irrigation systems to ensure a consistent water supply for their crops. Lowland agriculture can be practiced using different methods, including traditional farming techniques as well as modern agricultural practices that incorporate mechanization, fertilizers, pesticides, and other technologies to increase productivity. This type of agriculture is essential for providing food and resources to support growing populations in many parts of the world. In a report by https://steemit.com/stemng/@masterwriter/lowlands-and-fadama-agriculture, lowlands are flat areas with rivers and streams traversing the length and breadth of the farmlands. The river draining in these lowland areas tends to flood the valleys during the wet season. In the dry season, the water recede leaving coats and layers of fertile alluvial soils that can be used for agriculture.

In the wake of diminishing uplands, Nigeria has many ideal lowlands (FADAMAs) where erosion deposits the rich topsoil from the uplands, thus making the lowlands more fertile. Many farmers already carry on traditional lowland rice production under the continuum farming system and recognize the better fertility and higher yields under lowlands environments. Lowlands become hydromorphic (retain wet surfaces) during the rainy season; this high-water table makes it possible for the farmer to carry on dry-season farming (double cropping) in the same field. Lowlands are naturally fertile and because of the moisture regime, more suitable than uplands for intensive cultivation of rice and other crops during the dry season, i.e. lowlands support continuous rice farming and other crops such as cowpea, peanuts, okra, corn, vegetables, etc. (which can grow well on residual moisture) during the dry season. Lowlands generally respond better to high-input production practices. Varieties for lowland production are generally higher yielding than upland varieties. Lowland sites, once developed become permanent production facilities. One outstanding merit of lowlands is their increased and sustained productivity resulting from the many possible cycles of rice and other crops produced within the same locality/ area, once developed.

It has been a fact that the benefits of technology inputs in terms of enhanced productivity is about 15% and reduction in cost of production by 20% (Chandra et al., 2011). Some of the benefit includes increase in cropping intensity, timeliness in farm operations and reduction in the drudgery of farm workers. Increased production and productivity achieved through mechanization are due to accurate application and better placement of inputs, conserving soil and water resources from further degradation, increasing irrigation potentialities and efficiencies, reducing losses of produce, etc. Farming is easier to scale with the use of machinery, therefore, mechanization is important. According to Takeshima and Kennedy (2019), mechanization increases the power applied to agricultural operations and is one tool among many for improving farm productivity and increasing income for Nigeria's farmers and processors. Mechanization gives room for lower costs and timeliness of operations thereby allowing for greater area of land to be cultivated. The demand for mechanization is therefore determined by the stage of agricultural transformation reflecting the use of complementary inputs (improved seeds, fertilizer), the intensity of farming, land holdings, and rural labour supply and thus wages. Countries across the developing world have mechanized at different rates corresponding to the level of their agricultural transformation but are also strongly influenced by government policies. Assessments of agricultural mechanization at the continental level have found that Nigeria has an agricultural sector characterized by low productivity growth and low machinery growth relative to other African countries. According to ADF (2013), the percentage of arable land in Nigeria is 39.5% while the average for Africa is 8.4%, for developing countries is 9.9% and for developed countries is 11.6%.

Most countries in Sub-Saharan Africa depend on agriculture for their economic growth and poverty reduction, therefore the enhancement of agricultural productivity is key to their development (World Bank, 2007). The lowland ecology is a highly promising area for productivity growth, as much of the lowlands in Sub-Saharan Africa, especially in West Africa, remain underutilized or largely unexploited (Andriesse et al., 1994). Rice among others is a promising crop that does well in lowland ecology not only because it requires more water than other crops but also because its demand has been increasing due to urbanization and recent economic boom in Sub-Saharan Africa.

The tractor is one of the most available agricultural machinery used all over the world for farming operation. Despite this, Nigeria has more human involvement in the field than the use of tractors. Our reliance on human power cannot help us to meet the food demand of our growing population.

As good as these tractors are, it has been observed that conventional tractors are not suitable for use in lowland farming areas of Nigeria. The only time they are applicable in lowlands is when the soil water significantly reduces hence the use of conventional farming in lowlands is risky. Resulting from this, power tillers became so much useful to farmers for rice cultivation in lowlands.

A power tiller is a two-wheeled agricultural implement fitted with rotary tillers which gives a smooth resistance to all farm activities. In Nigeria, power tillers, also known as single-axle tractors, along with their accessories and other equipment, are being introduced for rice farming in lowland areas. Power tillers are more desirable for use in lowland rice farming than conventional tractors. This is because power tillers are cheaper and easier to maintain, versatile in operation, and supported with cage-wheel which is suitable for lowland operations which includes inland valleys, flood plains, river basins commonly known as FADAMAs in Nigeria. Today, Nigeria has attained the position of the largest producer of rice in Africa, however, the country needs to maintain this position for the next decades. The Nigerian government needs to do all it takes to make rice farming in Nigeria a thing that farmers will wish to put in all their effort (Ademiluyi et al., 2023a). Because of this, this paper takes a deep look at the machinery adaptable for tillage practices in lowland rice farming in Nigeria which is of utmost importance to rice farmers in Nigeria.

2. PLANTING OF RICE IN LOWLAND AREA OF NIGERIA

Rice is a very important grain food to the world. The domestication and cultivation of rice is one of the most important events in our agricultural history. The only most important raw material needed for commercial production of rice is the rice seeds or seedlings. There are different varieties of rice according to the morphology and topography of the soil (Okeke and Oluka, 2017). Lowland rice accounts for 50% of the total rice produced in Nigeria. In recent years, WARDA now known as AfricaRice has introduced several rice varieties, with efficient natural/crop management and pest and disease management technologies to rice farmers in Nigeria and other West and Central

African countries. Typical examples are the high yielding rice varieties such as FARO 44 (SIPI), FARO 51 (CISADANE), FARO 52 (WITA 4), FARO 57 (TOX 40043-1- 2-1), and the lowland varieties of the New Rice for Africa (NERICA) that are currently being evaluated in several parts of Nigeria before full release. The majority of these introduced technologies have been accepted and become widespread in some States of Nigeria.

Kamai (2020) reported that rice is one of the major staple foods in Nigeria, consumed across all geopolitical zones and socioeconomic classes. Rice consumption is increasing rapidly in Nigeria because of the shift in consumer preference towards rice, increasing population growth, increased income levels, and rapid urbanization. It is commonly boiled and eaten with stew or vegetable soup. It is also used in the preparation for several local dishes in every home, especially during festivals and ceremonies. Currently, most farmers producing rice rely on traditional technology with low use of improved input technologies. It is important for farmers to adopt improved varieties and have a good knowledge of rice agronomy to increase rice production and productivity in the various States of the federation.

3. MACHINERY AND TILLAGE PRACTICES SUITABLE FOR USE IN LOWLAND RICE FARMING IN NIGERIA

The power tiller as the most appropriate agricultural machinery suitable for use in lowland rice farming is less sophisticated and not too expensive. The power tiller has a locally manufactured frame equipped with an imported water-cooled diesel engine of 5.22 kW (7 hp). Presently manufactured power tillers are designed primarily for paddy areas which are best used during operation at high tractive efficiency. The versatility of the power tiller is seen in its operation which makes it to perform operations that include ploughing, puddling, bunding, spraying, levelling, transplanting, harvesting, transporting, canal digging, and water pumping. This can be referred to as the multi-purpose use of the power tiller. The description of the operations performed by the power tiller are as follows:

3.1 Ploughing

The power tiller has a mounted rotavator and/or plough which may be a mouldboard or disc plough which easily ploughs and turns the soil into loose tilt after the land has been cleared of virgin vegetation. Furthermore, it can be done under semi-moist or flooded conditions. Fig. 1 shows a picture of ploughing operation carried out during rice farming at the Lake Chad basin.

Fig. 1. Picture of ploughing operation during rice farming at Lake Chad basin
Source: Ademiluyi et al. (2023b)

3.2 Puddling

This is an operation during which the soil clod is being broken and mixed with water to form a slurry-like soil. This soil condition is ideal for transplanting rice seedlings, promoting vigorous tillering and resulting in optimal rice yields. Fig. 2 shows the picture of puddling operation carried out during rice farming at Lake Chad basin.

Fig. 2. Picture of puddling operation during rice farming at Lake Chad basin
Source: Ademiluyi et al. (2023b)

3.3 Bunding

This is the demarcation of fields into basins with the assistance of field topography by taking advantage of gradient variations to group closely related portions. Standard bunds should be 50 cm in width by 50 cm in height using a mouldboard severally in vertical motion to achieve good bunds (Ademiluyi et al., 2023b). The ploughs attached to the tiller can bund the soil when the machine is operated to move in a straight line repeatedly. This eventually carries the soil to form ridges or bunds which define the perimeter of a basin. Fig. 3 shows the picture of the bunding operation carried out during rice farming at Lake Chad basin.

Fig. 3. Picture of bunding operation during rice farming at Lake Chad basin
Source: Ademiluyi *et al*. (2023b)

3.4 Levelling

This is the movement of soil from higher to lower gradient, this is done to achieve almost 0% gradient or slope within the basin. The purpose is to achieve a basin when water is being introduced it will spread evenly within the basin, hence, give good water management. The closer to 0% gradient or slope the better water management achieved and the higher the yield. A sizable bar made of wood is attached to the power tiller to carry soil from higher points to low points to achieve a levelled basin. Fig. 4 shows the picture of levelling operation carried out during rice farming at Lake Chad basin.

Fig. 4. Picture of levelling operation during rice farming at Lake Chad basin
Source: Ademiluyi et al. (2023b)

3.5 Transplanting

Transplanting is one of the methods of planting rice. Rice seeds can be planted through transplanting, broadcasting, or dibbling, where 2 or 3 seeds are dropped into a hole and then covered with soil. Among these three common methods, transplanting is the most effective for achieving optimal yields. This involves preparing a seedbed in advance, where seedlings are grown before being transplanted to the field. For a transplanter machine there is a special crate with layers of manure gotten through composite of rice straw where seedlings are skillfully raised. A transplanter could be mounted on the power tiller for motion and transplanting. This operation is time managed with high coverage of the basin with appropriate spacing for planted seedlings.

3.6 Water Pumping

The pulley of the axial water pump is connected to the V-Belt transmission unit of the power tiller as its source of power. This rotates and allows water to be pumped from the desired source. The pump must be above 10 m long to achieve an efficient water pump.

3.7 Harvesting

This is one of the major and sensible operations. All efforts to rice production will be in vain if this operation is not effectively carried out. There is a need to promote the use of machinery for harvesting operation. A mini combined harvester could be mounted in front of the power tiller to harvest and thresh the paddy for further processing and storage.

4. CHALLENGES OF CROPPING RICE IN LOWLAND AREA OF NIGERIA

There are several challenges facing the cropping of rice in lowlands which are as a result of the machinery and tillage practices involved. These challenges are presented as follows:

1. Soils in lowland areas of Nigeria are typically heavy resulting from high clay deposits of soil particles which requires high tractive force to overcome soil resistance during land cultivation.
2. Soils in lowland are also predominantly soft, sinking and slippery in nature thereby making tractors and its accompanying implements not suitable for use in such terrain.
3. The presence of available water resources in the lowland makes the soils there to be water logged which is a challenge to cultivation.
4. Conventional tractors are of disadvantage due to the problem of sinking resulting from its weight. This gives power tillers of lesser weight advantage to be used in lowlands.
5. Power tillers engage for bund making is a great challenge resulting from the use of mouldboard plough implement which requires multiple passes in the making of bunds. Despite the use of this mouldboard plough implement for bund making, the desired height of bund has not been achieved thereby reducing the capacity to retain water in the basin for rice farming.
6. The sinking of the operator when handling the power tiller in a deep swamp has become a great challenge.
7. A lot of human power is involved when operating the power tiller in deep swamp thereby increasing the length of days in completing the operation. Time efficiency is affected which is one of the areas mechanization tends to tackle.
8. Manual labour is commonly used for lowland cultivation and therefore limiting the capacity to harness the lowlands and consequently reducing productivity.

5. WAYS FORWARD AND CONCLUSION

5.1 Ways Forward

Considering the challenges facing the use of machinery for the tillage practices involved in lowland rice farming in Nigeria as presented in section 4, it becomes necessary to provide ways forward in addressing these challenges. These ways forward include:

1. Bund makers which are part of conventional tractor implements should also be made for power tillers so as to increase the height of the water level needed in the basin for rice farming.
2. Timeliness of operation is one of the core objectives of mechanization and for this reason the use of conventional tractors in lowland area should be critically looked into to increase rice production in the country.
3. Power tillers should be incorporated with floater seat which will help the operator of power tillers in maintaining their stability on the field while handling the power tiller.
4. Power tillers between the range of 13 to 18 horsepower looks recommendable for use in swampy area. This power tiller range can provide for more tractive force than power tillers of lesser capacity.

5.2 CONCLUSION

The consumption of rice in so many households in Nigeria is gaining widespread. Reports gathered from FAO (2003) showed that more than half of the world's population depends on rice as a major source of calories. The present price at which rice is been sold in our local market today in this Tinubu and Shettima led government is relatively cheap than the amount food stuffs like semovita and beans are purchased. Rice farming is also gaining ground in Nigeria whether it is planted on uplands and lowlands. The growing population which has given room for higher food demand in the country encourages the need to promote rice farming in lowlands due to the availability of water it provides that is good for all year-round farming. This study was essential to promote lowland rice farming as a crucial method for boosting rice production in Nigeria. It is strongly believed that the recommendations provided in this study will significantly aid in encouraging our rice farmers to overcome the various challenges associated with using machinery for the different tillage practices involved in lowland rice farming.

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AGRICULTURE 4.0; A PANACEA FOR NIGERIA'S AGRICULTURAL SECTOR

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ABSTRACT
As the global population surges, the demand for food increases and meeting these demands requires a new approach as traditional practices are no longer sustainable and efficient. Nigeria faces these challenges, with a population of over 220 million people making the availability of cost-effective food and industrial raw materials difficult for both the government and the farmers. The evolution of digital technologies and their integration to Agriculture will give way to increased economic growth and development of Nigeria. Agriculture 4.0 is a new approach to digitalization and developing intelligent manufacturing processes over an entire agricultural value chain with increased customization and individualization. This study reviewed some of the key challenges the Nigerian Agricultural sector faces along the agricultural value/supply chains to pave the way for the successful implementation of Agriculture 4.0 in some key areas of the sector.

Keywords: Agriculture, Nigeria, IoT, Precision Agriculture, Smart Farms, CPS

1. INTRODUCTION

As the global population grows and technology advances, the demand for effective, fast, reliable, and timely production has been a factor of discussion from academia to industry. Academia focuses on finding concepts and developing systems, methodologies and business models, the industry focuses on changing machine-dominant manufacturing to intelligent machines and processes that improve productivity and increase customer satisfaction (Ercan & Samet, 2018).

Agriculture was the leading contributor to the Gross Domestic Product (GDP) of Nigeria before the discovery of crude oil by contributing 57% of GDP and 64.5% of export earnings from 1960-1969, between 1970 and 2000 the sector contribution declined to 23.5% and 5.1% as export earnings (PwC, 2017), in 2017 the production increased to 29.15% of GDP while in the second quarter of 2020, it declined to 24.6% as the result of the global pandemic(COVID-19) (NBS, 2020) Nigeria's agriculture potential is high with a population of around 180 million people, an estimated 82 Million Hectares of arable land of which on 34 million is being cultivated, feeding such population is a huge task indeed for the Government and its farmers. The sector is still underutilized as a result of the inability to add value to produced products the Country loses an estimated 9 million USD annually to post-harvest losses (Abdulhakeem, Muhammad, & Dagwa, 2020; NBS, 2020).

Some researchers (Ilaria, Massimo, Gianluca, Maria Grazia, & Andrea, 2019) defined Agriculture 4.0 as an approach that creates an environment in which elements, devices, and functionalities are continuously linked together to have constant communication with a high degree of coordination. while other researchers perceived it as a new level of organization and control over an entire value chain of products, increased customer individualization requirements, creating connections of physical systems, internet, designing and drafting production development, integrated approaches, processes and Information Technology-driven solutions to agriculture (Saurabh, Prashant, & Santosh, 2018), the author's see it as a collective approach that integrates machines, work schedule and manufacturing systems through integrated networks and value chain to enable constant communication and high level of coordination between each other.

The advancement of science and technology dynamically improved industrialization globally, industrial development evolved over three stages before the commencement of the fourth industrial revolution (Yongxin, Fernando, Loures, & Luiz Felipe, 2017), these industrial achievements developed over two hundred years ago; the first industrial revolution paved the way for steam and water powered facilities, the second gave birth to mass production and assembly systems while the third came with the integration of electronics and information technology (IT) to further automate and simplify manufacturing systems (Drath & Horch, 2014) (Stephan, Mathias, Moritz, & Dominic, 2015). This development has influenced industry through smart factories, products and services with integrated Internet of Things (IoT) and industrial Internet (Stock & Seliger, 2016) to achieve sustainable manufacturing of products and services using recent information and communication technology (ICT) infrastructure.

Agriculture 4.0 or Farming 4.0 as viewed by Anja-Tatjana (Anja-Tatjana, Eduardo, & Thilo, 2018) is aimed to increase the use of ICT technology to agricultural practices to enable past, present and future challenges to be addressed using intelligent networks that constitute the incorporation of several data from different sources to increase productivity, efficiency and transparency across the agricultural value/supply chain (Tejas & Sanjay, 2019). There is an intensive investigation going on in areas of precision agriculture, autonomous machinery, new measurement tools and agricultural production planning and control.

This study analyses some of the key challenges the Nigerian Agricultural sector faces along the agricultural value/supply chains to pave the way for the successful implementation of Agriculture 4.0 in some key areas of the sector.

2. BACKGROUND

2.1 Nigerian Agricultural Sector Challenges

Nigeria has a total land mass of 92.4 million hectares (ha) of which 91.1 million ha of made of land, and 1.3 million ha as water bodies, out of the 91.1 million ha of land 84 million ha is arable and only 34 million ha is utilized for agricultural production. Despite this huge land mass, Nigeria spends an estimated 5.8 billion USD for the importation of fish, wheat, dairy products and other food commodities (PwC, 2017; FMARD, 2016; Dayo, Ephraim, John, & Omobowale, 2009).

Researchers such as Dayo et al., (Dayo, Ephraim, John, & Omobowale, 2009) highlighted some of the challenges facing Nigeria's agricultural sector as: uncontrolled demographics, stressed natural resources, climate change, land degradation, insecurity and food waste. To tackle these challenges, The Government has made so many policies and reforms for the agricultural sector to thrive such as the National Agriculture Policy, the Agricultural Transformation Agenda and recently the Economic Recovery and Growth Plan. However, agriculture is still largely subsistence and the focus has been on production rather than value addition (Ata-Agboni & Beluchi, 2019; PwC, 2017)

2.1.1. Uncontrolled Demographics: demographics can be classified as rural-urban migration, overpopulation. The absence of basic and social infrastructures caused an imbalance in the rural areas of Nigeria resulting in people migrating to urban areas in search of a better life and standards (Tunde Charles, 2009). According to Kneoma Nigeria's population is estimated to be 200 million people as of 2019 a clear indication of an overpopulated country where natural resources will be stretched (Knoema, 2019), global population stands at 7.6 billion people in the next 3 decades the population is estimated to increase by 30% to a staggering 10 billion global citizens, this means by the year 2050 farmers need to produce 70% more food to meet with the food demand (UNPP, 2019; Matthieu, Anshu, & Alavaro, 2018).

2.1.2. Stressed Natural Resources: Human impact on land has caused several negative effects on the environment from overgrazing, land clearing, bush burning, deforestation, poor land fallow system, fertilizer misuse and other negative factors with the intent of either agricultural purposes, source of fuel and raw materials, food for livestock of which the resultant effect has reduced the quality of soil for agriculture, increased desertification and soil erosion (Matthieu, Anshu, & Alavaro, 2018; Macaulay, 2014; Isife, 2012).

The increasing demand for food to feed such a huge population as stated by Kneoma (Knoema, 2019) is never an easy task, the rural population that are largely farmers and nomads with an unbalance between the urban and rural areas, the act of sustainable agriculture has been traditionally active as such little use of technology, science and innovative means of cultivation.

2.1.3. Food waste: Global food waste stands at a staggering 1 trillion USD with around 50% of global production food production being wasted because of inefficiencies in handling, access to markets and inadequate industries. With over 800 million malnourished people, these wasted foods account for around 25% of global water consumption and other resources such as land, labour, capital, manufacturing, packaging and time; these are left to decay in landfills without oxygen give out methane which increases greenhouse gas emissions (Matthieu, Anshu, & Alavaro, 2018).

Nigeria lost an estimated 5.3 billion USD to food imports ranging from dairy, fish, cereals, sugar and molasses, fruits and vegetables (FMARD, 2016). The production of fruits and vegetables annually is around 16.4 million metric tons, making Nigeria the 2nd largest producer of tomatoes in Africa, 13th in the World and sadly 3rd largest importer of processed tomatoes commodities in Africa, over 50% of these produced fruits and vegetables are lost due poor infrastructures, lack of access to markets, poor postharvest handling costing Nigeria around 9 million USD annually (Abdulhakeem, Muhammad, & Dagwa, 2020). With global food consumption at 3.4% and predicted population growth of around 400 million people by the year 2050, an estimated 4% annual food consumption increment (PwC, 2017; FMARD, 2016), to feed this number of people will indeed be a great challenge as such an integrated approach that requires "Smart farming" practices, "smart Industries" for processing of raw materials to finished goods is urgently needed.

