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Agriculture and Physical Sciences

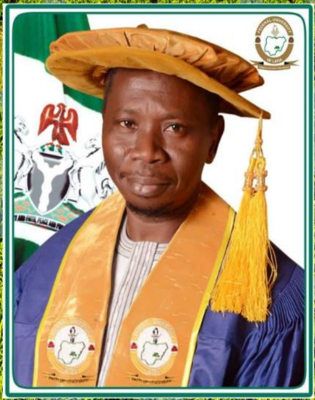
Breaking the Barrier of Food Security

in Honour of

Prof. Shehu Abdul Rahman

(FNAAE, FHORTSON, FASI, FASN)

Vice-Chancellor, Federal University of Lafia, Nasarawa State, Nigeria



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Agriculture and Physical Sciences: Breaking the Barrier of Food Security

LJSIR Book Series (Volume 2)

Editor-in-Chief: Prof. Matthew Olaleke Aremu

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Faculty of Science, Federal University of Lafia

AGRICULTURE AND PHYSICAL SCIENCES: BREAKING THE BARRIER OF FOOD SECURITY

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Preface

Africa is confronted with an unprecedented food crisis, according to a new report launched on December 7, 2023 at Johannesburg by the Food and Agriculture Organization of the United Nations (FAO), the African Union Commission (AUC), the UN Economic Commission for Africa (ECA), and the World Food Programme (WFP). Nearly 282 million people in Africa (about 20 % of the population) are undernourished, an increase of 57 million people since the COVID–19 pandemic began. Africa remains off–track to meet the food security and nutrition targets of the Sustainable Development Goals by 2030, and the Malabo targets of ending hunger and all forms of malnutrition by 2025. The deterioration of the food security situation and the lack of progress towards the WHO global nutrition targets make it imperative for countries to step up their efforts if they are to achieve a world without hunger and malnutrition by 20230.

The food security in Africa empowers individuals, communities and the continent as a whole by enhancing economic stability, promoting better health and nutrition, and fostering social and political stability. It improves living standards strengthens national economies, and contributes to overall progress and development. More importantly, food security is not just about having enough to eat; it's about building a foundation for sustainable development and prosperity.

The Lafia Journal of Scientific and Industrial Research (LJSIR) is a young and thriving journal published by the Faculty of Science, Federal University of Lafia (FULafia), Nasarawa State. The journal was established in 2023, in an effort of providing credible platforms for publications of research outputs by researchers across the globe. LJSIR also publishes Book Series which accommodate contribution chapters that allow more space for reflection on bigger ideas than journal articles. The LJSIR Book Series Volumes 1 and 2 are entitled, 'Agriculture and Life Sciences: The Power of Global Food Security', and 'Agriculture and Physical Sciences: Breaking the Barrier of Food Security', respectively.

Agriculture, Life Sciences and Physical Sciences empower food security by enhancing food production, improving access to nutritious food, improving food safety and reducing post–harvest losses, enhancing food distribution and accessibility, and promoting sustainable agricultural practices. This involves a multifaceted approach, including developing drought–resistant crop varieties, improving soil fertility, optimizing farming techniques, and utilizing biotechnology to improve yields and nutrition.

The two Volumes are dedicated volumes by honouring our amiable, indefatigable and digital Vice–Chancellor, **Prof. Shehu Abdul Rahman, FNAAE, FHORTSON, FASI, FASN**.

Prof. Shehu Abdul Rahman is a seasoned university administrator, the third and current Vice–Chancellor of Federal University of Lafia. Prof. Rahman was the pioneer and former Vice–Chancellor of Federal University, Ghasua, Yobe State, Nigeria. He was also a former Deputy Vice–Chancellor Administration, Nasarawa State University, Keffi, (NSUK) Nigeria. Prior to his appointment as DVC at NSUK, he was the Dean of Faculty of Agriculture, the position he held for two terms. During the period as a Dean, he served as the Chairman of Association of Deans of Agriculture in Nigerian Universities for two years. Shehu Abdul Rahman is a Professor of Agricultural Economics and he is widely published. Within the last four years as the Vice–Chancellor, he has transformed and taken FULafia to a greater height.

Prof. Matthew Olaleke Aremu
Editor–in–Chief, LJSIR

BRIEF PROFILE OF PROFESSOR SHEHU ABDUL RAHMAN

Shehu Abdul Rahman, the pioneer and former Vice-Chancellor of Federal University, Gashua (2013-2016), and former Deputy Vice-Chancellor (DVC) (Administration), Nasarawa State University, Keffi, is a professor of Agricultural Economics. Prior to his appointment as DVC he was the Dean, Faculty of Agriculture at Nasarawa State University, Keffi. He obtained a Bachelor of Agriculture degree in 1993, M.Sc. Agric. Economics in 1998 and a Ph.D. in Agric. Economics in 2001, all from Ahmadu Bello University, Zaria, Nigeria.