2.2. Need for Integrating Agriculture 4.0 into the Nigerian Agricultural Sector

The concept of Agriculture 4.0 lies mainly in creating an arena that connects all elements and functionalities in a hitch-free manner to achieve maximum outputs. This connection ranges from the agricultural value chain to the supply chain in a holistic system approach that entails digitalization of agricultural processes using sensors, devices, communication technology and the internet to monitor, track changes and make timely decisions and recommendations to change the way traditional farming practices are done (Lee, Kao, & Yang, 2014; Mohd Aiman Kamarul, Mohd Fauzi, Nor Hayati, & Muhamad Farihin, 2016), cost-effective automation, efficient operation conditions for farmers and other stakeholders and to improve on cross-industry cooperation (Bonneau, Copigneaux, Probst, & Pedersen, 2017; Eleni, Konstantinos, & Dimitrios, 2020).

3. TECHNOLOGIES OF AGRICULTURE 4.0

These technologies are the enabling components of Agriculture 4.0 which include Systems Integration, Big Data Analytics, Cloud Computing, Cyber Physical Systems (CPS), Internet of Things (IoT), Artificial Intelligence/Machine Learning, Autonomous Machines and Simulation. All these components enable the integration of production facilities, and supply chain service systems for the full synthesis of value-added networks that can coordinate real-time decision-making processes (Mohd Aiman Kamarul, Mohd Fauzi, Nor Hayati, & Muhamad Farihin, 2016; Alp & Emre, 2017).

3.1. Cyber-physical systems

CPS is a system that integrates information and physical dynamics to secure critical industry ecosystems using sensing, computation and communication to safeguard industrial systems using intelligence to achieve common tasks (Jun, Shibo, Seng, & Hongkai, 2019). The integration of these systems increases the flexibility and efficiency of industrial systems to increase the level of interaction between people to people, machines to people, and machine-to-machine in real-life solutions and virtually (Yu, Qi, & Li, 2019). Due to this integration of CPS, several smart devices are connected to the Internet at greater efficiency and scalability to improve the Internet of Things network (Heisheng, Heng, & Keqiun, 2019). It processes the data generated by sensors using powerful computing software and other resources to turn these data into useful real-life solutions (Hirofumi & Sugano, 2020).

CPSS architecture modules: these modules enable control of CPSS applications it comprises of Application-as-a-service (AAAS), Network-as-a-service (NAAS) and Infrastructure-as-a-service (IAAS). These modules detect how CPSS applications respond to input and execution of output (Haisheng, Heng, & Keqiu, 2019).

3.2. Internet of Things (IoT)

The Internet of Things is an electronic concept that connects the Internet to objects to convert them into connected devices, to enable smart objects for sensing, transmission of data, processing and feedback to the sensing environment for increased safety, sustainability and efficiency (Emiliano, Abusayeed, Song, Ulf, & Mikael, 2018).

4. STATE OF THE ART

For the implementation of Agriculture 4.0, three key factors need to be adhered to (Alp & Emre, 2017);

I. Horizontal integration,

II. Vertical integration and networking of systems,

III. End-to-end engineering of overall value chains.

4.1 Horizontal integration: this enables the acquisition of data on products produced between organizations to optimize product qualities using information systems, efficient financial management and flow of materials (Alp & Emre, 2017) to meet customer needs and improve the entire supply chain through situation analysis and environmental studies to develop models and strategies for sustainability of manufacturing or service operations, company's level of integration and technological adoption level to identify change elements within the organization (Magdiel, Jania, Jose´ Antonio, Toma´s Eloy, & Pandian, 2018).

4.2 Vertical integration: offers a digitalized cross-linking of business units in different hierarchical levels of the organization, it involves the creation, development, manufacturing of products and administration (Alp & Emre, 2017). It assesses the system to identify the social technical systems and value creation modules to provide support to operations and transformation into smart farms with high flexibility and profitability (Magdiel, Jania, Jose´ Antonio, Toma´s Eloy, & Pandian, 2018), to meet customer needs with maximum utilization of resources (Michael, 2018).

4.3. End-to-end Engineering integration: this facilitates the automation, flexible, digitalized and efficient production systems as products and services are key components of Agriculture 4.0 (Michael, 2018; Leyh, Martin, & Schäffer, 2017) to check for the compatibility of this union and bring about smart products to meet customer needs and give way for the production of cyber-enabled products and optimization along the entire value chain of the product (Kagermann, Helbig, Hellinger, & Wahlster, 2013; Michael, 2018). This integration of CPS, physical production system and products will allow monitoring, improved resource utilization, self-regulation, autonomous production and seamless flow of materials across production lines for faster production in real-time within or outside the organization (Bassi, 2017), (Axelsson, Fröberg, & Eriksson, 2018).

5. AGRICULTURAL PRODUCTION PROCESSES

Traditional cultivation and processing practices are being transformed into smart practices to boost productivity, reduce waste, increase profit, customer satisfaction and new business models. The digitalization of agricultural processes will improve traditional machines to bring in new tools and machines for production such as autonomous tractors and equipment, connected machines and tools, which will reduce the need for highly skilled operators, Global Positioning System (GPS) will give a real-time data for precise tracking of farm operations to pave way for enhanced billing and profit (Harold, Woodard, Glos, & Verteramo, 2016; Kovács & Husti, 2018), sensors for detecting weather conditions, soil conditions such as nutrient content, moisture content, irrigation requirements, drone technology for detection of insects and pest infestation and recording these data for present and future utilization and optimization of production practices (Anja-Tatjana, Eduardo, & Thilo, 2018).

6. AGRICULTURAL SUPPLY CHAINS

The Nigerian agricultural supply chain has its challenges which include poor inputs, subsistence farming, low adoption of mechanization, poor postharvest handling, lack of adequate rural infrastructures and access to markets, unfavourable credit facilities, government policies, low funding of Agricultural Research Institutions, poor adoption of modern agricultural practices across the value chain (Dayo, Ephraim, John, & Omobowale, 2009) (FMARD, 2016), (PwC, 2017).

Connecting Agriculture 4.0 components to the supply chain via the cloud and Internet of Things to provide more value-added services to close the gap between the virtual and physical world, the more the connectivity with farms and machines, the more increased the transparency and security in production, processing and increased customer satisfaction (Anja-Tatjana, Eduardo, & Thilo, 2018), (Kovács & Husti, 2018). This will further Increase the chances of modernization of farmers' production practices and the rural infrastructures to obtain and share real-time market and production information (Lorenzo, Antonio, Umberto, & Achille, 2019).

7. AGRICULTURAL BUSINESS MODELS (ABM)

Business modelling is an approach that seeks to minimize the current cost of processes in a system at a more efficient, increased profit, less production time and a satisfactory product (Sezi & Alp, 2018). It is a comprehensive tool that understands how business is done, conducts performance analysis and identifies and implements competitive strategies in product design or services offered to the market and customer engagements. In the case of agriculture, it is the digital transformation of the agricultural supply chain that enables innovative business approaches that combine economic, human, Animals and environmental for sustainable productivity to improve on the existing practices for more profit, reduced waste and increased customer satisfaction (Anja-Tatjana, Eduardo, & Thilo, 2018).

The components of ABM are value proposition, value creation, delivery and value capture. Value proposition deals with what the company or farmer has to offer as a product or service. These smart products or services will provide cost reductions, new income streams and innovations integrating IoT applications and platforms that allow connectivity between devices at different locations to gather data, analyze, and optimize processes and production at the lowest possible cost, reduce wastages, faster transactions and transparency which will increase customer satisfaction and loyalty (Sezi & Alp, 2018). Tracking and analyzing customer-buying behaviour using smart channels, utilization of data on soil and environmental conditions to provide adequate information for timely decision-making and recommendations for increased growth and innovative farming (Ilaria, Massimo, Gianluca, Maria Grazia, & Andrea, 2019), (Anja-Tatjana, Eduardo, & Thilo, 2018).

8. CONCLUSIONS AND RECOMMENDATIONS

The agriculture 4.0 revolution can offer several advantages to the Nigerian Agricultural sector, not just to the government and stakeholders but also to technological sophistication in simplifying production processes. These technological advancements will go a long way in transforming the sector challenges by adopting new technologies to replace traditional practices of agriculture, incorporating cross-industry methodologies for solving agricultural challenges and customer-focused goods and services with high efficiency and effectiveness. New technologies and software alone cannot address all the problems ravaging the agricultural sector in Nigeria. Necessary infrastructure, funding, favourable regulations and adequate investment in Agricultural Research and Education are needed to ensure the implementation of Industry 4.0.

8.1. RECOMMENDATIONS

Generally, in Nigeria, the Government plays the role of promoter/facilitator allowing other stakeholders to play the remaining part, for Agriculture 4.0 to thrive the Government needs to take the primary role with full engagement to ensure that food security is guaranteed to its teeming population with the following also taken into cognizance.

1. adopt a goal-oriented problem-solving mentality
2. upgrade the rural telecommunication infrastructures
3. seek for cross-industry collaboration
4. develop holistic research and development solutions
5. create educational programs and awareness initiatives
6. friendly regulations

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DESIGN AND CONSTRUCTION OF CENTRE PIVOT SPRAY UNIT

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Abstract

This research was carried out for the purpose of designing a centre pivot spray unit. The unit is composed of the nozzle, the spinner body which is the housing the nozzle, the deflection plate and the holder plate. The existing design arrangement of the Centre Pivot System (CPS) spray unit parts is such that the nozzle is at the middle followed by the deflection plate and the holder cover. During maintenance resulting from blockage or need for part replacement, the whole components are uncoupled. The frequency of the uncoupling leads to breakage or damages of the spray unit since the parts are made of plastics and has been exposed to environmental factors over time, they become brittle. This significantly affect the irrigation operation in terms of time, stress, cost and availability of the parts. This research designs and construct a reverse flow spray unit system for CPS where the nozzle is side access that only require turning of the nozzle in a reverse flow to remove any blockage without uncoupling the whole spray unit using additive manufacturing Technology. The selection and design of the nozzle diameters and groove numbers were done based on the CPS discharge, pressure requirements and applying relevant equations. Three functional side access reverse flow model nozzles, its housing, 3 curved and 2 straight grooves were successfully designed constructed using Acrylonitrile Butadiene Styrene (ABS).

Key words: Nozzle, Centre Pivot, Sprinkler, 3D printing machine, ABS filament.

Introduction

The Centre Pivot System (CPS) is one of the most efficient form of large sprinkler irrigation systems because of its peculiar characteristics like; high precision, labour saving, high level of uniformity, large coverage etc. Yet the CPS is not without challenges, such as maintenance of the CPS spray unit which is one of its important components. Its purpose is to distribute water over an area so that the appropriate amount of water is applied at all locations. The spray unit is composed of the spinner body, the nozzle, the spray plate and the holder cover.

In spraying systems, nozzles break the liquid into droplets and form the spray pattern. Nozzles determine the application volume at a given operating pressure, travel speed, and spacing.

Selecting nozzles that produce the largest droplet size, while providing adequate coverage at the intended application rate and pressure, can minimize drift.

In the recent times the use of, modification and creation of low- pressure spray plates or deflector plates in pivot sprinklers have increased. The first low-pressure spray plate sprinklers can be classified as Fixed-Spray Plate Sprinklers (FSPSs). Recent developments in this area have led to the commercialization of Rotating Spray Plate Sprinklers (RSPSs), in which a grooved spray plate rotates under the effect of a water jet. These sprinklers have been successfully introduced in irrigation machines. They have different plates that result in different droplet size distributions and water application patterns (Faci *et al*., 2001; Hanson and Orloff 1996; Liu *et al*., 2017).

Over the years a lot of research have been done on sprinklers, focusing on factors such as sprinkler nozzle characteristics, operating pressure, flow rate, riser characteristics, sprinkler spacing, pattern of sprinkler grid and environmental factors. It is important to know and understand what to expect from any sprinkler that the designer plan to use. Some general characteristics that should be understood include: sprinkler discharge, radius of throw, water distribution pattern and precipitation rate. A poor design of the spray unit will likely result in uneven water distribution with more water in some places than others.

The design and arrangement of the spray unit parts of the CPS is such that the nozzle is at the middle followed by the spray plate and the holder cover. During maintenance resulting from either blockage or need for part replacement, the whole components are uncoupled. The frequency of the uncoupling leads to breakage or damages of the spray unit since the parts are made of plastics and has been exposed to environmental factors over time, they become brittle. This significantly affect the farming operation in terms of time, stress, cost and availability of the parts. This research designs a reverse flow spray unit system where the nozzle is side access that only require turning of the nozzle in a reverse flow to remove any blockage without uncoupling the whole spray unit.
A great deal of research has been conducted on the effects of operating pressure, nozzle diameter and layout form on hydraulic performance, water uniformity for small or medium size sprinkler, characterization and evaluation of existing sprinklers (Culver and Sinker 1966; Chen and Wallender 1985; Edling 1985; Fischer and Wallender 1988; Louie and Selker 2000; Faci *et al*., 2001; Mateos 2006; Zhu *et al*., 2012; Liu *et al*. 2013a; Burillo *et al*., 2013; Fukui *et al*.,1980; Playán *et al*. 2006; Zhang *et al*., 2013; Charlie 2024) but there are little or no much literature on development of Rotating Spray Plate Sprinklers (RSPSs).

2.0 MATERIAL AND METHODS

2.1 Materials

The materials used in this study include, Solid Works Software, 3D printing machine, and ABS filament.

Figure1: ABS Filament (*source, B and H photos 2024*)

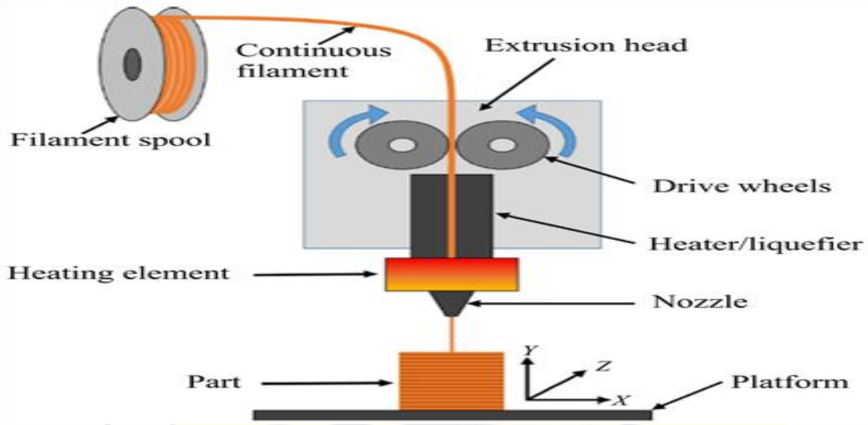


Figure 2: Schematic Diagram of A 3D Printer (*source Tridib ,et al.,2023*)

2.2 Material Selection

Acrylonitrile Butadiene Styrene (ABS) was selected for the construction of the spray units. This is because of the following properties, Tensile Strength, Toughness, Hardness, Low Density and Resistance Ultraviolet (UV) radiation (Koray *et al*,. 2021).

2.3 Preliminary Design of the System

In order to achieve the objective of the design concept, various spray nozzles and spray units were studied, including: Impact, flat fan, hollow cone, Air blast Rose can and the spray unit; Fixed Pad Spray, Multiple Pad Spray, Rotator Pad Spray and Oscillating Pad spray. After studying these systems and the existing challenges with the CPS spray unit, a new concept was developed that make maintenance of the unit much easier, durable and more efficient.

2.4 Detailed Design of the Spray Unit System

The detailed design of the system was done in two phases:

i. The design of the nozzles

ii. The design of the deflection Plates

The methodology for these two phases are presented as follows:

2.4.1 Design of the Nozzles

2.4.1.1 Diameter Selection

The design of a nozzle involves the selection of the diameters which controls its performances. The selection of the nozzle diameters were done based on the CPS discharge, pressure requirements and applying relevant equation. The inlet diameter is twice the outlet diameter. This is to increase the speed of flow of at outlet nozzle to make impact on the deflection plate for rotation.

- **Design Equations**

In designing the nozzles, a relationship proposed by Darrel, *et al*., (2017) were considered. It described the relationship between system nozzle discharge, pressure and diameter of the nozzle. These parameters are necessary for designing centre pivot nozzle spraying system. The relationships are described in equations 3.1.

According to Darrel *et al*., (2017), for a round orifice, the nozzle discharge for CPS can be calculated by:

$$q = C_d\ (29.83) d^2 P^{0.5} \qquad \ldots(2.1)$$

Where:

q = nozzle discharge in (gpm)

C_d = discharge coefficient

(often between 0.95 and 1.00)

d = nozzle diameter in inches

p = pressure in Psi

Given the following parameters: CPS nozzle flow rate = 7.8 gpm, Pressure = 10Psi, Discharge coefficient = 0.95, Various Nozzle diameters were calculated; Table 3.1. The discharge values obtained were converted to litres per second.

Table 1: Nozzle Diameters at Various Pressures Discharges

S/NO	Pressure Psi	0.49L/s	0.32L/s	0.63L/s	0.76L/s
		Nozzle diameters (mm)			
1	**5**	**9.0**	7.1	10.1	11.0
2	**10**	**7.0**	6.1	8.5	9.3
3	15	6.7	5.3	7.6	8.4
4	**20**	**6.0**	5.0	7.1	7.8
5	25	5.8	4.7	5.9	7.4
6	30	5.6	4.5	6.4	7.0
7	35	5.5	4.3	6.2	6.8
8	40	5.3	4.2	6.0	6.6
9	45	5.1	4.0	5.8	6.3
10	50	4.8	3.8	5.6	6.2

2.5 Design of the Spray Plate

To achieve appropriate water spray, rotating deflection plate was designed and incorporated into the spray unit. In doing this, deflection plate of 6 grooves was designed and produced adopting general geometric construction methods. The selected dimensions of the deflection plates were done to fit into the existing irrigation machine. The radial grooves were designed considering the equation by Sofiene *et al*,.(2018) as:

The radial grooves were designed considering the equation by Sofiene, *et al.,* (2018) as:

$$di = \left(\frac{D}{2} - L\right) \times 2 \times \frac{\pi}{N} \quad (2.2)$$

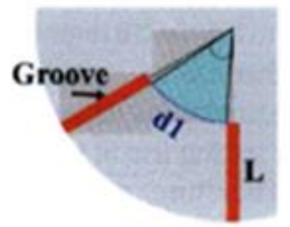
Where

D = Plate Diameter (m)

L = Groove Length

N= Groove Number

di = Distance between two successive Grooves



Substituting the selected dimensions as:

Distance between two successive Grooves = di

Plate Diameter D (m) = 3.8cm

Groove Length L= 1.5cm

N = number of grooves

Various Deflection Grooves were Calculated, Table 2

Table 2 Number of grooves at various spacing at 3.8cm Plate Dimeter and 1.5cm Groove Length

S/NO	Groove Spacing	No of Grooves
1	0.61	4
2	0.41	6
3	0.31	8
4	0.25	10
5	0.21	12
6	0.178	14
7	0.16	16

2.6 Nozzle Design Drawings

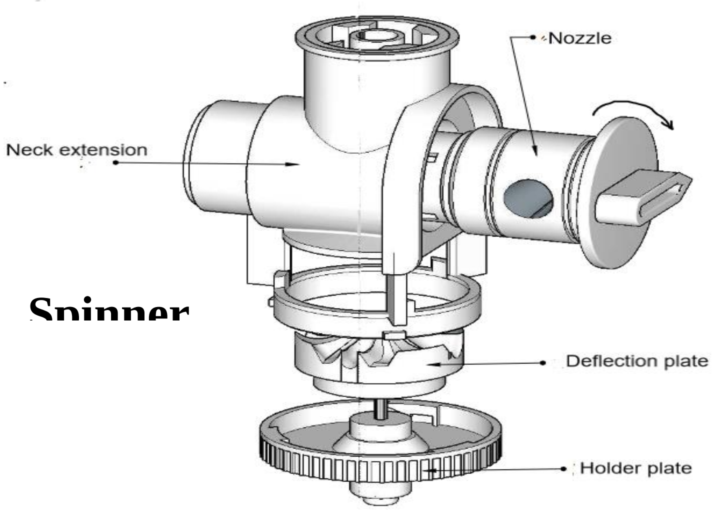


Figure 3: Design Drawings for Spray Unit Assembly

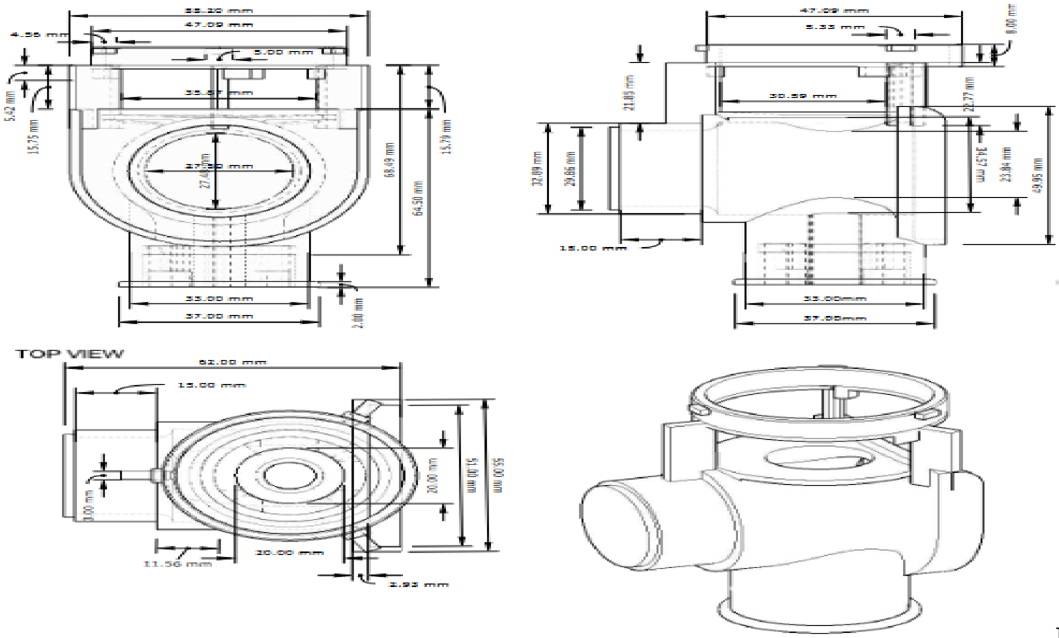


Figure 4: Views of Spinner Body

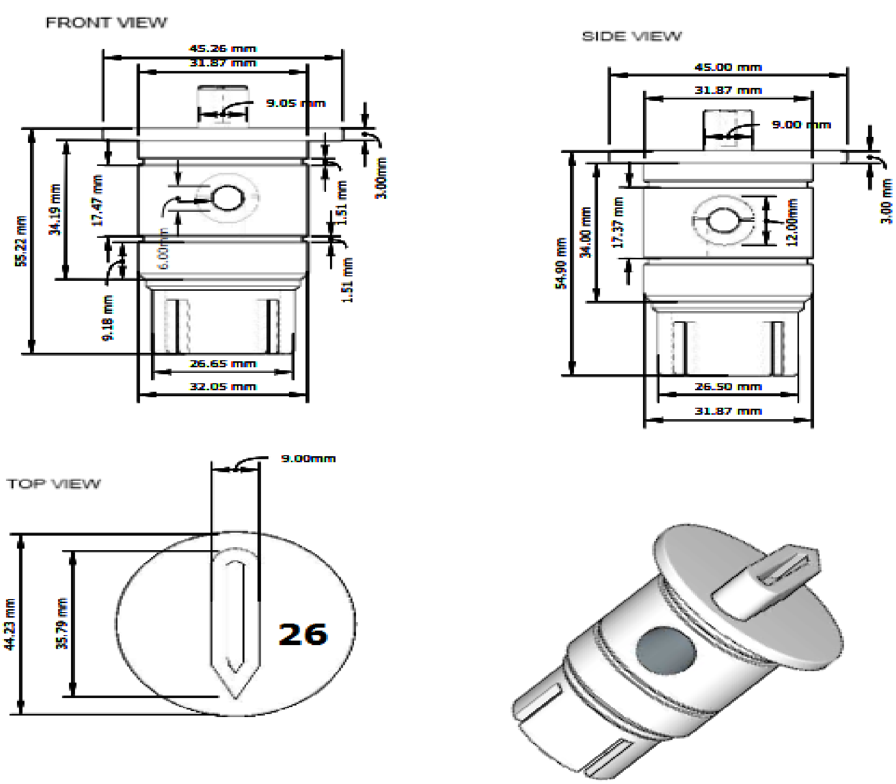


Figure 5: Views of Nozzle diameter 6mm

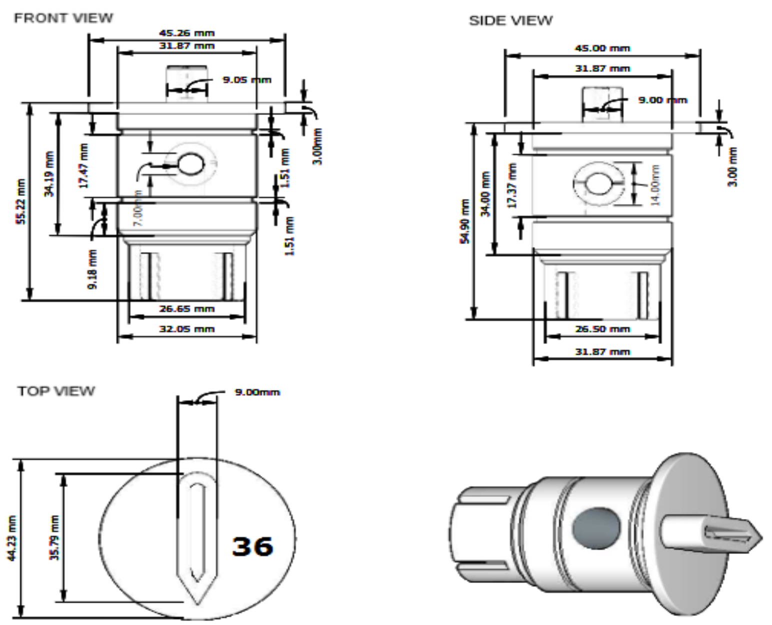


Figure 6: Views of Nozzle diameter 7mm

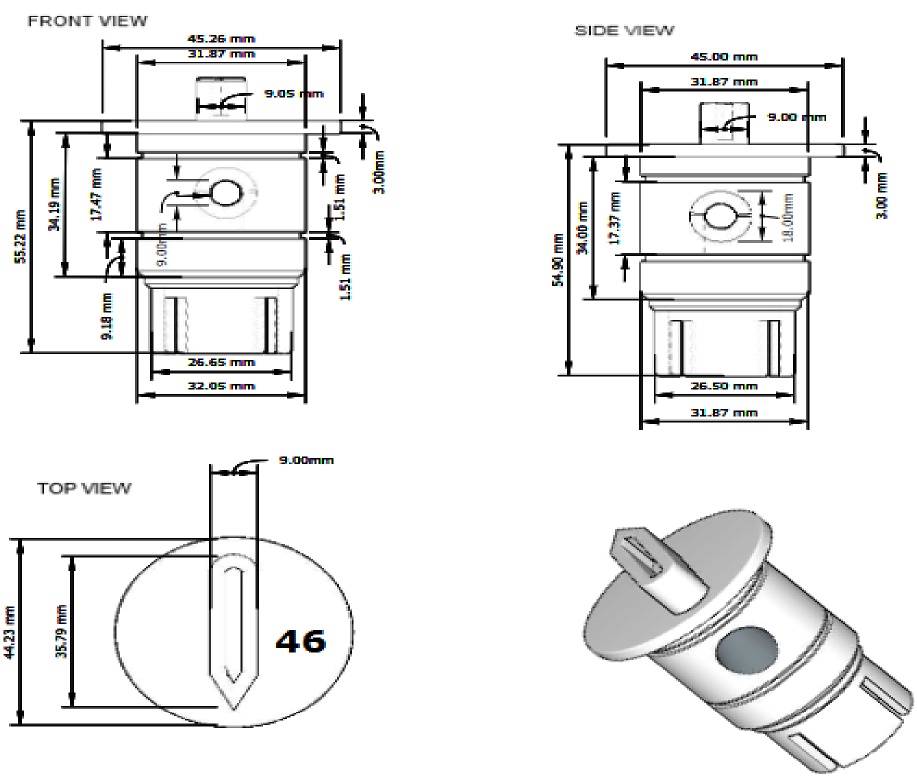


Figure 6: Views of Nozzle diameter 9mm

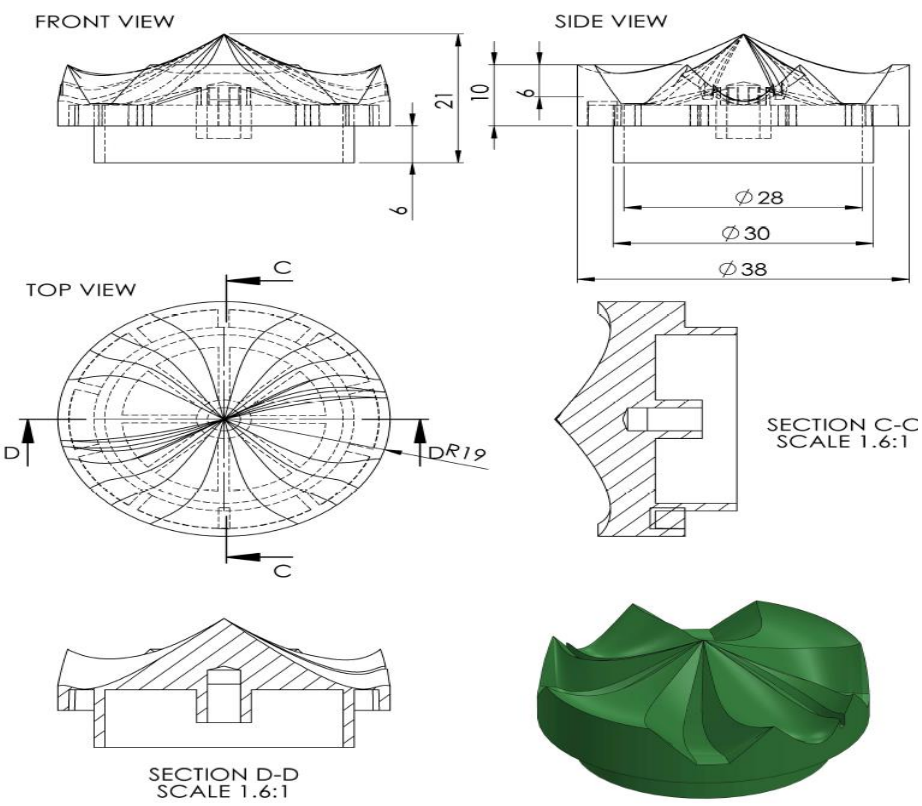


Figure 7: Design Drawings for spinner 6 Groove Deflection Plate

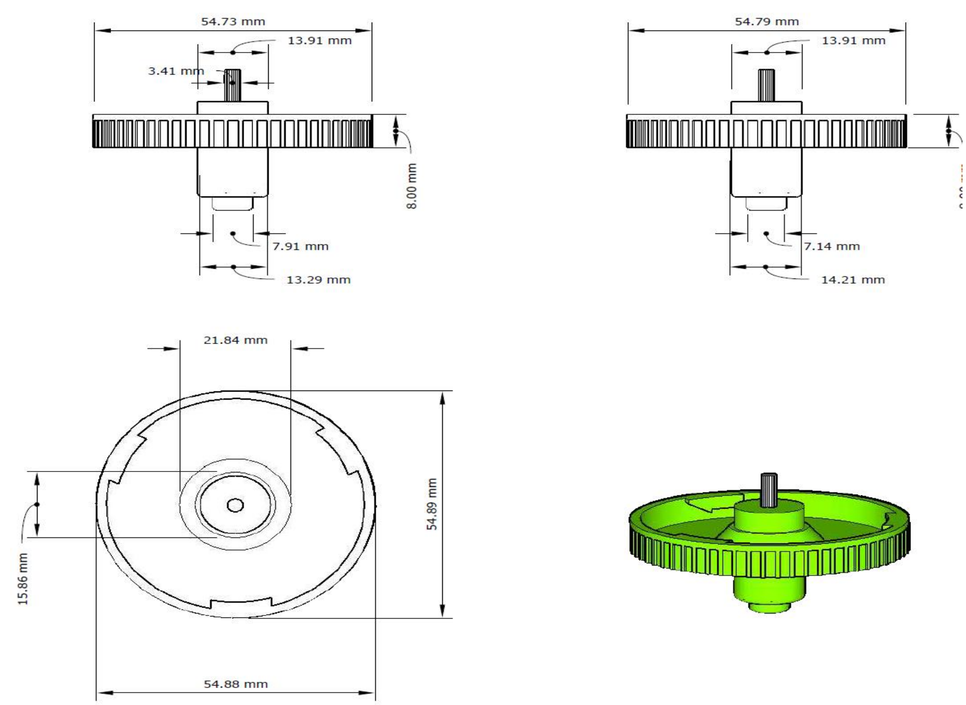


Figure 8: Design Drawings for Holder Plate

3.10 Construction of Spray Unit

The spray components – the nozzles and spray plates were constructed using the selected design measurements of the nozzle and the spray plates while additive manufacturing was adopted in the construction. The process of construction was as follows;

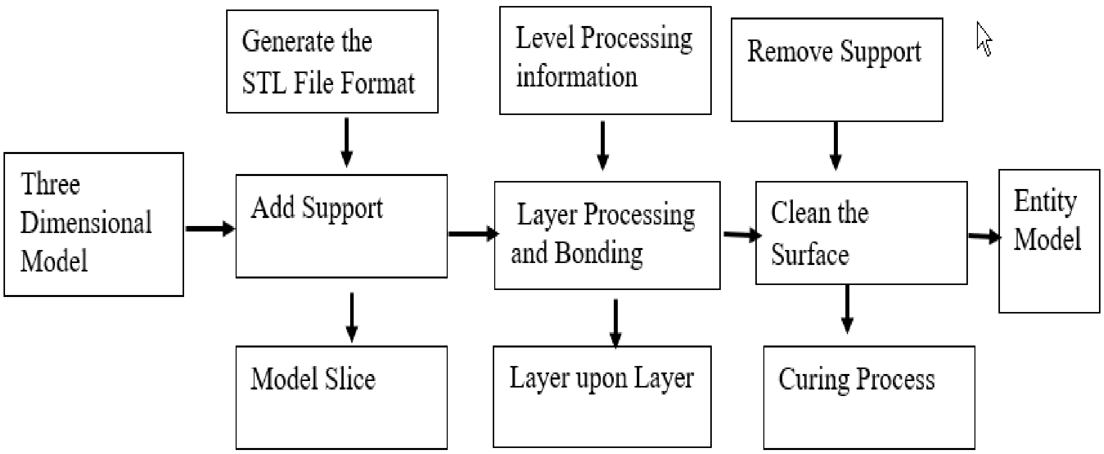


Figure 9: 3D Production Process

Figure 10: Constructed Pivot Spray Unit Components

CONCLUSION

Applying relevant nozzle design requirements, a Centre Pivot Spray Unit was designed and constructed. The designed components include: 3 spay nozzles of 6, 7, 9mm diameters and 5 deflection plate of 6, 8, 10 curved and 12 and 14 radial grooves. The components are made from ABS plastic filament.

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ENHANCING FLOOD RISK ASSESSMENT IN ASA RIVER, ILORIN, NIGERIA, THROUGH ISOCHRONE MAP USING SAGA GIS.

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ABSTRACT

An isochrone map offers a temporal dimension to flood risk assessment, illustrating how flood waters propagate over time which is crucial for understanding the evolving nature of flood events. Therefore, this research was conducted to generate the isochrones map and time area graph of Asa River which will provide valuable insights for decision makers whenever there is an intervention in the upstream of the river and support the development of flooding mitigation strategies. With the aid of System for Automated Geoscientific Analyses Geographic Information System (SAGA-GIS) with version 2.1.2. and the Digital Elevation Model (DEM) of the catchment area which was Sourced from Shuttle Radar Topography Mission (SRTM), the Isochrones map and time area graph of Asa River, Ilorin, Nigeria, was generated, the cumulative flow time was estimated for each grid cell in the watershed and the isochrones of equal Time of concentration, Tc (Travel time in hours) were developed. The isochrone map shows point that have equal travel time to the outlet of the watershed and the time area graph revealed that the minimum and maximum. Time of concentration for flood water in the river area is 0.72 hrs and 34 hrs and the percentage of watershed area contributing direct surface runoff from a given point to watershed outlet respectively. Therefore, this will help in executing hydrology procedures in logical sequence, also, decision makers can make use of this isochrone map to make informed choices during flood events along Asa River, whether allocating resources for evacuation or prioritizing response efforts as the map provides valuable insights that will help in flood mitigation projects.

KEYWORDS: saga-gis, time of concentration, isochrone, flood and Asa River

1.0 INTRODUCTION

Flood is a natural disaster that poses significant threats to human lives, infrastructure, and the environment which arises when the land surface is saturated and maximum soil's infiltration rate is exceeded. Also, flood may occur when the volume of water within a river, lake, or body of water exceeds the total capacity of its bounds resulting to some of the water flows outside the catchment (Ogunlela and Adelodun, 2014). Isochrones refers to lines delineated by points of equal Time of concentration of surface runoff from each grid cell or most distant point of the watershed area to the watershed outlet, while, Time Area Graph is the graph relating time of concentration of direct surface runoff from a given point in the watershed to its outlet and the percentage of watershed area contributing surface runoff to the outlet. However, the concept of Time of concentration is used in Hydrology to measure the response of a watershed to a rain event. It is defined as the time required for water to flow from the most distant point in a watershed to the watershed outlet (Ogunlela, 2018). Time of concentration is also referred to as travel time which is a function of the topography, geology, and land use within the watershed while isochrone is a line that joins points of equal travel time. The time of concentration of an ungauged watershed is important to the Hydrological analysis of watersheds, since it is significant for estimations of peak discharge. Knowing the basin's behavior regarding time of concentration aids in preventing flood risk and minimizing effects of natural disasters and punctual pollution of water resources. Therefore, SAGA GIS (System for Automated Geoscientific Analyses Geographic Information System) is a computer program used to edit spatial data.

Almeida *et al*. (2022) opined that Time of concentration, Tc is the main hydrological parameter used to characterize the response of a given Hydrological Response Unit (HRU) to a precipitation event because estimating Tc is an integral step in various studies involving surface runoff. McCuen *et al*. (1984); Wong (2009) discovered that amid all response time parameter of watershed, time of concentration is the most used one. Meanwhile, according to Pavlovic and Moglen (2008) time of concentration reflects how the watershed responds to rainfall events. Fang *et al*. (2008) called the attention to the importance of precision in estimations on time of concentration because, if the values for time of concentration are underestimated, they will lead to overestimated values for results related to peak discharge and vice versa. In addition, Fathi and Zolghadr (2024) stated that a good estimation of Tc value result in a more detailed design of expensive hydraulic structures, as well as a better estimation of flood discharge.

Haga *et al*. (2005) observed that both lag time and time of concentration are important indices that Mirror the hydrological characteristics of watershed, also, Yoo *et al*. (2019) reported that both are crucial when using flood hydrographs to determine peak flow and peak time for the planning, design, and operation of hydraulic infrastructure. Both can be used for flood warning to quantify flash flood response time (Wu *et al*., 2016). Koutroulis and Tsanis (2010) noticed that the two parameters are specifically pertinent in ungauged basins and have been used in several recent developed hydrological models. Therefore, time of concentration is defined as the time required for water to flow from the most distant point of the watershed to the watershed outlet and it is defined as the time for runoff to flow from the most hydraulically remote point of the basin area to the point under investigation. There may be a number of possible pathways to consider in determining the longest travel time (time of concentration). Mark and Marek (2011) reported that a designer must be able to envisage the flow path along which the longest travel time is likely to occur. Taghvaye *et al*. (2017) took a holistic approach in finding the best method for estimating the time of concentration in big watersheds. They selected seven formulas from 22 formulas that were allowed to use for calculating time of concentration in the watershed with 345.4 km^2 area. Grimaldi *et al*. (2012) referred to the time of concentration as a "paradox" and submitted that estimates by different methods can vary by 500%. However, time of concentration be used for the development of flood predicting models, flood alert systems, flood discharge rate and volume, and designing hydraulic structures.

Many researchers have worked on flood risk assessment of Asa River, but none has been able to enhance the flood risk assessment of the catchment through isochrones map. Adebayo and Ogunlela (2024) worked extensively on flood frequency analysis of Asa River, in their research they were able to predict the discharges for the different return periods in the Asa River which serves as a guide for decision makers on the development and flood risk management along Asa River. Also Adeniran *et al*. (2017) focused on the mapping and evaluation of flood risk zones of Asa River, in the Ilorin metropolis using GIS and remote sensing, they were able to produce the flood susceptibility map which shows the arrears that are prone to flood disasters along the Asa River in Ilorin. Ogunlela and Adelodun (2014) conducted the flood routing of Asa River using the kinematic wave theory method, computed the time of concentration of the watershed using Kirpich's formula and stated that Asa River is an important river in kwara state.

Jafry *et al*. (2024) focused on enhancing flood risk assessment in the Johor River Basin through trivariate Copula, a vital statistical tool in hydrology used for understanding complex relationships among flood characteristics, in their research, they focused on three key flood features, which are flood discharge, flood peak and flood duration using trivariate Copula to capture their interdependencies. Their research enhances hydrological modeling and decision-making for water resource management and flood mitigation projects.

Garcia-Rivero *et al*. (2017) used Digital Terrain Model and SAGA-GIS version 2.2.5 to identify and cartographically represent sensitive areas (scenarios) to river flooding in the lower section of Madre de Dios hydrographic unit the Peruvian Amazon, the indexed map was obtained, which once reclassified and allowed the spatial delineation of the flood scenarios and categories of susceptibility. Parmar (2019) proposed the use of SAGA-GIS with version 6.3.2 technique and remote sensing data integrally which showed how morphometric parameters are responsible for causing sedimentation by extracting river basin, stream networks and analyzing such parameters through Shuttle Radar Topographic Mission (SRTM) and Digital Elevation Model (DEM) used for preparation of maps and verification of the spatial extent of area of Watershed – 63 of Narmada River, Gujarat, India. Parmar (2019) reported that morphometric analysis along with GIS technique proves to be very helpful to identify the geo-hydrological, geomorphological characteristics of basin for planning, sustainable development and management of watershed. Also, Lemenkova (2021) contributed to the technical development of the application of Machine learning in cartography by demonstrating the effectiveness of SAGA GIS in remote sensing data processing applied for Vegetation and environmental mapping. Many researchers have worked on Asa River but a detailed report on enhancing the flood risk assessment of Asa River through Isochrone map is missing.

Moreover, Isochrone lines, also known as flood isochrones, are used to explain and visualize flood events by depicting the spatial extent and timing of floodwaters. These lines represent contours that connect areas that would be inundated by floodwaters in a given amount of time, typically measured in hours. The intensity of rainfall events is directly related to the return period and duration of the storm. The relationship between rainfall duration, rainfall intensity, and return period is important in the field of hydrology and is often used for designing infrastructure. Such as stormwater management systems, dams, and drainage systems. However, research on isochrones map for flood risk assessment using SAGA GIS is very limited, thus, making it very crucial to carry out this research. The objective of this research was to enhance the flood risk assessment of Asa River by generating the isochrones map of Asa River using SAGA GIS which will serve as a guide for flood mitigation strategies along the river.