His working experience spans from Assistant Lecturer at Ahmadu Bello University, Zaria in 1994 to a full Professor at Nasarawa State University, Keffi in 2008 at the age of 40. He is now in Federal University of Lafia in Nasarawa State. He has served in various capacities rendering administrative and community development services in addition to teaching and research. His research activities produced over one hundred (100) publications in both National and International Journals of repute. He has presented over sixty five (65) papers at various seminars, workshops and conferences. He has served as a consultant to Gesellschaft fur Technsche Zusammenarbeit (GTZ)(German Technical Agency) and World Bank. He has taught in the fields of Agricultural production Economics, Farm Management Economics, Econometrics and Statistics at Ahmadu Bello University, Zaria; Nasarawa State University, Keffi and Federal University of Lafia; and has been an External Examiner of both undergraduate and postgraduate students at various Universities in Nigeria. He has served as External Assessor of twenty five (25) candidates for promotion to Professorial positions in various Nigerian Universities. He was the Chairman of Association of Deans of Agriculture in Nigerian Universities for two years (May, 2010- May, 2012). He has also served in the university system as Chairman of over twenty (20) Committees and Member of over thirty (30) Committees. In recognition of his involvement in many cultural and developmental activities in Opanda (Umaisha) Chiefdom he was turbaned as Shetima of Opanda on the 31 December, 2011. He is a Fellow of Nigerian Association of Agricultural Economists (FNAAE), Fellow of Horticultural Society of Nigeria (FHORTSON) and Fellow of African Scientific Institute (FASI), Honourary Fellowship Awards of the FNSPS and FASN.

He is presently the Vice-Chancellor of Federal University of Lafia in Nasarawa State.

Foreword

In the face of growing global challenges which range from climate change, increasing population and finite natural resources, to persistent food insecurity, the intersection of agriculture and the physical sciences presents one of the most promising frontiers in addressing the global challenge of food security.

This second volume of the *LJSIR Book Series*, titled *"Agriculture and Physical Sciences: Breaking the Barrier of Food Security,"* showcases a collection of scholarly works that reflect both the depth and diversity of thought emerging from Nigeria's academic and scientific communities These studies do more than explore theoretical possibilities; they offer practical, data-driven insights with the potential to inform policy, empower rural communities, and foster sustainable agricultural practices

The compendium opens with a compelling chapter on the impact of agricultural subsidies on peasant rice farmers in Nasarawa State, delivering vital statistical insights into how targeted government support can meaningfully enhance food production at the grassroots level. Through rigorous field data analysis, the authors present evidence that when subsidies are effectively allocated, can significantly boost yields, encourage farmer participation, and potentially transform local economies. This contribution is particularly relevant to policymakers and stakeholders involved in rural development and food systems planning.

Subsequent chapters reflect a commitment to exploring innovation in agricultural practice. The second chapter, titled "From Seeds to Sensors: The Unstoppable Rise of the Internet of Sensing (IoS) in Modern Agricultural Technology," introduces the frontier of smart agriculture. It highlights how sensor-based technologies and real-time data analytics can optimize crop health monitoring, irrigation management, and yield prediction, which reshape traditional farming methods into intelligent, efficient systems. The discussion is both visionary and grounded in real-world potential, reinforcing the urgency of digital transformation in agriculture. Environmental sustainability, a recurring theme in this volume, finds detailed treatment in the chapter that assesses the impact of different tree species on soil nutrient enhancement in Shabu-Lafia. The research demonstrates how tree plantations such as *Khaya senegalensis*, *Tectona grandis*, and *Gmelina arborea* influence soil chemistry and fertility, providing crucial recommendations for afforestation strategies and agroforestry practices. The implications for land restoration, sustainable agriculture, and biodiversity conservation are far-reaching.

Further chapters build upon these foundational themes, investigating the physicochemical properties of indigenous plant seed oils as contributors to both nutritional health and food security, and analyzing the application of

statistical and software-based in resource exploration, notably lithium, which is pivotal for emerging agricultural technologies and energy systems
What sets this volume apart is its multidisciplinary approach. Collectively, the research presented in this volume underscores the importance of interdisciplinary collaboration in solving real-world problems. By integrating methods and perspectives from physics, chemistry, geology, statistics, and engineering, the authors contribute significantly to the evolving discourse on sustainable agriculture and resource management. This approach is particularly aligned with the Sustainable Development Goals (SDGs), notably those targeting zero hunger, responsible consumption, climate action, and economic growth.
I am proud to introduce this volume to a global audience of scholars, professionals, and policy leaders. I commend the authors for their scholarly rigor, the editors for their dedication, and the Federal University of Lafia for its continued support of cutting-edge research. It is my hope that this volume will serve as a valuable resource for researchers, practitioners, and decision-makers who are committed to transforming agriculture into a more efficient, inclusive, and sustainable sector.

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BRIEF PROFILE OF PROFESSOR ALERUCHI CHUKU

Prof. Aleruchi Chuku is a professor of Medical Mycology with the Department of Microbiology at Federal University of Lafia (FULafia), Nasarawa State, Nigeria. She is currently the Deputy Vice Chancellor, Academic Affairs, FULafia. She was the former Director, Academic Planning of the University, Head, Curriculum Development Unit of the University, Pioneer and former Director for Student industrial work experience Scheme, a two times Head of Department at the Microbiology Department of Federal University of Lafia among other responsibilities. She obtained her B.Sc. microbiology from the University of Port Harcourt and her M.Phil and PhD from the Rivers State University, Rivers State. Professor Aleruchi Chuku worked with the National Veterinary Research Institute (NVRI) Vom, Plateau State as a Research Scientist with the Dermatophytosis Unit of the Institute and she is an Associate of the Medical Laboratory Scientist Council of Nigeria (AMLSCN) and holds an International, Computer Driving License (ICDL).