2.0 MATERIALS AND METHOD

2.1 Study Area

Asa river has its source from Oyo state and flows through Ilorin, Kwara state, Nigeria in a South-North direction, it is an important tributary to the river Niger at 12,200m distance. The river which has its inlet at river Awon forms a separating borderline between Eastern and Western Ilorin. However, the river is 56km long with maximum width of 100m at the Dam site. It is merged to the west by river Imoru and to the East by River Afidikodi, Ekoro, Oyun and Obe are among the earliest tributaries of the Asa river while it tributaries in Ilorin includes River Osere, Atikeke, Odota, Agba , Okun, and Aluko. Also, the Asa river is about 1040 km^2 in area and lies between latitudes $8^0$36′N and $8^0$24′N and longitudes $4^0$36′E and $4^0$10′E (Adebayo and Ogunlela 2024). Asa River is a very important source of water when it comes to Agricultural, Environmental and Economic purposes in the city as it is used in industries and for domestics use at homes (Ahaneku and Animashaun, 2013). The catchment which is formed by a ridge of hills rising to almost 580m above sea level is fenced by farmlands, residential and industrial buildings along the bank of the river downstream. There are farmlands, residential and industrial buildings along the bank of the river downstream. The catchment is formed by a ridge of hills rising to almost 580 m above sea level and in most places the catchment is a gently undulating plane. The soils in the catchment area are as a result of weathering of parent rocks, which support vegetation along the source of the river (Salawu, 1987). The map of the study area is presented in Figure 1.

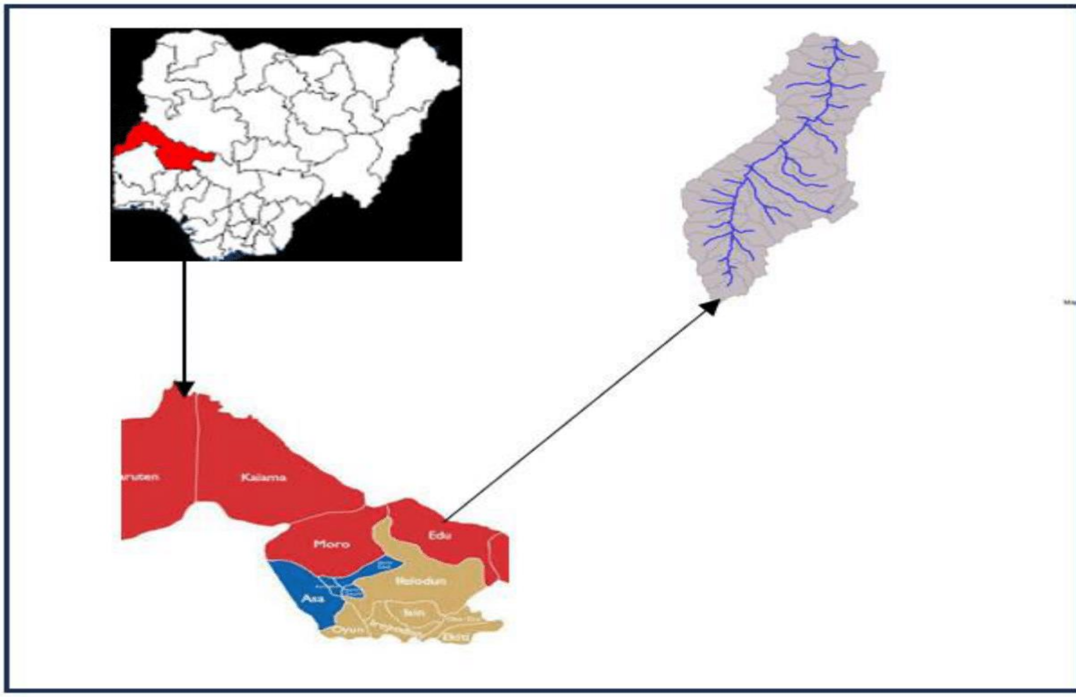

Figure 1: Map of Kwara State Showing the Location of the Study Area

Source: (Adebayo and Ogunlela, 2024)

2.2 Digital Elevation Model (DEM)

A digital elevation model defined the topography of a place and also describes the elevation of any point in a given area. In this research the DEM was processed and used to delineate the watershed and analyze the drainage patterns. Sub-basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width were obtained. The DEM of the study area is presented in Figure 2.

Figure 2: Digital Elevation Model of the Catchment Area.

2.3 Procedure used for generating the Isochrone Map using SAGA GIS.

SAGA-GIS was used to generate the Isochrone map and the Time Area graph of the watershed using the Digital Elevation Model (DEM) of the catchment which was obtained from Shuttle Radar Topographical Mission. The watershed was divided into some sub-areas which is done by constructing isochrones.

Procedures involved in using SAGA GIS to generate an Isochrones map of Asa River:

Step 1: Preparation of input Data

a) Digital Elevation Model (DEM): The DEM of the Asa watershed area was obtained from shuttle radar topographical mission which is crucial for hydrological analysis.
b) Hydrology Data such as stream networks.

Step 2: Loading of Data into SAGA GIS

The data was loaded into SAGA GIS after which the DEM was imported. Go to File > Grid > Import > ESRI Arc/Info Grid or GeoTIFF depending on the DEM format.

Step 3: Preprocessing the DEM

Fill Sinks: This was done to ensure that there are no depressions in the DEM that would disrupt flow paths. Go to Terrain Analysis > Preprocessing > Sink Removal, then the DEM was selected as the input grid.

Step 4: Watershed Delineation

Flow Direction: the flow direction was calculated from the DEM, the filled DEM was selected as the input. Go to Terrain Analysis > Hydrology > Flow Direction. Go to Terrain Analysis > Hydrology > Flow Accumulation. The flow direction grid from the previous step was used as the input.

Catchment Area: The watershed was delineated.

Step 5: Isochrone Map Generation

Travel Time Calculation: Travel time was calculated from each point in the watershed to the outlet. Go to Terrain Analysis > Hydrology > Travel Time or Time of Concentration.

The necessary input grids was selected (typically, your filled DEM and flow direction grid).

Configure parameters such as Manning's coefficient, slope, and flow velocity as required.

Isochrone Lines: Isochrone lines were generated. Go to Terrain Analysis > Hydrology > Isochrones. The travel time grid was used as the input. Define the interval for the isochrones (every 2 hours).

Step 6: Visualize and Export the Isochrone Map

Display the Isochrones: the SAGA GIS's display tools was used to visualize the isochrones over the DEM. Go to Layers > Add > Shapes and select your isochrones.

3.0 RESULTS.

The Digital Elevation Model **(**DEM**)** of the catchment area and the watershed outlet were imported into the SAGA GIS as well as some results from the GIS tool. The model inputs is presented in Table 1.

Table 1: Model input data in SAGA GIS

S/N	Data Type	Description	Resolution	Source
1	Topography	Digital Elevation Model	60 m x 60 m	Shuttle Radar Topographical Mission
2	Watershed outlet	Reprojected file of the watershed	1040 km^2	SWAT model

The Isochrone map and the time area graph of the catchment using the above procedures providing valuable insights into travel times and flow paths within the Asa river is presented in Figure 2.0. The Figure 2.0 is used to explain flood by providing a visual representation of the spatial extent and timing of floodwaters. The map depicts point that have minimum travel time of 0.7189hrs and points that have maximum travel time of 35.558hrs to the watershed outlet. This helped in understanding how floodwaters would propagate and affect different areas of the catchment over time. However, for a long duration rainfall, time to equilibrium at the outlet is equal to time of concentration. Also, the rainfall intensity is equal to at least time of concentration of the watershed. The figure shows the point of equal travel time to the watershed outlet, moving up the map it is obvious that there is uniform rainfall intensity at each point of the watershed, the rainfall intensity is the same and will reach the outlet at exactly the same time/ time of concentration. This is true for every isochrone line with each further away from the outlet corresponding to a greater travel time for runoff traveling to the outlet of the watershed. The spatial representation of travel time was transformed into a cumulative distribution plot detailing how travel times are distributed throughout the area of the watershed.

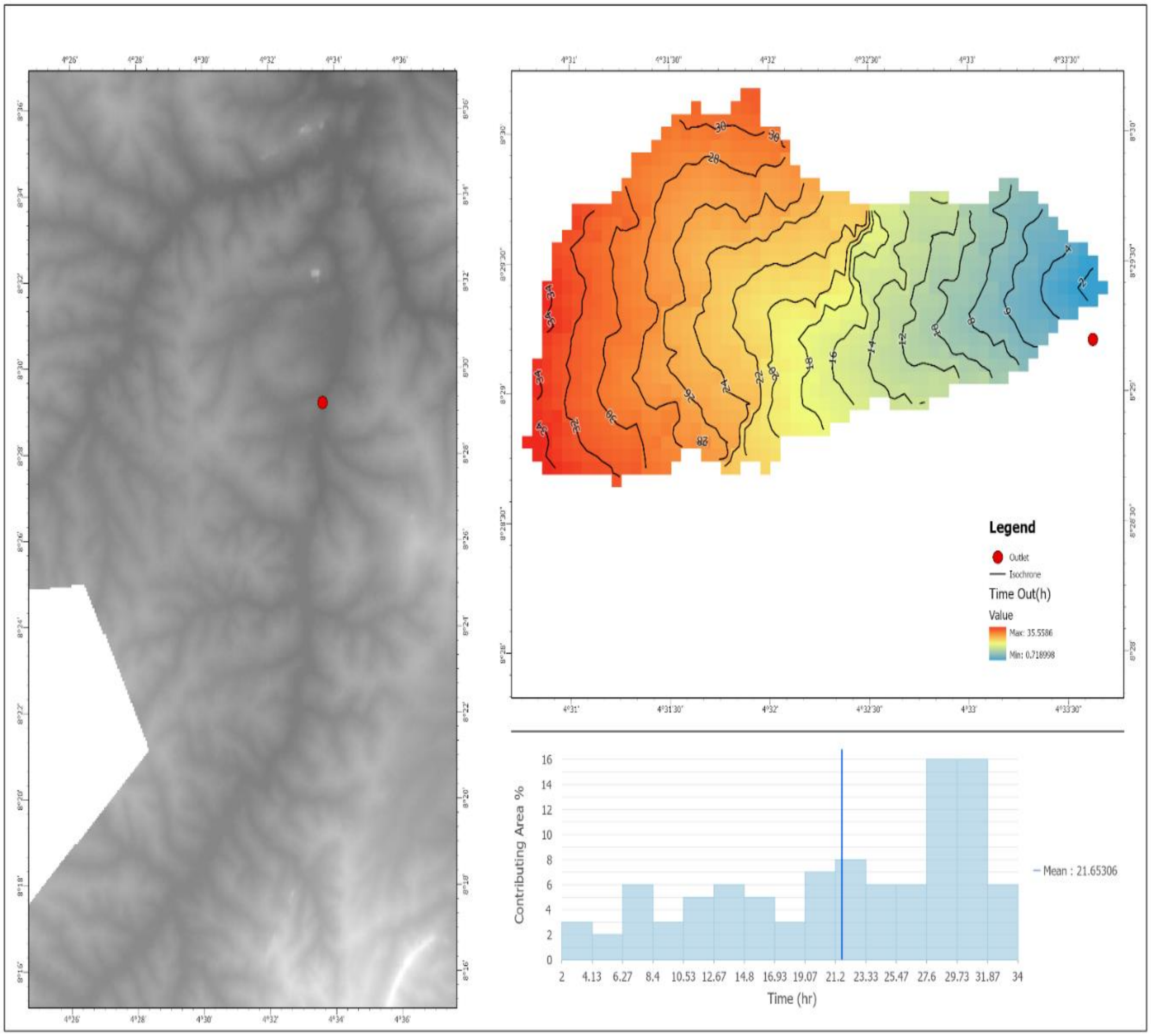

Figure 2.0. Isochrone Map and Time Area Graph of Asa River, Ilorin, Nigeria

Time area histogram is the lines in the graph that relates travel time to direct surface runoff from a given point of the watershed to its outlet and percentage of the watershed area that is contributing direct runoff to the outlet. It is the base of the Time-Area method as a rainfall- runoff model. The summary of the time are graph is presented in Table 2. Thus, the time- area method showed the importance of the effect of spatial distribution of sub watersheds located at different levels of the watershed on flood hydrograph formation. Also, it is concluded that the surfaces near the outlet have played a much smaller role in peak discharge. In general, from the outlet to the upstream and middle parts of the watershed, as travel time level increases, the effect of sub-watersheds on peak flow discharge increases.

Table 2: Summary of the Time Area Graph

S/N	Time (hr)	% Contributing Area
1	2	2
2	4.13	3
3	6.27	2
4	8.4	6
5	10.53	3
6	12.67	5
7	14.8	6
8	16.93	5
9	19.07	3
10	21.2	7
11	23.33	8
12	25.47	6
13	27.6	6
14	29.73	16
15	31.87	16
16	34.00	6

However, prediction of flood prone areas is a complex task influenced by many numerous variables. Therefore, the Isochrone map with the Time Area Histogram to identify patterns and areas of concern. Attention was given to where multiple polygons overlap, which indicates a higher likelihood of flood prone areas within the Watershed. The Time Area Histogram shows the frequency of areas within each travel time threshold, the histogram was analyzed to identify the areas with the highest frequency which shows higher flood risk due to shorter travel time. Therefore, the time of concentration can be used as the duration of the design storm event for estimating peak runoff rates with the Rational equation.

Conclusively, the observations made from the Isochrone map, Figure 2.0 above justify the assumptions of Rational equation, Q = CiA and therefore, the Isochrone map provided an effective means of communicating flood risks of the Asa river to the general public. This Isochrone and Time area Graph is in line with the observations made by Al-Smadi, (1998) who worked extensively on incorporating watershed response in GIS-Based Hydrological Model in Blacksburg. By using isochrone lines, people can easily understand the areas that would be impacted by floodwaters at different time intervals. This helps in raising awareness, encouraging preparedness, and facilitating informed decision-making regarding property protection and evacuation.

4.0 CONCLUSIONS

The isochrone map shows that the watershed has minimum travel time of 0.718998hrs and maximum travel time of 35.5586hrs with their corresponding percentage contributing area which provides valuable insights into travel times and flow paths within the Asa river. Isochrones, which indicate the areas that are likely to be affected by floods within a specified time frame, are valuable tools for spatial flood analysis. The integration of isochrones mapping through SAGA GIS significantly enriches the flood risk assessment process for the Asa river. This, however, underscores the importance of leveraging advanced geospatial tools to enhance our understanding and management of flood risks, ultimately contributing to the resilience and safety of vulnerable communities. Also, high-risk areas can be easily identified and prioritize flood mitigation efforts accordingly.

5.0 RECOMMENDATIONS

Future studies should focus on refining these methods and integrating real-time data to further improve predictive capabilities and response strategies.

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INVESTIGATING THE INFLUENCE OF DIFFERENT PLANTER TYPES, PLANTING VELOCITIES AND TILLAGE TECHNIQUES ON THE YIELD COMPONENTS OF MAIZE

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ABSTRACT

Developing countries often use imported planters without considering their effects on local soil types and yield components, resulting in inconsistent data and negatively impacting maize yields, farmer incomes, industries and national revenue. This study addresses the knowledge gap on the effects of planter type, planting speed and tillage on maize seedling emergence and stand uniformity, aiming to enhance planter efficiency, increase yields and support economic growth in Nigeria. The study evaluated four tillage systems (Conventional, Reduced, Minimum, and No-Tillage), two planter types (Pamita mechanical and Monosem Pneumatic), and two planting speeds (7.20 km/h and 11.30 km/h) in a randomized split-split plot design. Results indicate that reduced tillage method, mechanical planter, and optimized planting speed improve plant height, emergence rate and yield. The highest mean plant height of 45.80 cm was achieved using the reduced tillage (RT) system where the Pamita mechanical Planter (PMP) and the slower planting speed (S_1) were involved. The highest emergence rate index (ERI) of 14.87 was observed using the no-tillage (NT) system where the Monosem Pneumatic Planter (MPP) and the faster planting speed (S_2) were involved. The highest yield of 5.904 t/ha was obtained using the minimum tillage (MT) system where the Monosem Pneumatic Planter (MPP) and the faster planting speed (S_2) were involved. Conversely, the lowest values recorded were a mean plant height of 38.90 cm, an ERI of 10.70 and a yield of 4.85 t/h. These findings underscore the importance of integrated soil and planting management practices to maximize maize productivity.

Keywords: Planter, Velocity, Tillage techniques, Maize, yield, Pamita planter, Tillage systems

1. INTRODUCTION

Maize (Zea mays L.) is one of the most vital cereal crops globally, serving as a staple food source for millions and a key raw material for various industrial products (Shiferaw et al., 2011). The growing demand for maize necessitates the optimization of agricultural practices to enhance yield and ensure sustainability. The yield characteristics of maize are influenced by numerous factors, including the type of planter used, planting velocity and tillage techniques (Tsimba et al., 2013). For instance, precision planters have been observed to improve seed placement accuracy, which can enhance crop emergence and uniformity (Koch et al., 2020).

Planting velocity, the speed at which seeds are sown, is another critical factor. High planting velocities can lead to improper seed placement, resulting in uneven crop emergence and poor plant stands. Conversely, low planting velocities may ensure better seed placement but can be less efficient in terms of time and labour (Arvidsson and Kätterer, 2011). Balancing planting speed with precision is essential to maximize yield potential. Moreover, tillage techniques play a significant role in soil preparation and health, impacting seedbed conditions, moisture retention, and root development. Conventional tillage, which involves ploughing and harrowing, can improve soil aeration and weed control but may also lead to soil erosion and degradation. In contrast, conservation tillage methods, such as no-till or minimum tillage, aim to preserve soil structure and organic matter, potentially enhancing soil health and sustainability (Hobbs et al., 2008).

Conventional tillage, which involves deep ploughing and soil inversion, enhances soil aeration, root penetration and weed control but can lead to soil erosion, loss of organic matter and degradation of soil structure over time (Lal et al., 2007; Reicosky and Archer, 2007). While it may initially improve maize yields due to better seedbed conditions, its long-term impact on soil health can be detrimental (Pikul Jr and Allmaras, 1986). In contrast, conservation tillage techniques like no-till, strip-till and minimum tillage aim to reduce soil disturbance and maintain soil structure and organic matter (Hobbs et al., 2008). No-till farming, in particular, leaves crop residues on the soil surface, enhancing soil moisture retention, reducing erosion, and promoting beneficial soil microbial activity (Triplett Jr and Dick, 2008). However, conservation tillage can also lead to increased weed pressure and challenges in achieving uniform seed placement (Derpsch et al., 2010). Many factors, such as the type of planter used, planting velocity and tillage procedures, affect the yield characteristics of maize. The purpose of this study is to look into how these factors affect maize yield components in order to offer information that will help farmers and other agricultural stakeholders make wise decisions.

2. MATERIALS AND METHODS

The experiment was conducted at Mbilla Farms Limited in Adamawa State which is situated in the Northern Guinea Savannah agro-ecological zone of Nigeria. The farm is located at latitude 9°31' North and longitude 12°31' East, with an altitude of 158.5 meters. In this region, rainfall begins in April and continues until October, while the harmattan season lasts from November to February. The average annual rainfall ranges from 770 mm to 1600 mm (Adebayo and Tukur, 1999).

2.1 Experimental Design

The experimental design utilized a split-split plot arrangement within a randomized complete block, with three replicates for each treatment. This design was selected due to its ability to accommodate three plot sizes: the largest for the main factor, an intermediate size for the subplot factor, and the smallest for the sub-subplot factor, each with varying levels of precision (Gomez, 1984). Four tillage systems (Conventional, Reduced, Minimum and No-Tillage) were used as main plots, two planter types (Pamita Mechanical and Monosem Pneumatic) as subplots and two planting speeds (7.20 km/h and 11.30 km/h) as sub-subplots. Each sub-subplot had four rows with 0.76-meter spacing and a 25-meter length, consistent with the main plot dimensions. These combinations resulted in sixteen treatment levels, as shown in Table 1. The chosen planter types were the only available ones in the research environment, and the planting speeds were based on recommendations by Jasa and Dickey (1982). Treatment randomization was employed to minimize errors and enhance research precision.

Table 1. Treatments and their abbreviations as used in the Experimental design and Data analysis

Treatment (tillage systems)	Abbreviation	Description
Conventional tillage	CT	Disc plough + two (2) passes of disc harrow
Reduced tillage	RT	Two (2) passes of disc harrow
Minimum tillage	MT	One (1) pass of disc harrow
No-tillage	NT	Direct planting but no tillage
Monosem pneumatic planter	MPP	Pneumatic planting method
Pamita mechanical planter.	PMP	Mechanical method of planting
Speed level 1	S_1	Planting speed of 7.20 km/h
Speed level 2	S_2	Planting speed of 11.30 km/h

Two planters were selected to represent the current range of planter technologies available for maize in Adamawa and surrounding areas. These planters are: (i) Pamita Mechanical Planter, and (ii) Monosem Pneumatic Planter. Both planters were adjusted to a depth of 5 cm, with a row width of 76 cm and plant spacing of 10 cm between rows. Two planting speeds, 7.20 km/h and 11.30 km/h, were chosen to represent low and high speeds, respectively, as reported by Weidong et al. (2004).

2.2 Data Collection

2.2.1 Seedling emergence

Plant emergence was recorded by daily counting the number of emerged plants in randomly selected rows of each sub-subplot which commenced seven (7) days after planting (DAP) and the counting continued for the next thirty (30) days. Maize emergence rate was counted for several days at each plot during the mean emergence date (MED) in the four (4) rows.

The emergence rate index (ERI) was calculated directly from emergence counts as used in the study of Carman (1997), Mohanty and Painuli (2004) and Nasr and Selles (1995) as:

$$MED = \frac{N_1.D_1 + N_2.D_2 + \cdots + N_n D_n}{N_1 + N_2 + \cdots + N_n} \quad (1)$$

$$ERI = \frac{Total\ Number\ of\ emerged\ plant}{MED} \quad (2)$$

where, $N_1, N_2 \ldots\ldots N_n$ = The increase in the number of newly emerged plant stems compared with the previous count and $D_1, D_2 \ldots\ldots\ldots D_n$ = Number of days after planting.

2.2.2 Plant heights

Heights of 20 randomly selected plants from each plot were measured at 10, 20 and 30 days after seedling emergence using a meter rule from point of emergence to emergence after 30 days and the mean plant height was obtained for each plot.

2.2.3 Yield

The crop was harvested from each plot measuring 3 m by 4 m once the grains were matured for harvesting. The grains were then sun-dried to reduce their moisture content further. After drying, the grains were manually threshed to separate them from the stalks. The weight of the grains were measured and then converted to tonnes per hectare.

2.2.4 Data analysis

Analyses of variance for a split-split plot design were performed. All treatment factors in the experiments were considered as fixed effects with the locations, and blocks were treated as random effects. To determine the mean effect between treatments, mean comparison was performed using Turkey pairwise comparisons using Minitab software version 22.

3. RESULTS AND DISCUSSION

The ANOVA result presented in Table 2 evaluates the impact of Planter Type, Planting Speed, and Tillage on Plant Height (cm). The analysis reveals that Tillage (T) significantly affects plant height, with a P-value of 0.03. In the sub-plot analysis, Planter Type (P) shows a highly significant effect on plant height, with a P-value of less than 0.001. The interaction between Tillage and Planter Type (TP) is not significant, with a P-value of 0.074. In the sub-sub plot analysis, Planter Speed (PS) is also highly significant, with a P-value of less than 0.001. The interactions between Tillage and Planter Speed (TPS) and Planter Type and Planter Speed (PPS) are significant, with P-values of 0.003 and less than 0.001, respectively. However, the three-way interaction between Tillage, Planter Type, and Planter Speed (TP*PS) is not significant, with a P-value of 0.441. These significant effects and interactions suggest that variations in soil conditions, seed placement accuracy, and planting efficiency under different tillage methods, planter types, and planting speeds significantly influence plant height. Among the crop production factors, tillage contributes up to 20% (Khurshid et al., 2006).

Table 2. ANOVA for Effect of Planter Type, Planting speed, and Tillage on Plant Height (cm)

Source of Variation	df	SS	MS	Com. F	P-value
Main plot analysis					
Replication	2	3.6237	1.8119	2.53	
Tillage (T)	3	12.9642	4.3214	6.04	0.03*
Error (t)	6	4.2896	0.7149	1.83	
Sub-plot analysis					
Planter (P)	1	91.8533	91.8533	235.02	<.001*
T*P	3	3.985	1.3283	3.4	0.074Ns
Error (p)	8	3.1267	0.3908	0.44	
Sub-sub plot analysis					
Planter speed (PS)	1	16.3333	16.3333	18.36	<.001*
T*PS	3	19.735	6.5783	7.39	0.003*
P*PS	1	14.7408	14.7408	16.57	<.001*
T*P*PS	3	2.5275	0.8425	0.95	0.441Ns
Error (TPS)	16	14.2333	0.8896		
Total	47	187.4125			

* = Significant at 5% level. Ns = Not significant at 5% level

The plant height was affected greatly by the tillage system, type of planter, and planting speed, as shown by the main effects plot for plant height in Figure 1. The maximum mean plant height of 43.5 cm was obtained in the reduced tillage plot, most likely because it can retain soil structure and moisture balance to provide ideal soil conditions. Conversely, the mean height of plants grown under conventional tillage, low tillage, and no-tillage plots were around 42.5 cm, 42.3 cm and 42.2 cm, respectively. The mean plant height obtained by using the Panim mechanical planter was around 43.8 cm, which is much higher than the mean height obtained by using the Monosem pneumatic planter, which is approximately 41.5 cm. This implies that improved soil compaction and seed placement were provided when using the Monosem automated planter. Plants planted at a planting speed of 7.20 km/h have a mean height of about 43.5 cm, whereas plants planted at a planting speed of 11.30 km/h have a mean height of about 42.1 cm. This might happen as slower planting speeds results in keeping the seeds moist thereby encouraging fast germination by reducing their exposure to the environment. These results highlight how crucial it is to choose the right planter type, planting speed, and tillage strategy in order to maximize crop output and optimize plant growth.

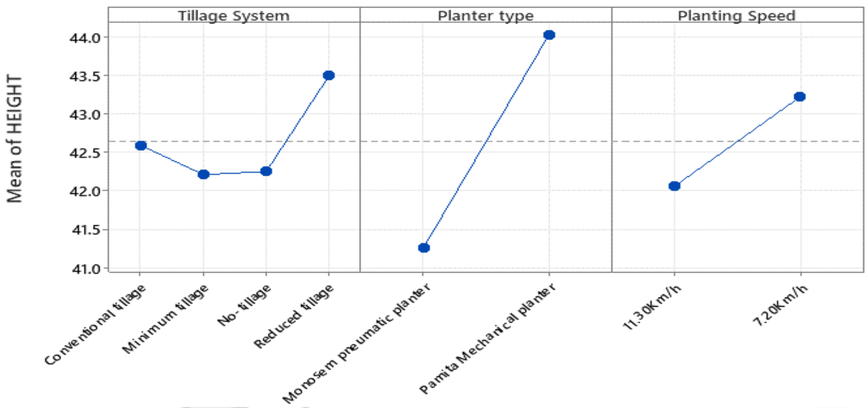

Figure 1. Main effects plot of tillage system, type of planter, and planting speed on plant height (cm)

Figure 2 shows the sub plot interaction for plant height, the combined effects of tillage systems, planter types and planting speeds. The graphs show that the use of Pamita mechanical planter generally results in higher plant heights across the various tillage systems compared to the use of the Monosem pneumatic planter. Additionally, planting at a lower speed of 7.20 km/h tends to produce taller plants than planting at a higher speed of 11.30 km/h. These interactions suggest that the use of mechanical planter may be more efficient in seed placement and soil engagement, leading to better germination and growth conditions. The reduced speed likely allows for more precise seed placement and better soil contact, enhancing early plant development. Variations in tillage systems also interact with planter types and speeds, indicating that the soil preparation method can significantly influence the effectiveness of different planting equipment and techniques. These interactions highlight the importance of optimizing both planter type and planting speed according to the specific tillage system to maximize plant height and overall crop performance.

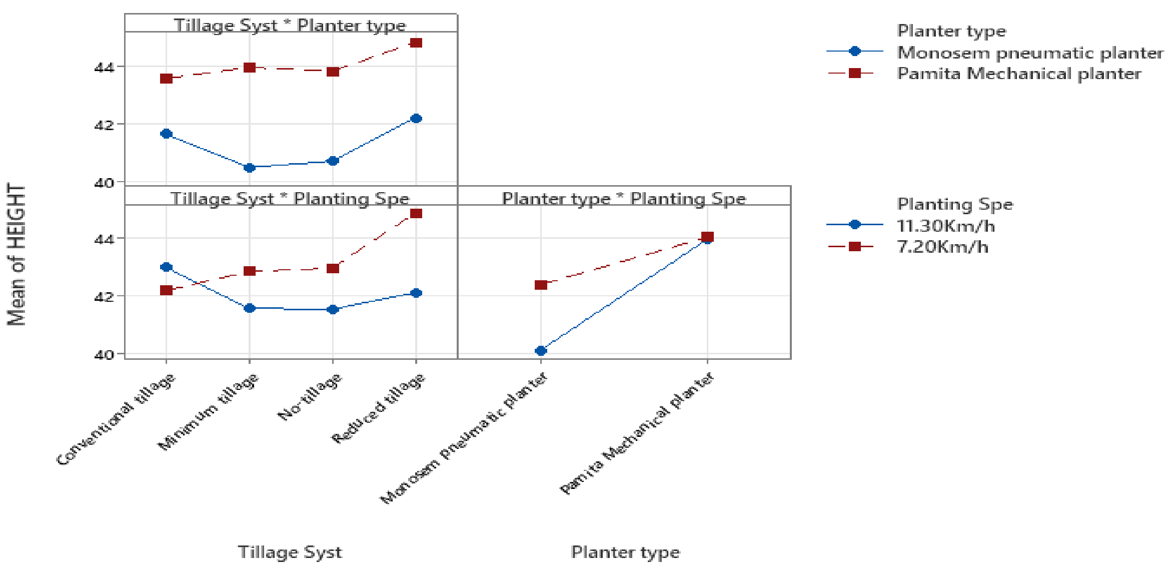

Figure 2. Sub plot 2-way interaction effects of tillage system, type of planter, and planting speed on plant height (cm)

The ANOVA result presented for Table 3 indicates significant effects of Planter Type, Planting Speed and Tillage on the Emergence Rate Index. Tillage (T) has a highly significant effect with a P-value of less than 0.001, highlighting the importance of tillage systems in plant emergence rates. Planter Type (P) also significantly impacts on the Emergence Rate Index, as shown by a P-value of less than 0.001. The interaction between Tillage and Planter Type (TP) is significant, with a P-value of less than 0.001, indicating that the effect of the planter type varies with different tillage methods. Planting Speed (PS) significantly influences the Emergence Rate Index, with a P-value of less than 0.001. The interaction between Tillage and Planting Speed (TPS) is also significant, with a P-value of less than 0.001. However, the interaction between Planter Type and Planting Speed (PPS) is not significant with a P-value of 0.432. The three-way interaction between Tillage, Planter Type and Planting Speed (T*P*PS) is significant, with a P-value of 0.001. These results suggest that the emergence rate index is influenced by the tillage method, planter type and planting speed, with complex interactions between these factors affecting the overall plant emergence. Different tillage systems alter soil conditions, affecting seed germination, while planter types and planting speeds influence seed placement accuracy and uniformity.

Table 3. ANOVA for Effects plot of tillage system, type of planter, and planting speed on plant Emergence Rate Index

Source of Variation	df	SS	MS	Com. F	P-value
Main plot analysis Replication	2	0.42273	0.21137	7.91	
Tillage (T)	3	64.28811	21.42937	802.42	<.001*
Error (t)	6	0.16024	0.02671	1.36	
Sub-plot analysis					
Planter (P)	1	3.52138	3.52138	179.5	<.001*
T*P	3	2.00956	0.66985	34.15	<.001*
Error(p)	8	0.15694	0.01962	0.22	
Sub-sub plot analysis					
Planter speed (PS)	1	18.33359	18.33359	203.94	<.001*
T*PS	3	4.41747	1.47249	16.38	<.001*
P*PS	1	0.05845	0.05845	0.65	0.432Ns
T*P*PS	3	2.23726	0.74575	8.3	0.001*
Error (PS)	16	1.43835	0.0899		
Total	47	97.04408			

* = Significant at 5% level. Ns = Not significant at 5% level

Figure 3 illustrates the main effects plot for the Emergence Rate Index (ERI). It shows the impact of tillage method, planter type and planting speed on ERI. Among the tillage methods, no-tillage recorded the highest mean ERI, followed by reduced tillage, while minimum tillage and conventional tillage show lower ERIs, indicating that less soil disturbance enhances seed emergence rates. The Monosem pneumatic planter outperforms the Pamita mechanical planter in terms of ERI, suggesting that planter type significantly influences emergence efficiency. Additionally, a higher planting speed of 11.30 km/h yields a better ERI compared to 7.20 km/h planting speed, potentially due to more uniform seed placement and improved soil contact. This plot underscores the importance of optimizing these factors to achieve better crop establishment.

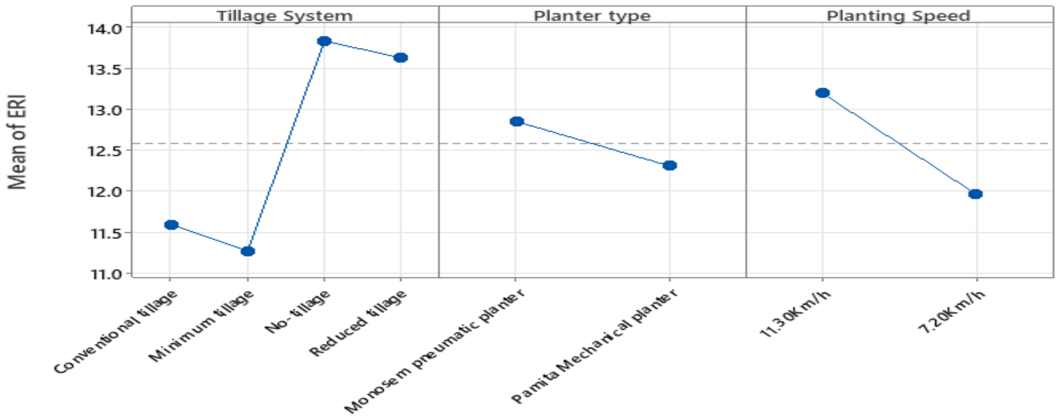

Figure 3. Main effects plot of tillage system, type of planter, and planting speed on Emergence Rate Index (ERI)

Figure 4 shows the interaction plot for the Emergence Rate Index (ERI) which reveals how tillage system, planter type and planting speed jointly affect the ERI. The Monosem pneumatic planter generally produces a higher ERI compared to the Pamita mechanical planter, especially under minimum and no-tillage systems. Additionally, the ERI is higher at a planting speed of 11.30 km/h using the Monosem pneumatic planter, whereas the Pamita mechanical planter shows similar ERI values at both planting speeds. These interactions suggest that the pneumatic planter is more effective in ensuring seed-soil contact and promoting quicker emergence in certain tillage conditions. The results emphasize the need to choose the right combination of tillage, planter type, and planting speed to optimize crop emergence rates.

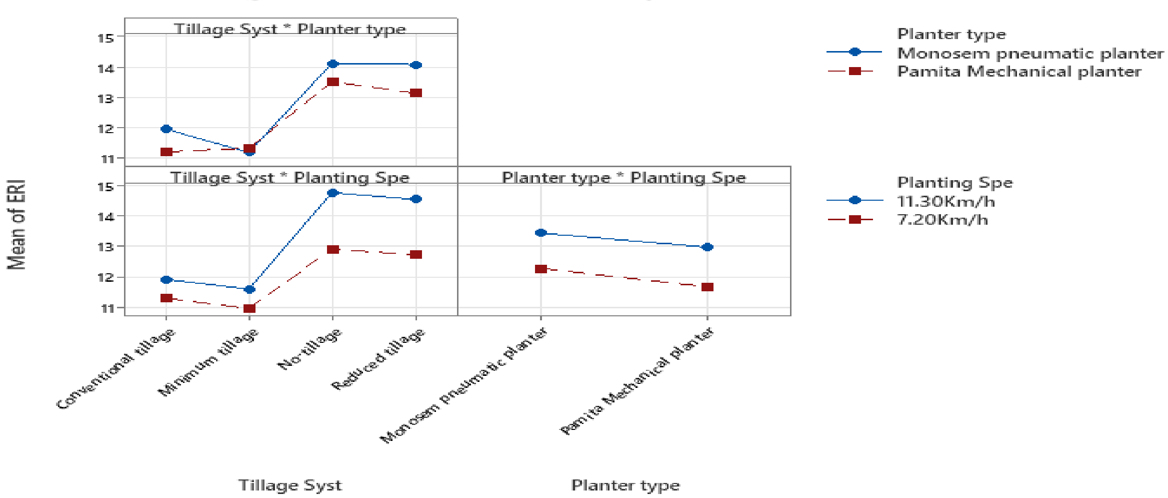

Figure 4. Sub plot 2-way interaction effects of tillage system, type of planter, and planting speed Emergence rate Index (ERI)

he ANOVA result presented in Table 4 shows the effects of Tillage, Planter Type, and Planting Speed on Yield (t/h). Tillage has a highly significant impact on yield, as indicated by a P-value of less than 0.001, suggesting that different tillage systems lead to significant variations in yield. This could be due to differences in soil structure and moisture retention associated with each tillage method, affecting plant growth and yield. The effect of Planter Type is not significant with a P-value of 0.47, indicating that the type of planter used does not independently affect yield. The interaction between Tillage and Planter Type (T*P) is also not significant with a P-value of 0.319. Planting Speed shows a significant effect on yield with a P-value of 0.022, suggesting that the speed at which seeds are planted can influence yield, potentially due to variations in seed spacing and depth. The interaction between Tillage and Planting Speed (T*PS) is highly significant, with a P-value of less than 0.001, indicating that the impact of planting speed on yield varies with different tillage methods. The interaction between Planter Type and Planting Speed (P*PS) is not significant with a P-value of 0.243. However, the three-way interaction between Tillage, Planter Type, and Planting Speed (T*P*PS) is highly significant, with a P-value of less than 0.001, suggesting complex interdependencies among these factors affecting yield.

Table 4. ANOVA for Effects plot of tillage system, type of planter, and planting speed on Yield (t/h)

Source of Variation	**df**	**SS**	**MS**	**Com. F**	**P-value**
Main plot analysis	2	0.00213	0.00107	0.09	
Replication					
Tillage (T)	3	1.67437	0.55812	48.23	<.001*
Error (t)	6	0.06943	0.01157	1.3	
Sub-plot analysis					
Planter (P)	1	0.00513	0.00513	0.58	0.47Ns
T*P	3	0.03669	0.01223	1.37	0.319Ns
Error (p)	8	0.07128	0.00891	0.84	
Sub-sub plot analysis					
Planter speed (PS)	1	0.0681	0.0681	6.45	0.022*
T*PS	3	0.98923	0.32974	31.24	<.001*
P*PS	1	0.01548	0.01548	1.47	0.243Ns
T*P*PS	3	0.98951	0.32984	31.25	<.001*
Error (TPS)	16	0.16888	0.01055		
Total	47	4.09023			

* = Significant at 5% level. Ns = Not significant at 5% level

Figure 5 shows the main effects plot for yield which reveals how the mean yield of maize is influenced by different tillage methods, planter types and planting speeds. Conventional tillage and minimum tillage produce the highest yields, around 5.6 t/h, while no-tillage and reduced tillage result in lower yields, just above 5.2 t/h. Regarding planter types, both the Monosem pneumatic planter and the Pamita mechanical planter yield similar results, with a slight advantage for the Pamita mechanical planter, both around 5.4 t/h to 5.5 t/h. Planting speed also affects yield, with the slower planting speed of 7.20 km/h resulting in a higher yield of about 5.5 t/h compared to the faster planting speed of 11.30 km/h, which yields around 5.3 t/h. Thus, the best maize yields are achieved with conventional or minimum tillage, using either planter type, and at a slower planting speed.

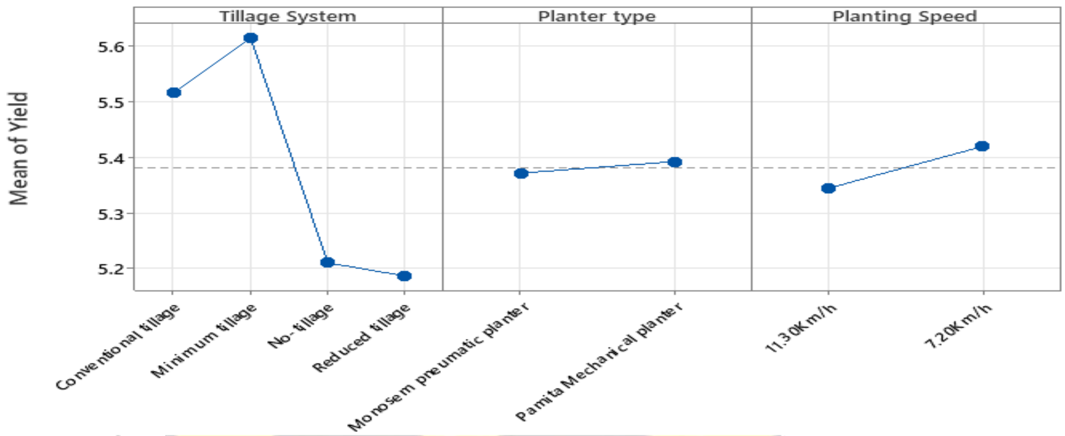

Figure 5. Main effects plot of tillage system, type of planter, and planting speed on Yield (t/h)

Figure 6 presents the "Interaction Plot for Yield" which illustrates how the mean yield of maize is influenced by the interactions between tillage system, planter type, and planting speed. In the top left graph, which shows the interaction between tillage and planter type, conventional tillage with the Pamita mechanical planter yields approximately 5.6 t/h, whereas the Monosem pneumatic planter yields about 5.5 t/h. For minimum tillage, the Pamita mechanical planter has a slight edge, yielding around 5.55 t/h compared to the Monosem pneumatic planter which yield around 5.45 t/h. No-tillage and reduced tillage both result in lower yields, with both planter types yielding close to 5.2 t/h. The bottom left graph, showing the interaction between tillage and speed, reveals that conventional tillage at 7.20 km/h yields the highest at around 5.8 t/h, while minimum tillage at 7.20 km/h follows closely at about 5.55 t/h. No-tillage and reduced tillage show lower yields, particularly at the faster planting speed of 11.30 km/h, where yields drop to about 5.0 t/h for reduced tillage. The bottom right graph, which depicts the interaction between planter type and speed, indicates that both planter types yield similarly, with the Pamita mechanical planter yielding slightly higher at 5.45 t/h at the faster planting speed of 11.30 km/h compared to the Monosem pneumatic planter. Generally, the interaction plots suggest that conventional tillage with a slower planting speed of 7.20 km/h yields the best results, while the planter type has a less pronounced effect on yield compared to tillage system and planting speed.