Agriculture and Physical Sciences: Breaking the Barrier of Food Security

EDITOR'S PROFILES

Prof. Matthew Olaleke Aremu currently works as Professor of Industrial Chemistry at Federal University of Lafia (FULafia), Nasarawa State, Nigeria. He is the current Dean of Faculty of Science and former Director of School of Basic and Remedial Studies at FULafia. He was a former Dean of Science and Deputy Vice–Chancellor, Academic Services at Federal University Wukari (FUWukari), Taraba State, Nigeria. He was once a Lecturer, Associate Professor, Ag. HOD Chemistry and Deputy Dean of Science at Nasarawa State University, Keffi (NSUK), Nigeria. He obtained his B.Sc, M.Sc and PhD Industrial Chemistry from three Nigerian Universities of Ilorin, Lagos and Ado–Ekiti, respectively. Prof. Aremu also obtained certificate in Development of University Based Entrepreneurship Centre at Kennesaw University, Atlanta, USA between August and September, 2015. He was elected and honoured with the Fellow of the prestigious Chemical Society of Nigeria (FCSN), Fellow of African Scientific Institute (FASI) and Fellow of Institute of Chartered Chemists of Nigeria (FICCON). He is a Certified Food Scientist of Nigeria (CFSN).

Prof. Bassi Ibrahim Garba is a seasoned academic in Mathematics and currently serves as the Editor-in-Chief of the *FULAFIA Journal of Science and Technology (FJST)* and Head of the Department of Mathematics at the Federal University of Lafia. He earned his BSc in Mathematics from Ahmadu Bello University, MSc from the University of Ibadan, and PhD in Mathematics from Abubakar Tafawa Balewa University, specializing in Functional Analysis with a focus on non-commutative stochastic integration on W*-algebra. He taught at the University of Maiduguri for 15 years, reaching the rank of Senior Lecturer before joining Federal University of Lafia in 2014. Promoted to Professor in 2019, he has supervised numerous postgraduate students and published extensively in local and international journals in Mathematics, Science, and Engineering.

Prof. Abdullahi Usman hails from Toto Local Government Area of Nasarawa State, Nigeria. He attended Central Primary Umaisha from 1978 to 1984. Government Secondary School Miango 1985 to 1990. School of Remedial Studies, University of Jos 1991 to 1992, and a Bachelor of Science Degree in Pure Chemistry from the same University in 1997. In 2005, he bagged a Master of Science Degree in Pure Chemistry from Usmanu Danfodiyo University, Sokoto, Nigeria. He capped his academic

career by obtaining a Doctor of Philosophy Degree in Chemistry from the University of Bangor, United Kingdom, in 2015.
He was employed as an Assistant Lecturer in 2007 at Nasarawa State University Keffi, where he taught and rose through the ranks to an Associate Professor. He later transferred his service to the Federal University of Lafia in 2021 and became a Professor of Organic Chemistry in 2024. He is currently the head of the Chemistry department and Director, Muhammadu Buhari Research Centre of Excellence.

Amos Idzi Ambo is a Professor of Industrial Chemistry with Federal University of Lafia. He has been a lecturer for over seventeen years at both monotechnic and University. He completed his Undergraduate degree in Chemistry at Nasarawa State University, Keffi and return to the same University for a Master's degree in Industrial Chemistry and later pursued a PhD in Industrial Chemistry at the University of Exeter, UK. His PhD thesis titled *''Chemical investigation of leaching and electrochemical behaviour of sensor-based preconcentrated copper ores with alkaline lixiviant''* was supervised by Professor Hylke J. Glass. His experience spans from administrative to academic. He was one time a student nominee to represent international students at a special session of the University Management at the prestigious University of Exeter, Cornwall campus, United Kingdom. His research focus is hydrometallurgy with special interest in the processing of Rare Earth and Precious metals for industrial applications. He also has interest in environmental geochemistry with interest in oil and gas, chemical pollution and chemical ecology, waste management and soil analysis, bioremediation of polluted soils and water analysis, solid waste management and production of reusable material from waste. He is a member of the Royal Society of Chemistry, United Kingdom, Chemical Society of Nigeria, Mineralogical Society of Great Britain and Ireland and a Member of the Institute of Chartered Chemist of Nigeria amongst others. He is widely travelled and has visited so many Countries including the United States of America and United Kingdom. He is passionate about impacting knowledge and research to young minds.

Prof. Oladiran Johnson Abimbola (LNSPS) obtained his BSc (Physics) degree at the prestigious Obafemi Awolowo University, Ile-Ife in the year 2000 and thereafter proceeded to serve the nation in the 2000/2001 NYSC program in Plateau State, he did his primary assignment at the Calvary Science College, Rock-Haven (a private secondary school) in Jos. After the NYSC program, he continued working at the secondary school and during the same period undergoing his Master's study in Physics at the University of Jos where he graduated in the year 2006 with an MSc degree in Applied Physics. In January 2007 and with a Ph.D. degree conferred on him by the University of Ilorin in the year 2018. he joined the service of Bauchi State

Government at the College of Education, Azare as a lecturer of Physics, he worked there for six and half years. He joined the Federal University of Lafia in the year 2014 as Lecturer II. He was the Acting HoD, Physics at the Faculty of Science, Federal University of Lafia between January 12, 2021 and January 12, 2024. He is a life member and president of the Nigerian Society of Physical Sciences (NSPS). He has published numerous scientific articles in the field of Atmospheric Physics.