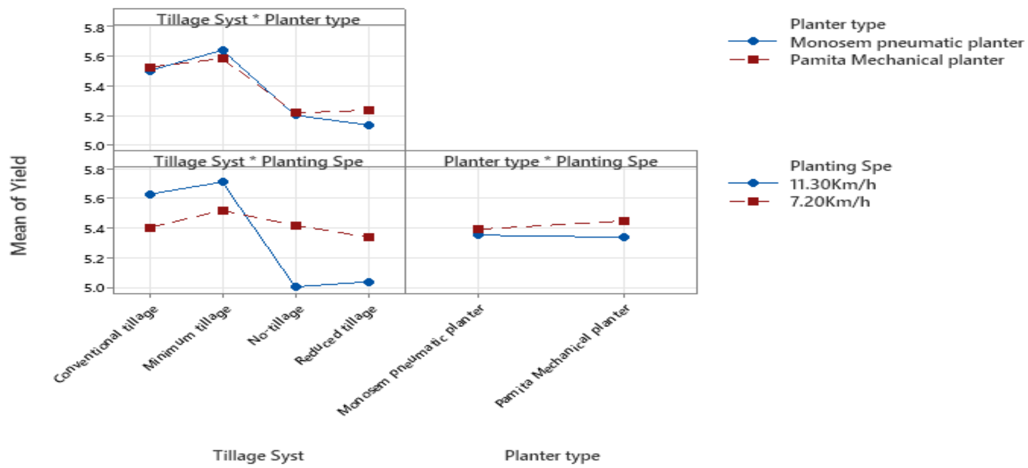

Figure 6. Sub plot 2-way interaction effects of tillage system, type of planter, and planting speed Yield (t/h)

Table 5 shows the mean height of maize measured in centimeters which reveals significant differences based on tillage system, planter type and planting speed. The highest mean height of 45.80 cm was obtained in the "Reduced Tillage" (RT) system plot where "PMP" planter type and "S_1" planting speed were involved. This combination likely provides optimal conditions for maize growth, as reduced tillage often preserves soil structure and moisture, and the "PMP" planter may offer better seed placement at slower speeds. Conversely, the lowest mean height of 38.90 cm was obtained in the "Minimum Tillage" (MT) system where "MPP" planter type and "S_2" planting speed were involved. This lower height could be attributed to the intensive soil disruption associated with minimum tillage and the faster planting speed, which might affect seedbed conditions and seedling establishment. Generally, reduced tillage and slower planting speeds tend to promote better plant growth due to improved soil conditions and better seed-to-soil contact, whereas more intensive tillage and faster planting speeds can lead to less favorable growth conditions.

Similarly, the Mean ERI reflects how quickly maize seeds emerge from the soil. The highest ERI value of 14.87 was recorded using "No-Tillage" (NT) system where "MPP" planter type and "S_2" planting speed were involved as illustrated in Table 5, suggesting that seeds emerge most rapidly under no-tillage conditions and at the faster planting speed. No-tillage often maintains better soil moisture and reduces soil compaction, facilitating quicker seedling emergence. In contrast, the lowest ERI of 10.7020 was using "Minimum Tillage" (MT) system where "MPP" planter type and "S_1" planting speed were involved. Minimum tillage can result in a less ideal seedbed compared to no-tillage, which may slow down seedling emergence. Faster planting speeds can also lead to increased soil compaction or inadequate seed coverage, affecting emergence rates. Therefore, combinations that maintain optimal soil conditions and appropriate planting speeds tend to result in quicker emergence, which is beneficial for early plant growth and development.

Table 5. Effect of Planter Types, Planting Speed and Tillage System on Plant Height (cm), Emergence Rate Index and Yield (t/h) using Tukey Test

TS × PT × PS	Mean Height (cm)	Mean ERI	Mean Yield (t/h)
RT × PMP × S_1	45.8000a	11.9417cd	5.28300defg
CT × PMP × S_2	44.4667ab	11.3467def	5.48400bcdef
MT × PMP × S_2	44.2333abc	11.4760def	5.51633bcde
NT × PMP × S_1	44.1333abcd	12.4000c	5.28067defg
RT × MPP × S_1	43.9667abcd	13.4783b	5.39167cdefg
RT × PMP × S_2	43.8000abcd	14.3663a	5.18933fg
MT × PMP × S_1	43.6333abcd	11.1933def	5.65533abc
NT × PMP × S_2	43.4667abcd	14.6520a	5.15500gh
CT × PMP × S_1	42.6333bcde	11.0827ef	5.57067bcde
MT × MPP × S_1	42.0667bcdef	10.7020fi	5.38067cdefg
NT × MPP × S_1	41.8000bcdef	13.4043b	5.55600bcde
CT × MPP × S_1	41.7333cdef	11.4790def	5.23500efg
CT × MPP × S_2	41.5333def	12.4593c	5.77200ab
RT × MPP × S_2	40.4333efg	14.7103a	4.88133hi
NT × MPP × S_2	39.6000fg	14.8663a	4.84833i
MT × MPP × S_2	38.9000g	11.6927cde	5.90400a

Means along the column that do not share a common letter are significantly different
Note: TS = Tillage System, PT = Planter Type, PS = Planting Speed

Table 5 also shows the mean yield measured in tons per hectare which varies significantly based on the interaction of tillage system, planter type and planting speed. The highest yield of 5.904 t/h was achieved using the "Minimum Tillage" (MT) system where "MPP" planter type and "S_2" planting speed were involved. This suggests that minimum tillage, combined with the "MPP" planter and faster planting speed, provides the best conditions for maize productivity. Minimum tillage helps preserve soil structure and moisture, which can enhance nutrient availability and root development, leading to higher yields. Conversely, the lowest yield of 4.85 t/h was recorded using the "No-Tillage" (NT) system where "MPP" planter type and "S_2" planting speed were involved. Although no-tillage can benefit emergence rates, it may not always be optimal for yield due to factors like limited soil aeration and potential nutrient deficiencies. Yield differences across various combinations highlight the complex interplay between tillage practices, planter types and planting speeds in determining overall crop productivity. Optimal yield is often achieved by balancing these factors to create favorable growing conditions for maize.

4. CONCLUSION

The study highlights the significant impact of tillage methods, planter types and planting speeds on maize yield components. No-tillage and reduced tillage systems, combined with the Monosem pneumatic planter at higher planting speed of 11.30 km/h were found to enhance seedling emergence rates and overall maize yield. The findings underscore the importance of selecting appropriate combinations of tillage practices, planter technologies, and planting speeds to optimize maize production. These results can guide farmers and agricultural stakeholders in making informed decisions to improve maize yield and maintain sustainability in similar agro-ecological zones.

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IMPACT ASSESSMENT OF HERBICIDES ON AQUATIC, SOIL BIODIVERSITY AND WATER QUALITY IN SUNTI SUGARCANE FARM, MOKWA NIGER STATE

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ABSTRACT

Herbicide application has become an integral part of vibrant agricultural productivity in the whole world since its benefit has been overwhelming over the years. However, its toxic impact on the non-target soil microorganisms which play roles in degrading organic matter, nitrogen and nutrient recycling and decomposition needs to be considered. In the present study, the effect of herbicides most commonly used in Sunti; Premixtral Gold, 2, 4 D, round up, Diuron Powder Diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea), Monosodium Methanearsonate (MSMA) were evaluated on microbial population and water quality. Soil samples were taken from three fields. Four soil samples at the depth of 10cm, 100cm distant from one another from three fields were randomly collected from sugarcane field and outside the field as control (upper, middle, lower altitude and outside the field) using soil auger. This was repeated three times on each plot. The samples from each field were bulked together, shaken to mix thoroughly and later air dried. The samples were sieved using a 2.0mm mesh size to remove stones and plant debris for the laboratory analysis. Water samples were collected from the Snake River close to the fields, samples were collected from the upstream before the fields as control, upper, middle and downstream to determine herbicides residual and water quality. Physico–chemical properties of the soil were also determined. The soil was determined to be sandy loam and chlorine residuals were detected, signifying the presence of organochloride. The microbial population of the soil where herbicides were used were lesser as compared to control which is outside the field. This could be as a result of the presence of residuals. The isolated bacterial and fungi were also identified. The study also shows presence of some residuals (Phosphate 8.01mg/l, Nitrates 10.5mg/l, TSS 90.94mg/l COD 63.31 mg/l) in water samples taken and the need for water treatment before use for domestic activities. It will also be very appropriate if further research work is carried out to identify the specific components of these herbicides which favour the growth and development of certain beneficial microorganisms such as fungi and bacterial.

Key Words: Herbicide, microorganisms, microbial population, organochloride, soil.

1.0 INTRODUCTION

1.1 Background of the Study

Over the years, herbicides have emerged as an important tool in management of weeds. Herbicides use is increasing throughout the world due to increasing labour cost, choice of application of herbicides, quick weed control in crop and non-crop areas etc. After the discovery and use of 2,4-D as an herbicide following 2nd World War, there has been a phenomenal growth in development of new molecules as herbicides. Due to intensive research in herbicide discovery and mode of action of herbicides, many new molecules are available to cater for the farmers need. Globally consumption of herbicides is 44% followed by the insecticides (22%), fungicides (27%) and others (7%) (Samuel, *et., al* 2022). In Nigeria, herbicide use has increased to 40% during the last 10 years in managing weeds in the country (Abakpa, *et al* 2024). Herbicides are chemical in nature and thus excessive and repeated use may pose residue problems, phytotoxicity to crop plants, residual effect on susceptible inter-crops or succeeding crops or non -targets organisms and ultimately health hazards due to accumulation of herbicide residues in the soil, crop produce and ground water. Many herbicides are found as bound residues which make them not only unavailable to the targets but also polluting the soil ecosystem in a number of ways.

Herbicides are used quite extensively in most farming systems. Herbicides, when applied to the field do not only control targeted weeds, but may also leave unwanted residues in the soil, which are ecologically harmful (Haney *et al*., 2000; Derksen *et al*. 2002; Riaz *et al*., 2007). Although the efficacy of herbicide in controlling weeds is very high, its residual impact should also be considered for environmental safety. Preferred herbicides should not only have good efficacy, but also poses minimum adverse effects on crops, ecology, and the environment (Faheed and Abd-Elfattah, 2007). Contamination of soil, water resources, and agricultural products by herbicides is an increasing environmental concern (Ouyang *et al*., 2004; Akinloye *et al*., 2011). Bioassay and chromatography are among the several methods commonly used to determine pesticide residue (Wahyu *et al*., 2009; 2010).

The vast majority of the Nigerian population are into agriculture, and this vocation accounts for a significant portion of the nation's gross domestic product (GDP). Over the years, as environmentalists continue to mount pressure on government, successive regimes have responded by initiating policies that deter bush burning, due to its attendant risk and negative impact on the environment. These measures have compelled many farmers and households to switch to herbicides and other chemicals as their principal means of clearing lands, and for the control of seasonal weeds and unwanted plants. With relatively little or no knowledge about the composition of the chemicals they purchase or the required ratio of water to herbicides, these users are transforming Nigerian farms and communities into enclaves saturated with toxic levels of dangerous chemicals especially organophosphates and organochlorides which has the potential of persisting in the environment for a long time, thereby forming persistent organic pollutants (POP) in the soil and atmosphere and also impacting negatively on the wellbeing of the population both human and animals. .

Most times the impact of herbicides tend to be underestimated largely due to the wrong perception of the word ''herb'', and the wrong notion that herbicides hardly come in contact with our food. This is not so because the contamination of groundwater, soil, plants, and habitats has a huge impact not just on humans, but also on animals. A vast number of chemical agents found in the environment are known to be toxic to biological systems, especially in high concentrations. These substances found in the environment are usually as a result of industrial and agricultural activities. They sometimes occur naturally in the lithosphere. Human exposure to toxic materials carries a great risk of morbidity, and mortality (Nnodimele, 2016). The aim of the Study is to determine the level of herbicides residuals and its impact on aquatic, soil biota and water quality in Sunti.

3.0 MATERIALS AND METHOD

3.1 Materials

Materials used include; plastic bottles, weighing balance, soil auger, and nylon bags.

3.2 Study Area

Sunti Sugar Company is located on the banks of River Niger, in Mokwa, Niger state. The study area is on longitude 9.157⁰ N and latitude 5.3505⁰ E at an average altitude of 88m above mean sea level. The sugar estate covers about 17, 000 hectares of irrigable farmland for sugar cane production.

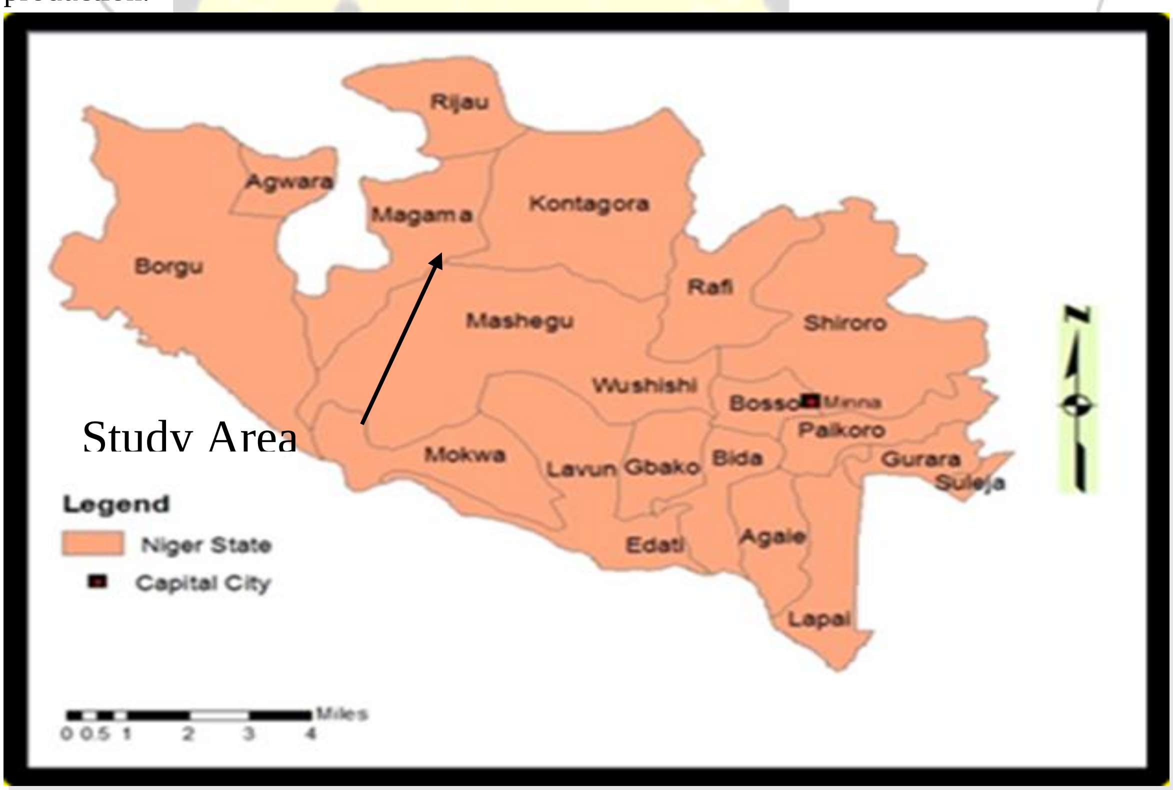

Figure. 2.1: Map of Niger State Indicating the Study Area

3.2.1Climate and Agro-ecology

Mokwa local Government experiences two distinct seasons, the dry and wet seasons. The annual rainfall varies from about 1000mm to 1,200mm. The duration of the rainy season ranges from 150 to 210 days. Mean maximum temperature remains high throughout the year, hovering about 40 ˚C in march and 32 ˚C in June. However, the lowest minimum temperatures (21 - 23ºC) occur usually between December and January when most parts of the state come under the influence of the tropical continental air mass which blows from the north. Dry season commences in October.

3.2.2 Topography and Soil

The study area has a flat to low land terrain with more than half the total area rising to an average height of about 88 meters above sea level. The land is relatively flat. The soils are mostly sandy loam, having relatively high silt contents. This may be due to the nature of the parent material which is sedimentary rock (Adepoju, 1993).

3.3 Methods

3.3.1 Soil Sampling

Four soil samples at the depth of 10cm and 100cm distant apart from one another from three fields were randomly collected from sugarcane field and outside the field as control (upper, middle, lower altitude and outside the field). This was repeated three times on each plot at three days interval. The samples from each field were bulked together, shaken to mix thoroughly and later air dried. The samples were sieved using a 2.0mm mesh size to remove stones and plant debris for the laboratory analysis.

3.3.2 Water Sampling

Water samples were collected early in the morning from the snake river close to the fields, according to Obiri-Danso (2004). Samples were collected from the upstream before the fields as control, upper, middle and downstream to determine herbicides residual and water quality. This was replicated three times at 30 days interval.

3.3.3 Common Herbicides used on Farm in the Study Area

Premixtral Gold, 2, 4 D, Round up, Diuron Powder, Monosodium Methanearsonate (MSMA).

3.3.4 Soil Sample Analysis

Soil analysis was done using standard laboratory procedures

3.3.5 Analyses of Water Samples

The physicochemical parameters for water samples were determined using standard methods of analysis. Electrical conductivity (EC), pH, temperature, turbidity, and total dissolved solids (TDS) were determined using electrical conductivity meter Jenway 430, pH meter Jenway 430, mercury bulb thermometer, SGZ 200BS turbidity meter, and TDS meter Jenway 430 respectively (Opaluwa *et al*., 2020). Parameters such as total suspended solids (TSS) was determined by gravimetric method, total hardness (TH) by EDTA titrimetric method, alkalinity, and chloride by titrimetric method, nitrate and Sulphate were determined by methods prescribed by AOAC, 1990 and adopted by Ademoroti (1996).

3.3.6 Determination of phosphate

In determining the available phosphate ion in the water samples, 50cm^3 of water sample was pipetted into a 500cm^3 volumetric flask, 5cm3 of Ammonium molybdate solution and 3.0cm3 of ascorbic acid were added with swirling, the mixture was diluted to the mark with deionised water and was allowed to stand for 30 minutes for maximum colour development, the absorbance was then read at 660nm including the blank.

3.3.7 Determination of Nitrate and Chloride

In determining the available phosphate ion in the water samples, 10 cm^3 of the water sample was pipetted into a 50 cm3 volumetric flask. 10cm3 of 13N sulphuric acid was added and mixed with swirling, the flask was allowed to come to a thermal equilibrium in cold water bath (0 - 10) ^{o}C. 0.5cm^3 of brocine-sulfanilic acid was added and diluted to the mark with deionised water, the solution was then placed on the 100^{o}C hot water bath for about 25 minutes for maximum colour development, the flask was then cooled to room temperature. The absorbance was read at 410nm including the blank. This procedure was repeated on the other samples including the standard solutions for making standard calibrations. The Mohr Method was used to determine the amount of chloride in the sampled water.

3.3.8 Enumeration of microbial population

The enumeration of microbial population analysis of the soil and water samples were done in a standard laboratory at national research institute Badegi.

3.3.8.1 Baseline determinations (Control)

This is the point where the bacteria and fungi population in the soil were determined without any chemical treatment to serve as the baseline to compare with the soils that were treated with the various herbicides. The soil organic matter was determined before the chemical treatment and after treatment.

3.3.8.2 Bacteria

The enumeration of the bacteria population was done using Pour Plate Counter. The plate count agar was prepared by suspending 20.5 g of dehydrated medium (powder) in one litre of distilled water. The content was heated and boiled for one minute with constant agitation until the powder is completely dissolved. The agar was poured into a flask and sterilized in an autoclave at 121 ^{0}C. One gram of each treated soil sample was weighed and serially diluted. 1 ml aliquot was taken from an inch below the surface with sterilized 1ml pipette and placed in an empty sterile plate. 15

ml of the melted plate count agar which has been cooled to 45^0C was poured into the diluted sample. This was swirled to ensure that the mixture is thoroughly mixed and cooled to solidify on a flat laboratory bench before incubation is done under a lamina flow. These labelled specimens were inverted to prevent it from being soaked through condensation. Incubation will be done at room temperature of 25 ^{0}C for 24 – 48hours. Total viable colony on each plate was counted using the colony counter and the data recorded.

3.3.8.3 Fungi

The enumeration of the fungi was done by using Potato Dextrose Agar (PDA) supplemented with each of tetracycline and streptomycin to inhibit bacterial growth. The PDA was prepared by weighing 200g of freshly peeled and washed potato in the laboratory. It was then boiled, mashed and the pulp squeezed through a fine sieve. 20g agar was added and boiled to dissolve and again 20g dextrose was added and boiled to dissolve and make up to one litre with water. The content was then be sterilized at 15 psi for 20 minutes in an autoclave. 1ml of the test samples were added to a sterile Petri dish and then a required amount of sterile, molten agar was added to the test sample. The content was cooled to 45^0C and swirled gently to mix well before it was allowed to solidify. Incubation of the fungi was done under a lamina flow at room temperature of 25^0C for 48hours and identified with reference to Bergey's manual of systematic bacteriology. The total number of a particular organisms on each plate was identified and scored based on a maximum count of four (4) on a particular plate (Barnett and Hunter, 1972; Alexopoulos and Beneke, 1968).

3.3.8.4 Soil organic matter

The organic matter content was determined by the wet combustion (Walkley and Black, 1934). One gram of the sample soil was weighed out into a 500ml Erlenmeyer flask and 10 ml of 1.0 N Potassium dichromate ($K_2Cr_2O_7$) solution added using a burette (Potassium dichromate oxidizes Carbon in the organic matter, itself being reduced in the process). This was followed by the addition of 20 ml conc. H_2SO_4 to generate heat to facilitate the reaction between carbon and Cr_2O. The mixture was swirled for one minute to ensure that the solution is in contact with all the particles of the soil. The flask and the content was allowed to cool on an asbestos sheet for 30 minutes. Two hundred milliliters of distilled water was added, followed by 10 ml orthophosphoric acid (to sharpen the colour change at the end point of titration). One milliliter of diphenylamine indicator was added and the solution titrated with 1.0 M normal ferrous sulphate solution until the colour changed to blue, and then finally to a green end-point. The titre value will be recorded and the blank solution corrected. Organic carbon was calculated using the formula below:

$$\%\, organic\ C\ in\ soil = \frac{(\{m.e.K_2C_{r2}O_7 - m.e.F_eSO_4\} \times 0.003 \times f \times 100)}{weight\ of\ soil} \quad (3.4)$$

Where; m.e. = milli equivalent = normality of solution × ml of solution used 0.003 = m.e. weight of C f = correction factor = 1.33 % Organic matter was calculated using the formula:

Percentage (%) organic matter = Percentage organic carbon× 1.724 (3.5)

3.3.9 Experimental Design

The experiment was completely randomized design.

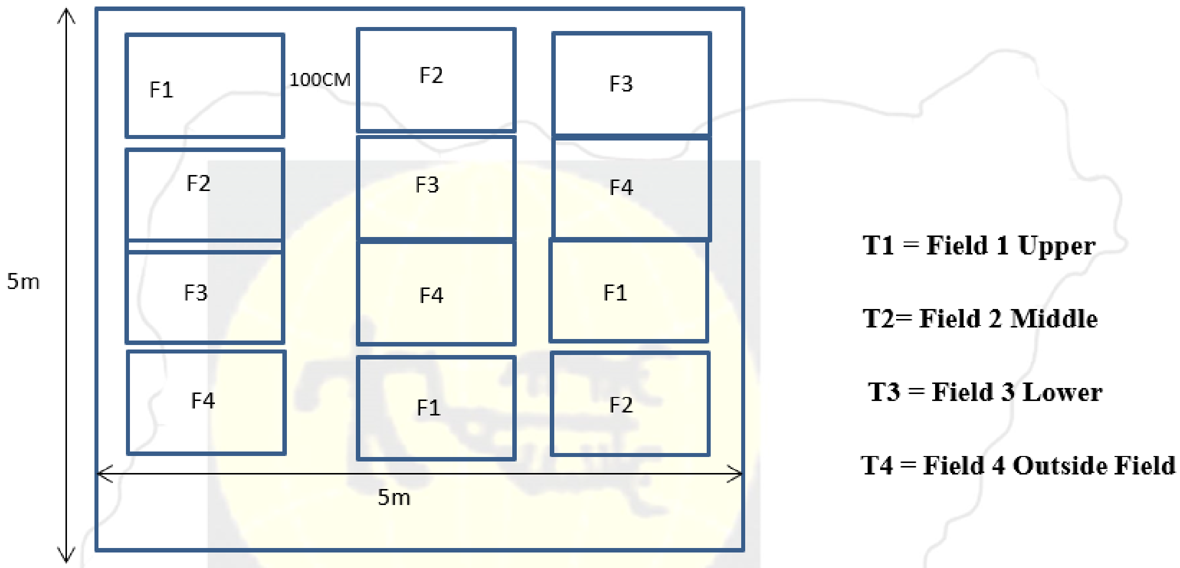

Figure 2.2: Experimental Layout

3.3.10 Data Analysis

The data collected was subjected to descriptive statistics

4.0 RESULTS AND DISCUSSION

Table 4.1: Bacterial, fungal Count of River Side

Sample	Bacterial Count	Bacteria Isolated	Fungal Count	Fungi Isolated
River side beginning	$5.6x10^5$	Vibrio vulnificus Listeria monocytogenes Yersinia enterocolica Bacillus tetanus B. radicicola Azotobacter chroococcum Cyanobacteria spp Bacillus stearothermophilus Nitrsomonas spp	$4.2X10^4$	Fusarium oxysporum F . nivale Cephalosporium spp Aspergillus nivale A. niger Trichoderma spp Norcadia spp Micromociospora spp
River side middle	$5.2x10^5$	Methanobacterium spp Desulfovibrio spp Micrococcus luteus M . lylae Salibacillus spp Brevibacterium linens Bacillus subtilis	$3.8X10^4$	Calothrix spp Cylindrospernum spp Anabaena Aspergillus restrictus A . oryzae Waksmania spp Rhizopus oligosporus
River side end	$4.7x10^6$	Clostridium histolyticum Cl. pasteurianum Rhodopseudomonas spp Rhodospirillum Pseudomonas flourescens p. telluria Bacillus stearothermophilus B. polymyxa	$3.5X10^4$	Calothrix spp Bacillariopyceace spp Micromonospora spp Nostoc spp Fusarium poae F . oxysporium Trichoderma spp Trichothecium spp Waksmania spp Monillia spp

Table 4.1 shows the microbial soil analysis from the study area. There is a trend of reduction of the bacterial and fungal population from the upstream downstream. It shows that as we descend

down the stream the micro population increases, which could be ascribed to the fact that as water travels from the upstream to the downstream the concentration of possible residual chemical reduces, this helping the survival and activity of microorganisms. Chemicals applied to the fields along the water area are also been moved along and deposited downstream affecting the microbial population. This is always of concern for the downstream users. This is in agreement with Barcelo (1997) in their work Trace Determination of Pesticides and Their Degradation Products in Water.

Table 4.2: Microbial Analysis of Field 1

Sample	Bacterial Count	Bacteria Isolated	Fungal Count	Fungi Isolated
Field 1 beginning	$3.5x10^5$	Rhodotorula pullularia Micrococcus luteus M . lylae Salibacillus spp Brevibacterium linens Bacillus subtilis	$7.4X10^4$	Calothrix spp Nostoc spp Aspergillus restrictus A . oryzae Waksmania spp Rhizopus oligosporus
Field 1 middle	$1.1x10^4$	Thiobacillus denitrificans Proteus vulgaricus Nitrosomonas spp Bacillus subtilis Salibacillus spp Pseudomonas aminobacter	$1.0X10^3$	Chlorophyceae spp Rhizopus oligosporus Aspergillus restrictus A . oryzae Waksmania spp Nocardia spp
Field 1 end	$1.3x10^6$	Micrococcus luteus M. lylae Cyanobacteria spp Proteus vulgaris Azotobacter chroococcum Pseudomonas acidovorax	$1.0X10^5$	Aspergillus restrictus A . oryzae Waksmania spp Rhizopus oligosporus Stretomyces spp Talaromyces flavus

Table 4.2 shows the microbial analysis of field 1 of the study area. Samples taken from outside the field presumed to be free from chemicals have the highest bacterial population of $6.1x10^4$. This could be attributed to the non or limited chemicals applied to the field. The isolated bacterial and fungi are shown in the table. Field 1 beginning has the second largest population then the end of the field. The middle field has the highest bacterial population; this could be from the fact that chemical are more in application in the middle of the farm owing to it been the central area. This trend applies to field 2 and 3.

Table 4.3: Microbial analysis of soil sample from field 2

Sample	Bacterial Count	Bacteria Isolated	Fungal Count	Fungi Isolated
Field 2 beginning	$4.2x10^5$	Salmonella enterica Klebsiella pneumoniae Clostridium histolyticum Cl sporogenes Micrococcus lylae M.luteus Cyanobacteria spp Proteus vulgaris Azotobacter chroococcum Pseudomonas acidovorax	$5.8x10^4$	Rhodotorula pullularia Chlorophyceae spp Cyanophyceae spp Aspergillus restrictus A . oryzae Waksmania spp Monilia spp Penicilliun roquefarti Cephalosporium spp Streptosporangium spp Rhizopus oligosporus
Field 2 middle	$7.2x10^4$	Micrococcus dinitrificans Clostridium pasterianum Pseudomonas telluria P . aminobacter P. aeruginosa Serratia marcescens Cellulomonas spp Proteus vulgaricus Cyanobacteria spp Chromatium spp	$6.3x10^3$	Micromociospora spp Nocardia spp Penicillum dangeardi P . expansum P . rubrum Streptosporangium spp Waksmania spp Streptomyces spp Monilia spp
Field 2 end	$4.3x10^4$	Pseudomonas flourescens p. telluria Bacillus stearothermophilus	$4.0X10^3$	Aspergillus glaucus A . nidulans Talaromyces flavus Neosaterya fischen Waksmania spp
Outside field Control	$6.1x10^4$	Spirillum spp Rhodospirillum spp Bacillus subtilis B. polymyxa Salibacillus spp Aneurinibacillus spp Azotobacter	$4.4X10^3$	Bacillariophyceae spp Anabaena spp Aspergillus restrictus A. oryzae A. niger Penicillum roquefarti P. dangeardi

Table 4.4: Microbial Soil analysis of Field 3

Sample	Bacterial Count	Bacteria Isolated	Fungal Count	Fungi Isolated
Field 3 beginning	$7.4x10^5$	Spirillum spp Escherichia coli Proteus vulgaris Pseudomonas aminobacter P . acidovorax P. flourescens	$5.4X10^4$	Cyanophyceae spp Aspergillus oryzae A. niger A. restrictus Penicillum roquefarti P. dangeardi
Field 3 middle	$6.3x10^6$	Chromatum spp Corynebacterium ovis Pseudomonas flourescens p. telluria Bacillus stearothermophilus	$5.0X10^5$	Rhodospirillum spp Trichoderma spp Fusarium oxysporum F . nivale Cephalosporium spp Monillia spp
Field 3 end	$1.4x10^6$	Bacillu tetanus B. radicicola B.stearothermophilus B. subtilis B. brevis Brevibacterium linens	$1.0x10^5$	Cyanophyceae spp Aspergillus glaucus A . nidulans Talaromyces flavus Neosaterya fischen Cephalosporium spp

Table 4.5: Soil Textural Analysis of the Study Area

SAND %	CLAY %	SILT %
82.08	7.16	10.76
82.06	7.18	10.76
82.08	7.14	10.78
80.64	8.15	12.21

The analysis shows that the soil from the sample area is sandy loam. Generally, soils that are high in clay/organic matter or both, have greater potential for herbicide carryover because there is increased adsorption to soil colloids with a corresponding decrease in leaching and loss through volatilization. This can affect the extent of water retention and also any residual chemical. This can also have effect on the microbial activities of the area as the moisture retention level and microbial activities can be hindered.

Table 4.6 Physico–Chemical Properties of Soil Samples Taken from Selected Fields in Sunti

Field	pH	Elect. Cond. Ppm	OC g/kg	Aval P mg/kg	Total N g/kg	Na Cmol/kg	K Cmol/kg	Ca Cmol/kg	Mg Cmol/kg	EA Cmol/kg	CEC Cmol/kg
F_1	5.84	8.0	15.36	26.12	0.37	4.23	0.37	0.16	0.16	0.63	5.99
F_2	5.42	18.0	18.15	31.71	0.36	2.78	0.28	0.41	0.41	0.37	5.15
F_3	5.78	6.0	18.95	38.98	0.84	2.75	028	1.88	1.88	0.45	7.24
Out field	4.48	6.0	12.33	14.13	0.21	2.43	0.12	0.21	0.02	0.30	3.23

Table 4.6 shows the physico – chemical properties of soil samples from the study area, the content of the exchangeable potassium, ranged value for exchangeable potassium (0.12– 0.37 Cmol/kg) is less than the required value to support the growth of crops, but is often large enough to satisfy the requirement of one crop (Spark & Huang, 2002). The CEC wa also low for plant growth, it ranged from 3.23 to 7.24. 10 cmol(+)/kg is preferred for plant production.

4.1 Soil Microbial

Microorganisms play an essential role in many soil biological processes, including nitrogen transformations, organic matter decomposition, nutrient release and their availability, as well as stabilize the soil structure and affect its fertility.

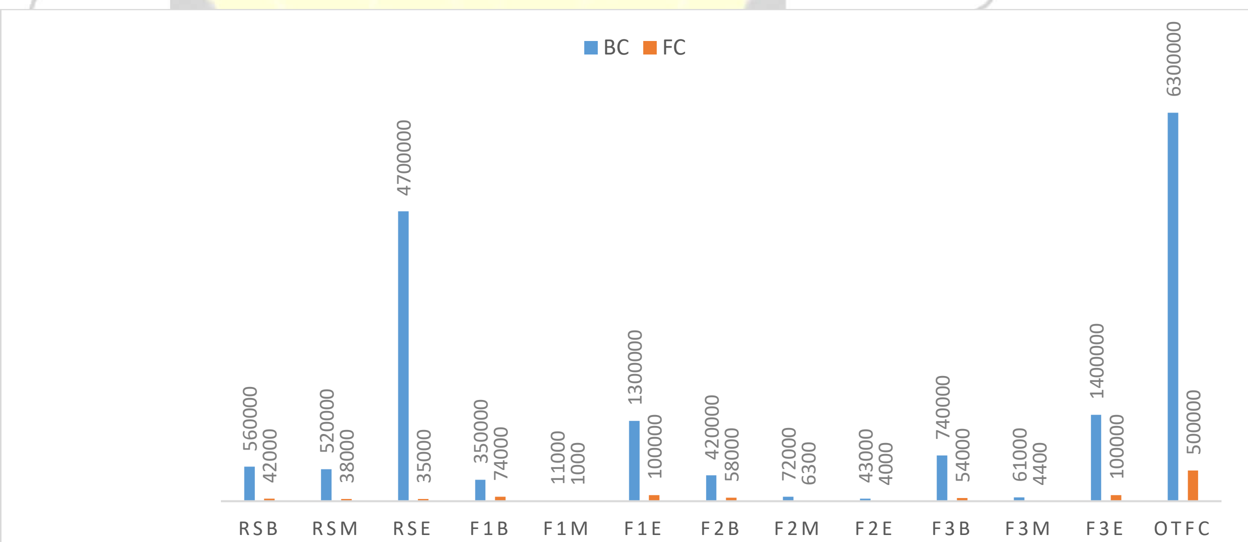

Fig. 4.1: Microbial Analysis of Soil from the Study Area *RS: river side, B: before, M: middle: E: end F: field, OTFC: out of field control

Figure 4.1 illustrates the microbial soil investigation from the study area. It shows a drift of reduction of the bacterial and fungal population from the upstream downstream. It displays that as we run down the stream the micro population surges, which could be attributed to the fact that as water voyages from the upstream to the downstream the concentration of possible residual chemical reduces, this helping the survival and activity of microorganisms. Chemicals applied to the fields along the water area are also been moved along and deposited downstream affecting the microbial population. This is always of concern for the downstream users. This is in agreement with Barcelo (1997) in their work Trace Determination of Pesticides and Their Degradation Products in Water.

The microbial analysis of the soil also shows that the control which is assumed to be free from chemical has the highest microbial population as can be seen in figure 4.1. This agrees with the findings of Marius *et al.*, (2007) in their work Effect of selected pesticides on soil microflora involved in organic matter and nitrogen transformations: Pot experiment. They agreed that pesticides reduce the microbial population of soil.

Table 4.7: Water Quality Analysis of the Study Area

Sample	BOD Mg/l	COD Mg/l	TDS Mg/l	TSS Mg/l	Nitrates Mg/l	DO Mg/l	Phosphates Mg/l
Middle Stream	79	62.31	90.94	31.40	10.51	4.97	8.01
Upper Stream	81	65.70	88.05	30.62	11.28	5.89	9.17
Down stream	96	70.18	79.37	28.91	8.64	7.35	8.77

Table 4.7 shows the water quality analysis of the study area. This is done to see if there are influence of residual chemicals in in the water around the farm. The vales were compared with the NAFDAC and WHO water quality standard to see if limits were exceeded. The pesticides/ herbicides residuals usually are organochlorides. The residual chlorine obtained in table 4.7 exceeds the NAFDAF limits which may imply chemical residual effects. Nitrates and Phosphates also exceeds limits. The table of standard for water quality can be referred to for further details.

Table 4.8: Water Quality Analysis of Study Area

Sample	pH %	TDS Mg/l	Conductivity (uS/cm)	Hardness (CaCO3)	Chloride Mg/l
Middle Stream	0.074	0.036	1.173	0.423	0.34
Upper Stream	0.081	0.034	1.188	0.420	0.67
Down stream	0.068	0.030	1.163	0.423	0.55

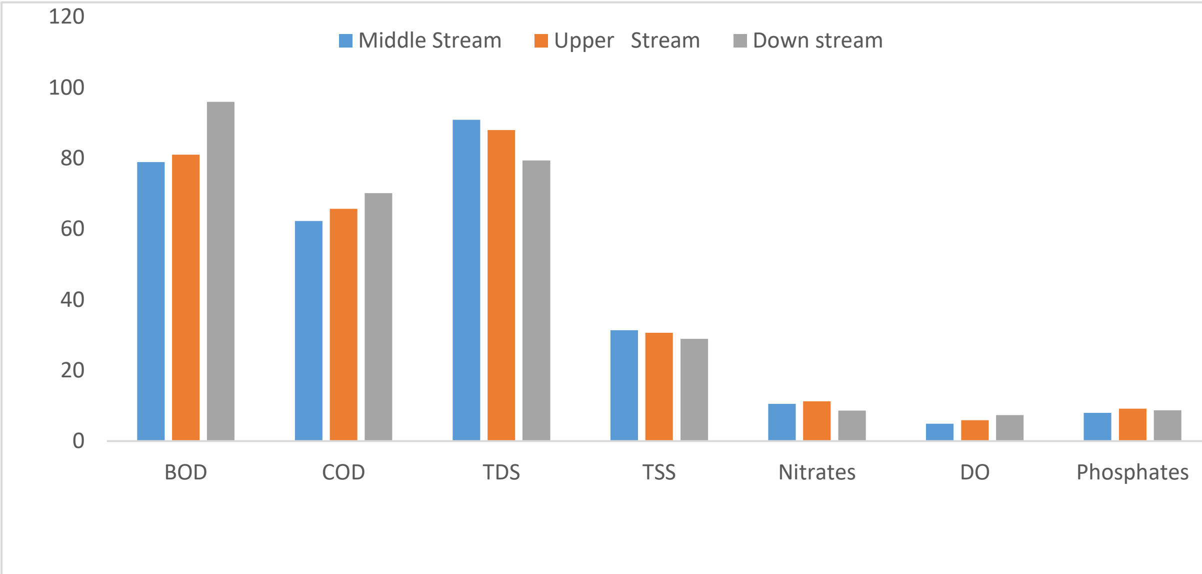

Fig. 4.2: Water quality Analysis of the Study Area

Figure 4.2 shows that downstream has the highest BOD followed by the upper stream and the middle point. COD has the same trend. But for TDS middle has the highest followed by the upper and the downstream. The nitrate and the Phosphate values were also large signifying presence of residuals. This shows the need for treatment before drinking and caution.

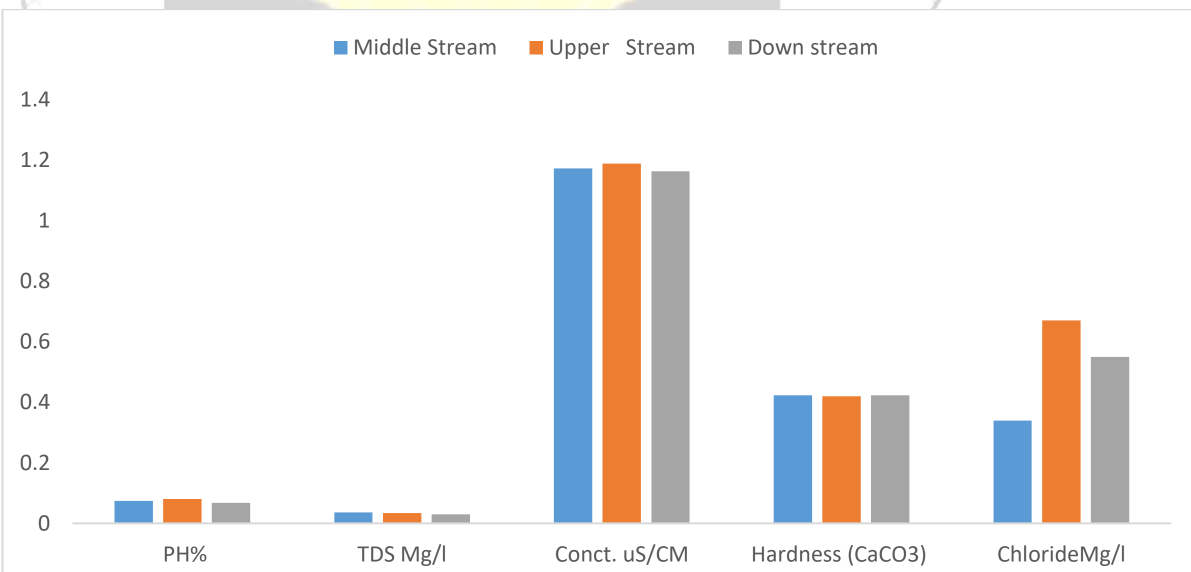

Fig. 4.3: Water quality Analysis of the Study Area

The figure 4.3 shows the water analysis of the study area. It shows that all factors: PH, TDS. Conductivity, Hardness are normal and within the limits standards but the residual chlorides have exceeded limits. This signifies caution and need for treatment before domestic use.