Dr. Johnson Akinade Bamikole is an Associate Professor of Nuclear and Radiation Physics at the Federal University of Lafia, Lafia, Nasarawa State, Nigeria. He is currently the Head of the Department of Physics. He was formerly working at the Federal College of Forestry Mechanisation Afaka, Kaduna in Kaduna State where he served as the Head of the Department of Basic Science and General studies for eight years and was later appointed the deputy Provost of the College. He obtained his B.Sc. and M.Sc. in Physics from the University of Jos in Applied Physics with Electronics. He also obtained M.Sc. in Nuclear and Radiation Physics from the Nigerian Defence Academy and later PhD in Nuclear and Radiation Physics. He was elected and honoured with the Fellow of the Resources and Human Development in 2016. Member, Nigerian Institute of Physics, Member, The Nigerian Association of Mathematical Physics and Member, Research and Development Network.

Dr. Nuhu Degree Umar obtained BSc (Geology and Mining) in 2000 from the University of Jos, MSc (Environmental and Resource Management) in 2010 from the Benue State University, Makurdi Benue state. He also obtained an MSc and PhD (Hydrogeology) from the University of Nigeria, Nsukka in 2014 and 2019 respectively. He is a member of several professional bodies viz: International Association of Hydrogeologists (IAH); International Association for the Promotion of Geo-ethics (IAPG); Nigerian Association of Hydrogeologists (NAH); Nigerian Society of Physical Sciences (NSPS), and the Nigeria Mining and Geosciences Society (NMGS), among others. A World Bank-trained Environmental Safeguard Specialist with over 15 years in World Bank-assisted projects in the areas of Sustainable Water Supply, Watershed Management, Environmental Management, Project Management, Security Management, etc. With research interests in computational hydrogeology, modelling, geo-ethics, sustainable water resources management, flood risk assessment etc, he has published extensively in high-impact international journals. He is a COMEG registered Geoscientist.

Dr Ayeni Omini Abam is a Nigerian by birth and holds a Bachelor's Degree in Mathematics and Statistics (Second Class Upper Division in

1997); Postgraduate Diploma in Education (2004); Master of Science in Statistics/Operations Research (2014) all from the University of Calabar and a PhD in Applied Mathematics/Statistics (Operations Research) from the Nigerian Defence Academy, Kaduna, Nigeria. He is a Senior Lecturer/Head, Department of Statistics at Federal University of Lafia. He has been involved in teaching, researching and community services from 2012 till date. Member, Nigerian Statistical Association; North-Central Coordinator, Institute of Operations Research and Management Science (IORMS) and a Member of the Governing Council; Member, Mathematical Analysis and Optimization Research Group (MANORG); Member, Teachers' Registration Council of Nigeria (TRCN). Published over thirty-five articles in reputable journals. Won awards for Masters and PhD programmes; Awardee of the National Research Fund (NRF) grant cycle award for 2020. Reviewer of some scholarly journals and member, Special Marshal Unit 7, Lafia Command and Member, Red Cross Society, Lafia.

CONTENTS

CHAPTER ONE

Analyzing the Impact of Agricultural Subsidies on Peasant Rice Farmers' Productivity in Nasarawa State

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Abstract

This chapter assesses the impact of agricultural subsidies on peasant rice farmers' productivity in Nasarawa State. Primary data was gotten using in-depth field survey while secondary data between 2019 and 2023 was obtained from Green Power Agro Empowerment Cooperative Society Limited. 100 sample size and 120 questionnaires were administered at random to peasant farmers selected within Lafia, Awe, Doma, and Obi. The work used Python software for both quantitative and qualitative methods to analyze data on the increment in rice production resulting from the impact of agricultural subsidies. Two hypotheses were tested to ascertain the objectivity of the work. The findings revealed high-variance in 2019, 2020, and 2023, exhibiting significant yield variability, with values close to or exceeding 50% with fluctuations and consistency in production across locations over the years. Awe exhibited the highest average rice yield among the LGAs, with a mean of 18.697%, having the highest variability of 10.39%. The yields range widely from 0.16% to 33.1%. The inter-quartile range (IQR) of 15.45% to 24.7% suggests a high concentration of yields in Awe. Doma recorded a lower mean rice yield of

9.14%, with a standard deviation of 5.31%, indicating moderate variability. Lafia had a mean rice yield of 9.90%, similar to Obi, but with slightly lower variability, as reflected in a standard deviation of 5.64%. The yield ranged from 0.95% to 19.2%, with the 50% of values falling between 4.71% and 14.55%. This indicates moderate performance with some consistency in yield distribution. Obi’s average rice yield is comparable to Lafia’s at 9.89%, but showing higher variability, with a standard deviation of 6.22%. Yields range from as low as 0.07% to a maximum of 19.4%. The findings have evidently shown with clear results that agricultural subsidies have very significant impact on peasant farmers' productivities and to a very large extent the State's economy can fully rely on income generated from agricultural related activities. The work recommends that formulation of agricultural policies by government agencies and other stakeholders and making subsides available to empower peasant farmers as well as train them on modern farming techniques as well as introduce hybrid seeds to them with loans.

Keywords: Agricultural Subsidies, Food Security, Peasant Farmers

1. Introduction

Peasant Farmers are said to be the local agricultural products producers who annually produces in smaller scales for their primary consumption through the use of crude implements and hard labour. Food security according to Yusuf [12] has remained a key human right-related issue and ranks second only to poverty on the Sustainable Development Goals (SDGs). In 2009, the World Summit on Food Security supported by World Health Organization (WHO) and Food and Agricultural Organization (FAO) defined food security as a situation 'when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life' supporting Shaw [9]. Food security has been identified using indices like physical availability, economic and physical access and food utilization.

Agricultural Subsidies according to the Nigerian Government is categorized into three, namely: production subsidy; investment subsidy and an entry subsidy. Investment subsidy is a form of government support provided to farmers or individuals, businesses or companies to encourage investment like cash grants, tax incentives, low-interest loans, guarantees while entry subsidy is a type of government assistance to provide new entrants in a market or industry like financial subsidies, tax breaks, regulatory support, training and mentorship. For the purpose of this work, the production subsidy alone will be considered. The work of [12] revealed that "Food production subsidy is a broadly used tool to achieve food security in many developed countries, through the adoption of protectionist policies not only in the agro-industry, but also in others. Subsidy polices very often are used to overcome certain issues such as supporting uncompetitive industries or provide a buffer to an infant industry to influence market participants and therefore to adjust their market behaviour". Food insecurity and hunger are forerunners to nutritional, health, human and economic development problems [4]. The food security challenge has become more difficult, as the world ought to have produced about 70 percent more food by 2050 to feed an estimated 9 billion people [11]. FAO [2] believe that increment in farmers' productivity could be gotten by using the right knowledge in response to production challenges such as pests, diseases, and changes in weather patterns [2]. Farmers' performances and productivity hinges on the technical know how they have gotten in their fields of endeavors. Hence, empowering farmers is a key agent of change while fostering co-creation of knowledge, integrating traditional, practical, and local practices and skills required for sustainable production [3]. Agricultural services and training programmes have much positive effect on farmers including extension services by passing information from global, national, and local researchers to farmers. It aids the farmers in identifying their set objectives, actualizing their goals, assessing their opportunities, educating them about decision making processes, and promoting desirable agricultural development [5]. This extension services conducted by agriculturists help to improve farmers' performances, productivity and income, which in turn increases food security and also reduces poverty [7].

Rubenstein [8] examined the United States position as a global Agricultural, Research and Development vanguard using the Agriculture Improvement Act of 2018. The 2018 Farm Act was established as a pilot authority to develop technologies, research tools, and products through advanced research on long-term and high-risk challenges for food and agriculture. It was enacted and established the Agriculture Advanced Research and Development Authority (AGARDA) that focuses on Research and Development that private industries are unlikely to undertake. For other places like South Korea, it is one of the highest subsidies providing country, where government support accounts for 54.0% of farmers' income

[6]. Their local agriculture has been greatly dependent on government subsidy to compete with cheaper imported products and to shift to modern farming practices [12]. Smart subsidy is one of the newest forms of subsidy programmes designed to improve access and use of farm inputs, increase agricultural production and productivity, as well as improve the well-being of farmers [10]. Smart subsidies are based on the economic principles of efficiency, equity, and sustainability thereby providing specific beneficiaries over a given period with measurable impacts and achievable goals. The instruments used by Smart Subsidy include vouchers, targeting, rationing, loan guarantees, demonstration packs and matching grants [1]. From the back drop, this chapter seeks to consider how agricultural practices like provision of agricultural subsidies affect the production of rice by peasant farmers in Nasarawa State of Nigeria.

2. Research Methodology

In this work, an in-depth field survey was practically carried out (to obtain pure primary Data). A Survey of already existing secondary data obtained from Green Power Agro Empowerment Cooperative Society Limited, were used. Data was collected between the period of 2019 and 2023 with a sample size of 100 from the four Subsidy allocated predominant Rice producing Local Government Areas (LGAs) in Nasarawa State. The data was collected primarily through Simple Random Sampling of peasant farmers within the four LGAs of Lafia, Awe, Doma, and Obi in Nasarawa State where 120 Questionnaires were share amongst the farmers who benefitted from agricultural subsidy. The study used Python software for both quantitative and qualitative methods to analyze data on the increment in rice production resulting from the impact of agricultural subsidies on peasant farmers in Nasarawa State. Two hypotheses were tested to ascertain the objectivity of the work. These hypotheses are:

H_{01}: There is no significant difference between the mean annual increments in rice production in the 4 LGAs when subsidies are given and when not given.

H_{o2}: The increase in farmers' productivity is not dependent on the Subsidy allocation.

3. Data Presentation, Analysis and Discussion of Rice Yields from 2019-2023

Table 2 provides a detailed statistical summary of rice yield performance across four Local Government Areas (LGAs): Awe, Doma, Lafia, and Obi. Awe exhibits the highest average rice yield among the LGAs, with a mean of 18.697%. However, it also has the highest variability, as indicated by a standard deviation of 10.39%. The yields range widely from a minimum of 0.16% to a maximum of 33.1%. The inter-quartile range (IQR), spanning from 15.45% (25th percentile) to 24.7% (75th percentile), suggests a concentration of yield values in the higher range compared to other LGAs. Doma records a lower mean rice yield of 9.14%, with a standard deviation of 5.31%, indicating moderate variability. The yields range from a minimum of 0.87% to a maximum of 19.8%. The IQR (4.88% to 12.38%) reveals that most yields are below 12.38%, showing a tendency for lower yields compared to Awe. Lafia has a mean rice yield of 9.90%, similar to Obi, but with slightly lower variability, as reflected in a standard deviation of 5.64%. The yield ranges from 0.95% to 19.2%, with the central 50% of values (IQR) falling between 4.71% and 14.55%. This indicates moderate performance with some consistency in yield distribution. Obi's average rice yield is comparable to Lafia's at 9.89%, but it shows higher variability, with a standard deviation of 6.22%. Yields range from as low as 0.07% to a maximum of 19.4%. The IQR (6.24% to 13.6%) reflects a relatively even distribution of yields around the median value of 11.25%.