5.1 Conclusion

From the study the following conclusions were drawn; Some physical and chemical composition of the soil were determined. The soil was determined to be sandy and chlorine residuals detected, signifying the presence of organochlorides. The detected microbial population of the soil at the herbicides treated areas were lesser than outside the field, this could be as a result of the presence of the herbicide residuals. The isolated bacterial and fungi were also identified. The study shows the need for water treatment before use for domestic activities.

5.2 Recommendations

1. More samples need to be taken for further studies
2. There should be further chemical residual analysis of the soil and water samples.
3. There is, a need to carry out an elaborate study and monitor the use of herbicide residues in soil and water in Nigeria to assess build up, bio magnifications and bioaccumulation of residues and adverse effects if any.

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EFFECT OF BLADE TYPES AND WEEDING DEPTH ON THE WEEDING PERFORMANCE OF A MODIFIED MANTIS POWER TILLER

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ABSTRACT

Weeds are unwanted and undesirable plants that interfere with the utilization of land and water resources, compete for plant nutrient and adversely affect crop production. Power tiller could be used for weeding operation. Therefore, the study aimed at improving the performance of Mantis power tiller through modification of two major components viz; weeding blades and depth gauge. Three sets of pairs of blade gang of four, six and eight as well as the depth gauge were made from 3 mm mild steel sheet metal. The fabrication was carried out at the Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria. The modified power tiller was evaluated based on weeding efficiency, field capacity and plant damage in a maize field during 2017/2018 irrigation season at the research farm, Institute for Agricultural Research, IAR, Ahmadu Bello University, Zaria. Four levels of blade types 'B' and three levels of weeding depth 'D' were considered. The field was laid in a 4×3 Randomized Complete Block Design (RCBD) at two (2) weeks after sowing (2WAS). DMRT was used for mean separation ran in SAS package. Results obtained showed that the effects of blade types and weeding depth were significant on the weeding performance of the modified power tiller. The mean weeding efficiency, field capacity and least plant damage of 85.4 %, 0.00595 ha/hr and 9.0 % respectively were recorded.

Keywords: Weed; weeding blade; weeding depth; field capacity, weeding efficiency

1.0 INTRODUCTION

Tillage is a basic operation in farming. It is generally done to create a favourable condition for seed placement and plant growth. These operations include ploughing, harrowing and mechanical destruction of weeds and soil crust, (Ojha and Michael, 2005). Lighter and finer operations performed on the soil after primary tillage but before and after seed placement are termed secondary tillage. The operations are usually done on the surface soil, very little inversion and shifting of the soil take place. A power tiller is basically a set of blades (called tines) that are mounted within a wheeled housing and powered by either gasoline engine or an electric motor (tractorsupply.com). Power tiller is otherwise known as cultivator or rotavator. Besides preparing the seedbed, it can be successfully adopted for removal of weeds and stubbles, mixing the manure, fertilizers and crop residues (Ojha and Michael, 2005). Weed removal is one of the post planting operation usually carried out by application of chemicals (herbicides), manual uprooting of the weed and mechanical manipulation of the soil.

Weeds are plants “out of place” in cultivated fields, lawns and other places, that is, a plant growing where it is not desired. A weed can be thought of as any plant growing in the wrong place at the wrong time and doing more harm than good. It is a plant that competes with crops for water, nutrients and light. This can reduce crop production. To check this, agricultural implements and machines enable the farmers to employ the power for production purposes. Agricultural machines increase productivity of land and labour by meeting timeliness of farm operations and increase work output per unit time.

A mechanical device to remove the weeds from an agricultural land is known as weeder. A weeder may be manual or animal drawn and tractor mounted or power operated (Aditya, 2016). Mechanical weed control not only uproots the weeds between the crop rows but also keeps the soil surface loose, ensuring better soil aeration and increase water intake capacity. Mechanical weeders perform simultaneous job of weeding and can reduce the time spent on weeding (man hours), cost of weeding and drudgery involved in manual weeding. The wider and equal spacing between the plants allow easy operation of mechanical weeders. Weeds are seen as growth promoters when they are appropriately managed because the weeding process incorporates the weeds into the soil as green manure crops, which helps build up soil organic matter and subsequently large and diverse microbial population in the soil.

Manual weeding is common in Africa, particularly in Nigeria. This method is labour intensive and is one of the major problems of farming in Nigeria (Olawale and Oguntunde, 2006). Alternatively, weed control involves industries providing the necessary herbicides, and individuals engaging in the practices of weed control (Nkakini and Husseni, 2015). In developed countries chemical weeding is more prominent than mechanical weeding. However, in the recent times the problem of environmental degradation and pollution exacerbated by the application of herbicide is making the world to have a re-think on the adoption of mechanical weeders (Olawale and Oguntunde, 2006).

The problems with existing power weeders are diverse. The problems of improper design of farm machinery for specific ecological zone, excessive manual labour required to move the machine and high energy requirements to propel the operational components of the tillage machines is higher for soil engaging equipment. Also, the implications of the unfair competition of imported alternatives, and design and development of some prototypes that are not yet perfected among other factors constitute the major problems in soil tillage machinery development in Nigeria (Olaoye and Adekanye, 2011). According to Kepner *et al.* (1978) and Buckingham (1976), the primary objective of row crop cultivation is to enhance the use of farm machinery for eliminating weeds from the crop land. The effect of this method is to promote plant growth and better quality crops. However, the use of such machines is not common because mechanical weeders are scarce. Mantis power tiller is capable of removing weeds and harrowing for viable seed bed. The intrinsic characteristic of Mantis Power tiller of clogging and clogging of the tines are highly challenging. This inhibit and lower the weeding efficiency of the machine.

Manuwa *et al*. (2009) reported that mechanical methods would remain by far the most widely used means of weeds control for years to come. Mechanical weeding is more likely to be sustainable than chemical weeding because it carries fewer risks (financial, health and environmental) and easier to maintain with existing skills and facilities (Manuwa *et al*., 2009). There is an increasing interest in the use of mechanical intra row weeders because of concern over environmental degradation and a growing demand for organically produced food (Madhusudhana *et al.*, 2015). Therefore, low weeding efficiency attributed to the Mantis power tiller since it was not primarily designed for weeding operation, attracted interest in design and fabrication of new weeding blades and depth gauge for effective weeding. The tiller is a light weight machine, compact and designed to suit easy mobility and operator convenience. With the incorporation of depth wheel which controls the depth of cut of the weeder, this eliminates the challenge of clogging during operation. Also, with the adoption and design of "L" shaped weeding blades as a weeding unit, would help to improve weeding and better soil engagement of the tiller. The aim of this study is to assess the effect of weeding blade and depth gauge on the weeding performance of the power tiller.

2.0 MATERIALS AND METHOD

Figure I and II show the power tiller with the existing weeding blades. The concept of the research was targeted at modifying the Mantis power tiller (figure 1 and 2) as weeding tool. The modification of the power tiller entailed design and fabrication of weeding unit and depth gauge component of the Mantis tiller as well as to assess the effect of the weeding blade and weeding depth on the performance of the modified power tiller.

Figure 1. Mantis power tiller

Figure 2. Blade section of Mantis power tiller

2.1 Tools and Materials

The following materials were employed in the fabrication of the modified components of the power tiller; i. mild steel sheet, ii. bolts and nuts; and mild steel pipe. Instrumentations employed in the evaluation were stopwatch, metre rule of 100 m, tachometer and measuring cylinder.

2.2 Machine component modification

Two components of the machine were modified. These were the weeding unit and the depth gauge. The weeding unit which was basically a set of blade gangs (4, 6 and 8), modified for improved weeding and soil engagement. The depth gauge was incorporated for effective gauging of depth of cut during weeding operation, ease of mobility and to prevent the clogging of the weeding unit.

2.3 Design of Components

The design of the modified components entails the design of shaft, determination of total power required for weeding by the machine, selection of the modified weeding blades and depth gauge components. In the design of the weeding unit, factors associated with ease of operations, machine and plant were considered. The design specifications include,

i. The radius of the blade from the centre of the shaft was 9 cm. This was selected to check the blades against making contact with the mud flap during weeding operation.
ii. The depth of cut of 4 cm and effective width of cut of 12 cm was observed.
iii. The walking speed of a healthy man was 1 km/h (Pandey, 1994) equivalent to 0.28 m/s.
iv. Minimum speed of revolutions required for weeding was 150 rpm (Niyamapa and Chertkiattipol, 2010).
v. The transmission efficiency of the operation was assumed after Aditya (2016) to be 82%.

2.3.1 Design of Shaft

The power tiller was coupled with a solid shaft, hence a hollow pipe which accommodates the blades was designed. The tangential force, F, was computed as 308.4 N and subsequently, the torque, M_t was computed as 20.97 Nm. The external diameter, d_o of the shaft was computed as 14 mm. The Mantis engine is coupled with a 12 mm solid shaft. Therefore, the outer shaft size d_o (14 mm) was computed and sufficient for the design. The hollow shaft size was determined as shown in Table 1.

Table 1. Summary of design calculation

s/n	Design component	Initial Data	Design procedure
1.	Power required by the blades to remove the weeds P_w	$S_R = 1.05$ kg/cm^2, d = 4 cm w = 6 cm, v = 1.73 m/s η = 0.82	$P_w = \frac{S_R \times d \times w \times v}{75}$ $P_{aw} = \frac{P_w}{\eta}$
2.	Power required for the thrust P_{th}	$F_{th} = 64.35$ N, V = 1.73 m/s	$P_{th} = F_{th} \times V$
3.	Power requirement for the weeding	$P_{aw} = 0.707$ hp $P_{th} = 0.15$ hp	$P = P_{aw} + P_{th}$
4.	Power required to propel the machine	$T_f = 16.77$ N V = 0.28 m/s	$P_t = T_f \times V$
5.	Shaft	di = 0.012 m $M_t = 20.97$ Nm T=103.95 MN/m^2 π = 3.142	$(d_o^3 - d_i^3) = \frac{16M_t}{\pi\tau}$
6.	Weeding blades		4, 6 and 8 blades gangs were adopted and designed as stated in section 2.3.2
7.	Depth gauge		Designed following the procedure stated in section 2.3.3

2.3.2 Weed Removal Blade Power Requirement

The power required to remove weed by the blade was determined as presented in Table 1. The weeding was carried out by a gang of blade from both sides. A blade each from both gangs cuts the soil simultaneously with the weeding blade. Therefore, total of two (2) blades cut the soil.

Effective width of cut = 2 × 3 cm = 6 cm

The power required to remove the weed P_w was computed as 0.58 hp (0.43 kW). Thereafter, the actual power P_{aw} required to remove the weed was determined as 0.707 hp (0.53 kW).

2.3.3 Power Required for the Thrust

The power required due to thrust by the machine rotational weeding blade was expressed as Equation 2.1 given by Liljedahl (1979).

$$F_{th} = [0.75(1 - e^{-0.3C_nS})]W \qquad 2.1$$

where, F_{th} = thrust (N)

C_n = cone Factor (dimensionless)

S = wheel slip (0.1)

W = machine weight (130 N)

The Cone factor C_n was determined by Equation 2.2, given by Liljedahl (1979)

$$C_n = \frac{CIbd}{W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

where, CI = cone index

b = wheel width (6 cm)

d = overall depth of the wheel (12 cm).

W = machine weight (130 N)

The power required due to thrust P_{th} was expressed after Aliyu (2012)

$$P_{th} = F_{th} \times V \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

where, F_{th} = thrust (64.35 N)

V = speed of the weeding gang (1.73 m/s)

According to Wismer and Luth, (1974), the sandy loam soil at a depth of 4 cm, the cone index CI was selected as 65 N/cm^2. Also, assuming the weeding tine as a pneumatic wheel, contact width 'b' was 6 cm and the overall depth 'd' was 12 cm. Therefore, the cone factor C_n was computed as 36 using equation 2.2.

Using equation 2.1, and substituting the parameters C_n (36), S (0.1), and W (130 N), the thrust F_{th}, was computed as 64.35 N.

The power required due to thrust P_{th} was determined using equation 2.3. Therefore, the power required was computed as 111.34 W equivalent to 0.15 hp.

The total power required by the engine for the weeding operation is the sum of power require to remove the weed by the blades and power required due to thrust.

Total power = 0.707 hp + 0.15 hp

= 0.857 hp

The Mantis tiller engine has a rated power of 1.6 hp (1.2 kW) which is suitable to power the weeding operation.

2.3.4 Power Requirement to Propel the Machine

The power required to propel the machine (P_t) during operation was determined as follows

$$P_t = T_f \times V \qquad 2.4$$

where, T_f = Towing force (N)

V = operator linear speed (0.28 m/s)

The Towing force, T_f for a pneumatic wheel is determined from the dimensional analysis as stated by Liljedahl (1979).

$$T_f = \left(\frac{1.2}{C_n} + 0.04\right) W \qquad 2.5$$

where, C_n = cone factor

W = weight of the machine (130 N)

T_f = towed force (N)

The power required to propel the machine during operation was determined using equation 2.4. Considering the wheel width of 3 cm and cone index of 65 N/cm^2 (Wismer and Luth, 1974) for sandy loam soil at the depth of 4 cm, the cone factor C_n of 13.5 was computed. Using equation 2.5, the towed force T_f was calculated as 16.77 N. The power required for propeling the machine P_t was computed as 4.70 W, as presented in Table 1.

2.4 Modified Mantis power tiller

The Mantis power tiller was modified by the designed, fabricated and replaced with weeding unit (also called tine) and the depth gauge. The "L" shaped weeding blades were selected as replacement for the modified power tiller tines. The blades were arranged in four, six and eight gangs, made of 3 mm mild steel sheet metal as shown in figure 3, 4 and 5. The adjustable depth gauge made from mild steel sheet metal is attached to the Mantis tiller as shown in figure 4. Also, isomeric and orthographic design of the modified Mantis tiller is shown in figure 7.

Figure 3. Four blade type

Figure 4 . Six blade type

Figure 5. Eight blade type

Figure 6. Modified power tiller

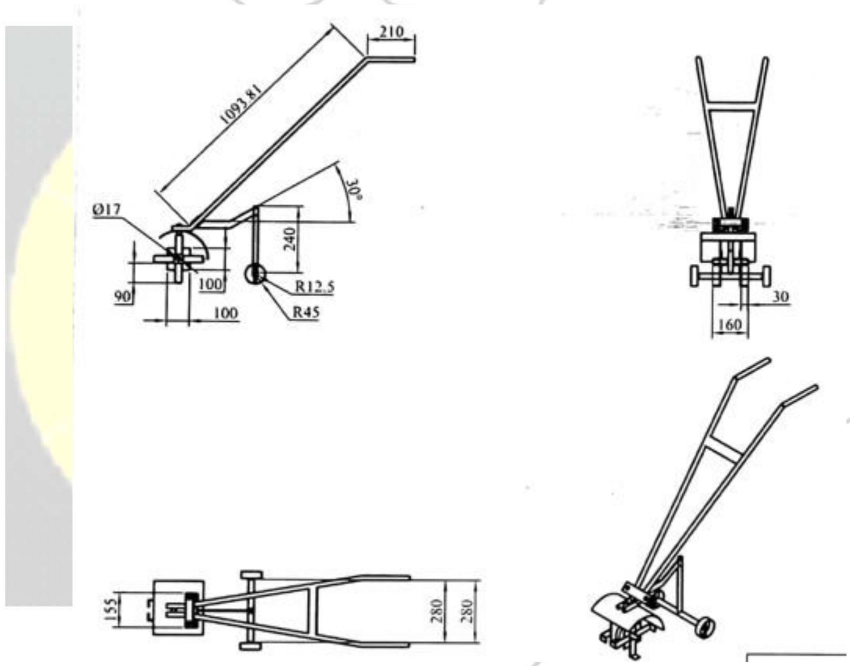

Figure 7. Design Drawing of the modified power tiller

2.5 Performance Evaluation

The performance of the modified power tiller was evaluated under the following indicators;

i. Weeding efficiency, W_e

ii. Field capacity, C_e

iii. Plant damage, P_d

2.5.1 Weeding Efficiency

Weeding efficiency is the ratio of number of weeds removed to the number of weeds counted before weeding in the quadrant. This was determined using equation 2.6 as given by Nkakini and Hussein, (2015).

$$W_e = \frac{(W_1 - W_2)}{W_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.6)$$

where, W_e = weeding efficiency (%)

W_1 = weed count before weeding in the quadrant

W_2 = weed count after weeding in the quadrant

2.5.2 Field capacity

This is the total area of the quadrant covered by the modified tiller during weeding operation in a specific time. Effective field capacity was calculated using equation by Shakya *et al*. (2016).

$$C_e = \frac{A}{T \times 10000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.7)$$

where, C_e = effective field capacity (ha/h)

A = area of the quadrant (m^2)

T = total time of weeding the quadrant (h)

2.5.3 Plant Damage

Plant damage is the measure of damage on crop during weeding operation. Plant damage was observed in terms of buried plants by soil mass as well as cutting of crop leaves by rotating action of weeding blades.

Number of plants in the quadrant before and after weeding was observed and the plant damage 'Q' was calculated by using the relation given by Nkakini and Hussein, (2015).

$$Q\ (\%) = \left[1 - \left(\frac{q}{p}\right)\right] \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.8)$$

where, Q = Plant damage (%)

p = Number of total plants in the quadrant before weeding

q = Number of plants in the quadrant after weeding

2.6 Experimental Setup

The performance indicators were determined by considering the independent variables; weeding depth (D) and weeding blade type (B). Three (3) levels of weeding depth (D1 = 1 cm, D2 = 2 cm and D3 = 3 cm) were selected. Likewise, four sets of weeding blades (B1 = 4 blades, B2 = 6 blades, B3 = 8 blades) along with the existing blade B4, were evaluated. The experiment was laid in a

Randomize Complete Block Design (RCBD) with three replications. The weeding operation was carried out on a maize field at two weeks after sowing (2WAS). Each combination of parameters was tested in a quadrant of 1 m by 0.75 m. Data obtained from the interaction of the independent variables were subjected to analysis of variance (ANOVA). Duncan Multiple Range Test (DMRT) was used to assess significant variables. Statistical Analysis System SAS Software was employed for the analysis.

3.0 RESULTS AND DISCUSSION

3.1 Effect of weeding blade and weeding depth on Weeding Efficiency

The result of analysis of variance (ANOVA) shows that the effect of blade types and weeding depth on weeding efficiency were highly significant at two weeks after sowing (2WAS). Further analysis using Duncan Multiple Range Test (DMRT) to assess the effect of blade types and weeding depth on weeding efficiency at 2WAS are presented in Table 2 and Table 3. The result shows that the mean weeding efficiency were statistically different. The mean weeding efficiency increased with increase in number of blades at 2WAS. Eight blades gangs recorded highest mean weeding efficiency of 85.4% while existing blade recorded least mean weeding efficiency of 54.7 %. The result agrees with Aditya (2016) with highest weeding efficiency of 88.62% for a six blades types as well as Jonathan (2011) and Shakya *et al*. (2016) with 88 % and 87.7 % weeding efficiency respectively.

Table 2. Effect of blade types on mean weeding efficiency, field capacity and plant damage

Treatment	Mean weeding efficiency (%)	Mean field capacity (ha/h)	Mean plant damage (%)
Blade type (B)			
4	73.8c	0.00456d	9.1b
6	81.5b	0.00542c	14.8ab
8	85.4a	0.00595b	19.5a
Existing	54.7d	0.00693a	13.5ab
SE±	1.035	0.000105	2.355

Table 3. Effect of weeding depth on mean weeding efficiency, field capacity and plant damage

Treatment	Mean weeding efficiency (%)	Mean field capacity (ha/hr)	Mean plant damage (%)
Weeding depth (D) cm			
1	70.1b	0.00567b	17.3a
2	75.1a	0.00551b	16.4a
3	76.3a	0.00598a	9.0b
SE±	0.896	0.0000913	2.039

3.2 Effect of weeding blade and weeding depth on Field capacity

The result of analysis of variance (ANOVA) shows that the effect of blade types and weeding depth on field capacity were highly significant at two weeks after sowing (2WAS). Further analysis using Duncan Multiple Range Test (DMRT) to assess the effect of blade types and weeding depth on field capacity at 2WAS are presented in Tables 2 and 3. The result shows that there is statistical difference among the mean field capacity recorded by the blade types. The mean field capacity increases with the increase in the number of blades. The existing blade recorded the highest mean field capacity of 0.00693 ha/h while the four blades type recorded least mean field capacity of 0.00456 ha/h. From Table 3, the result shows that the mean field capacity was statistically the same at 1 cm and 2 cm weeding depth. The highest mean field capacity of 0.00598 ha/h was recorded at 3 cm weeding depth.

3.3 Effect of weeding blade and weeding depth on Plant Damage

The result of analysis of variance (ANOVA) shows that the effect of blade types and weeding depth on plant damage were significant at two weeks after sowing (2WAS). Further analysis using DMRT to assess the effect of blade types and weeding depth on percentage plant damage at 2WAS are presented in Tables 2 and 3. The result shows that the mean percentage plant damage increased with increasing number of blade and decreased with the increase in weeding depth. This could be inferred that, the plant is prone to damage when weeding at shallow depth and more plant contact due to the increasing number of blades. The least mean percentage plant damage of 9.0 % was recorded across eight blade types.

4.0 CONCLUSION

The power tiller was modified with a set of weeding blades specifically four, six and eight gangs and depth gauge. It is concluded that weeding using six or eight blades type at either weeding depth of 2 cm or 3 cm, results in maximum weeding performance. With these combinations, the best machine performance was recommended based on mean weeding efficiency, field capacity and least percentage plant damage of 85.4%, 0.00595 ha/h and 9.0% respectively.

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