Table 1: Percentage Mean increment of Rice production in 4 LGAs (Awe, Doma, Lafia and Obi) between 2019 to 2023

S/No.	Location	2019	2020	2021	2022	2023
Lafia LGA						
1.	Asakio	15.0	17.3	14.4	7.40	19.2
2.	Ashangba	12.6	13.4	11.1	4.12	18.4
3.		8.17	10.1	9.32	3.07	15.3
4.	Mai-Akuya	4.33	4.83	2.16	0.95	6.9
Awe LGA						
1.	Awe Town	22.9	19.3	19.0	1.60	26.5
2.	Baure	31.5	22.5	23.2	2.11	33.1
3.	Tunga	24.1	19.6	17.4	1.07	28.4
4.	Ariba	16.3	32.0	12.9	0.16	20.3
Doma LGA						
1.	Aragye	15.8	18.0	13.8	7.19	19.8
2.	Yelwa	10.2	12.6	11.6	5.11	12.3
3.	Agbabo	7.27	10.0	8.97	2.92	10.8
4.	Iza	3.79	4.20	2.38	0.87	5.2
Obi LGA						
1.	Adudu	12.2	18.3	18.1	1.13	19.4
2.	Agaza	11.8	15.1	13.1	0.15	15.8
3.	Agwatashi	10.7	11.9	9.49	0.10	12.2
4.	Torka	8.31	7.14	3.54	0.07	9.3

Table 2: Descriptive Statistics of Rice Yields

Local Govt Area	**mean**	**Std**	**Min**	**25%**	**50%**	**75%**	**max**
Awe	18.70	10.391	0.16	15.45	19.95	24.7	33.1
Doma	9.14	5.310	0.87	4.88	9.49	12.4	19.8
Lafia	9.90	5.644	0.95	4.71	9.71	14.6	19.2
Obi	9.89	6.219	0.07	6.24	11.25	13.6	19.4

3.1. Data Visualizations of Rice Yield Trend across Local Government Areas

Figure 1 illustrates the rice yield trends for the LGAs (Lafia, Awe, Doma, and Obi) from 2019 to 2023. Awe emerges as the top performer, consistently achieving the highest rice yields throughout the period. Its performance peaks in 2020 and rebounds strongly in 2023 after a sharp decline in 2022, showcasing its dominance over the other LGAs. In contrast, Lafia, Obi, and Doma exhibit more moderate performance, with Lafia slightly outperforming Obi and Doma in most years, except in 2023, when Obi showed a stronger recovery. Doma consistently records the lowest yields among the LGAs. A significant drop in yields across all LGAs in 2022 suggests a widespread disruption, potentially caused by external challenges. However, 2023 marks a strong recovery for all LGAs, with Awe and Obi showing the most substantial rebounds, reaching or surpassing pre-2022 levels. While Lafia and Doma also recover, their gains are less pronounced.

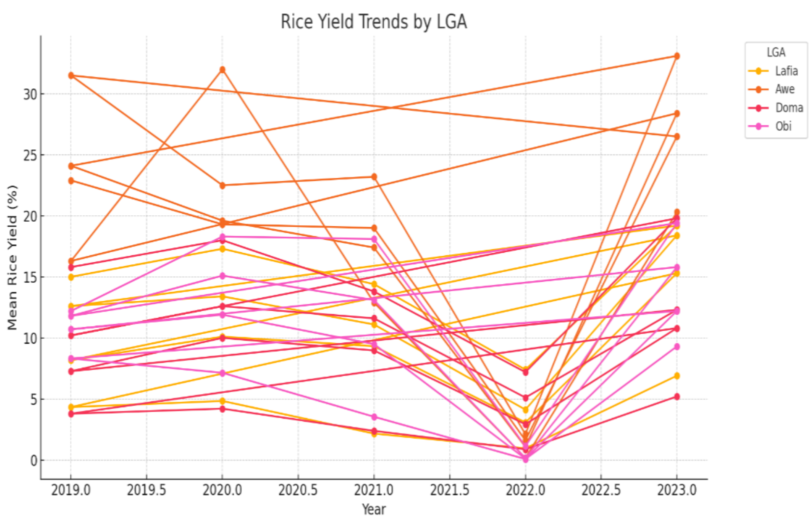

Figure 1: Line Chart of Average Rice Yields trends by Local Government Area

3.2. Tukey's HSD (Honestly Significant Difference) Test for LGA Groups

The Tukey HSD test reveals significant differences in rice yields between Awe and the other LGAs (Doma, Lafia, and Obi). Awe consistently shows significantly higher rice yields, with mean differences ranging from -8.8% to -9.5%. These differences are statistically significant, as indicated by p-values (0.0004, 0.0013) below 0.05 and confidence intervals that do not include zero. The reject column confirms that the null hypothesis (no difference in means) is rejected for these comparisons, highlighting Awe's superior performance. These results demonstrate Awe's consistent dominance in rice production relative to the other LGAs. In contrast, the differences in rice yields among Doma, Lafia, and Obi is not statistically significant. The mean differences between Doma and Lafia, Doma and Obi, and Lafia and Obi, are small (ranging from -0.01% to 0.76%) and have p-values close to 1, indicating no evidence of meaningful differences. The confidence intervals for these comparisons include zero, supporting the conclusion that the null hypothesis cannot be rejected. This indicates similar rice yield performance levels across these three LGAs, with none showing a distinct advantage over the others. Overall, while Awe stands out as the top-performing LGA, the remaining LGAs demonstrate comparable yield outcomes.

Table 3: Turkey HSD test for Local Government Area in Nasarawa state

group1	group2	Mean diff	p-adj	Lower	upper	reject
Awe	Doma	-9.557	0.0004	-15.528	-3.5857	TRUE
Awe	Lafia	-8.7945	0.0013	-14.766	-2.8232	TRUE
Awe	Obi	-8.8055	0.0013	-14.777	-2.8342	TRUE
Doma	Lafia	0.7625	0.9869	-5.2088	6.7338	FALSE
Doma	Obi	0.7515	0.9874	-5.2198	6.7228	FALSE
Lafia	Obi	-0.011	1	-5.9823	5.9603	FALSE

Figure 2 highlights that Awe consistently outperforms the other LGAs regarding rice yield, with statistically significant differences. Meanwhile, the remaining LGAs (Doma, Lafia, and Obi) have yield performances that are more similar, with no significant differences detected between them.

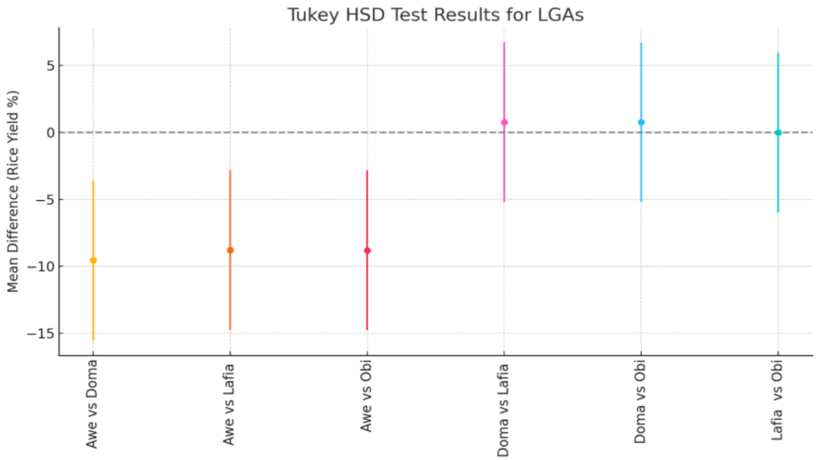

Figure 2: plot of Turkey HSD test results for LGA

The plot compares the rice yield performance of the top-performing LGAs (Awe, Lafia, and Obi) over a five-year period. Awe consistently outperforms the other LGAs, contributing the largest share to the total yield, particularly in 2019, 2020, and 2023. Its dominance is reflected in its substantial contributions, especially during years of higher total production. Obi and Lafia, while producing lower yields compared to Awe, also play significant roles, particularly in years like 2019 and 2020. Obi demonstrates steady performance, with an increase in its yield contribution in 2023, whereas Lafia shows variability, contributing more prominently in 2019 and 2022 but less in other years. A notable trend in the plot is the significant dip in rice yields for all three

LGAs in 2022, suggesting the impact of external challenges such as adverse weather, policy changes, or other disruptions. However, 2023 marks a strong recovery, with Awe and Obi reaching or exceeding their earlier yield levels, while Lafia shows a smaller rebound. The visualization underscores Awe's consistent dominance in rice production, the steady contributions of Obi, and the more fluctuating performance of Lafia. These insights highlight both the resilience and variability of rice production in the top-performing LGAs over time.

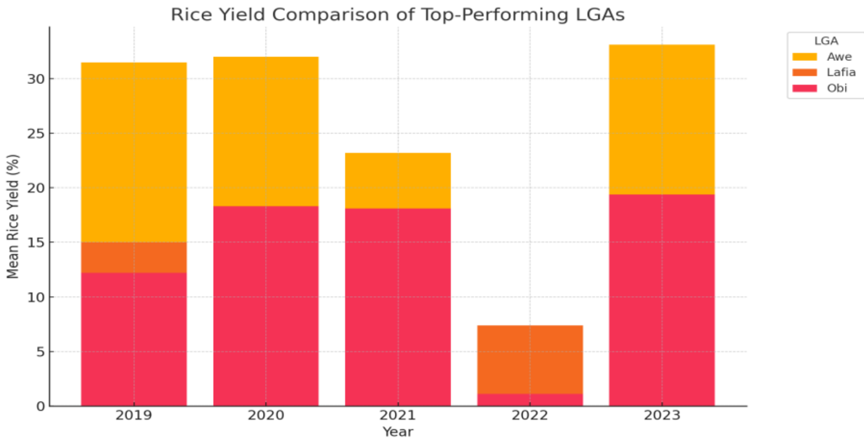

Figure 3: Rice Yield Comparison of Top Performing LGA across the years

3.3. Variance Analysis

Variance measures the degree of fluctuation or inconsistency in rice yields within each LGA and location over the analyzed period.

Figure 4 compares the variance in rice yields across four Local Government Areas (LGAs): Awe, Obi, Lafia, and Doma. Awe exhibits the highest variance, indicating significant fluctuations in its rice yield over time. While Awe is known for its high average yields, this elevated variance suggests periods of both exceptional performance and occasional declines, making its production less predictable compared to the other LGAs. In contrast, Obi, Lafia, and Doma show much lower variance, with relatively stable rice yields across 2019-2023. This consistency, while reflective of lower average yields than Awe, indicates more predictable performance and less sensitivity to external factors. Overall, the Bar chart underscores Awe's potential for high yield variability, which may result from changing environmental conditions, agricultural practices, or other influences, while highlighting the steadier but lower performance of the other LGAs.

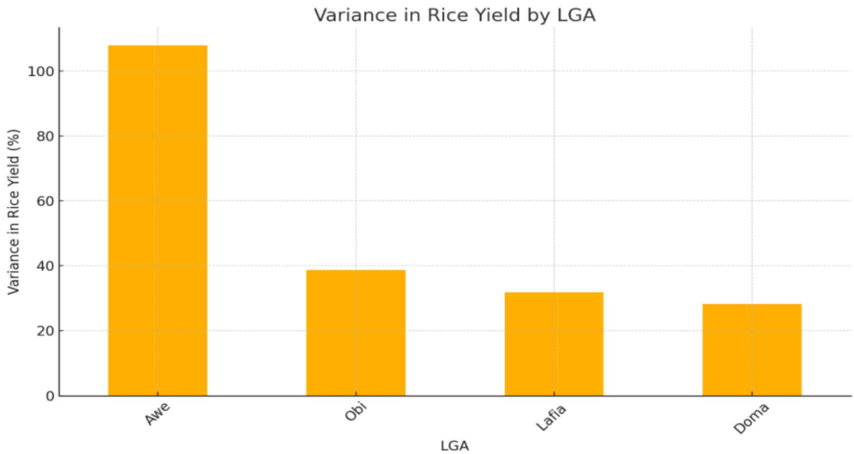

Figure 4: Variance in Rice yields by LGA from 2019-2023

Figure 5 displays the variance in rice yields across various locations, reflecting the degree of fluctuation in production over time. Locations such as Baure, Ariba, and Tunga exhibit the highest variance, suggesting that rice yields in these areas are highly inconsistent. Such variability could stem from external factors like changing weather patterns, pest infestations, or fluctuating agricultural inputs. Similarly, Awe Town also shows notable variability, though slightly less than the top three, indicating that while it performs well in some years, its output is not consistently stable. In contrast, locations like Mai-Akuya, Iza, and Yelwa exhibit the lowest variance, demonstrating more stable and consistent rice yields over the analyzed period. These locations likely benefit from steady environmental conditions, effective agricultural practices, or less exposure to disruptive factors. Their low variance indicates predictability in rice production, which is crucial for planning and resource allocation. Moderate variance is observed in locations such as Adudu, Agaza, and Ashangba, which fall between the extremes. While these areas experience some fluctuations, they are less pronounced than in high-variance locations like Baure. This variability in yield patterns across locations underscores the importance of targeted interventions. High-variance areas could benefit from measures to mitigate external shocks and improve consistency, while low-variance areas can focus on sustaining their stable performance.

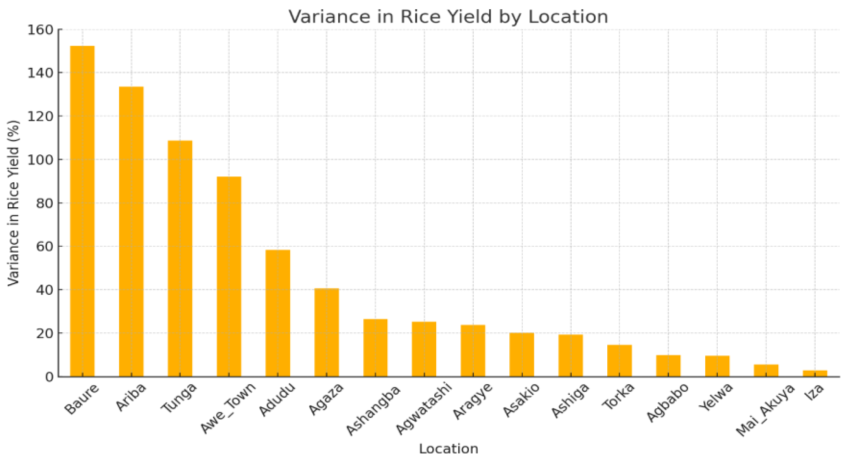

Figure 5: Variance in Rice yields by location from 2019-2023

Figure 6 showcases the variance in rice yields from 2019 to 2023, highlighting the fluctuations and consistency in production across locations over the years. High-variance years, such as 2019, 2020, and 2023, exhibit significant yield variability, with values close to or exceeding 50%. This indicates uneven performance likely caused by external factors, such as varying weather conditions, resource availability, or localized agricultural practices, which differentially impacted the LGAs. However, 2022 shows a sharp drop in variance, reflecting minimal fluctuations in rice yields across locations. However, this low variance likely corresponds to uniformly poor performance rather than stability. The year 2022 was characterized by a significant overall decline in rice production, possibly due to widespread adverse factors like unfavorable weather or economic pressures affecting all regions equally. This uniformity highlights the shared challenges faced by all locations during that year. The year 2021 represents a middle ground, with moderate variance levels indicating some degree of fluctuation while maintaining relatively balanced performance compared to the more extreme variability observed in 2019, 2020, and 2023. This suggests that while some locations experienced better or worse yields, the overall spread of rice production was less dramatic. These trends emphasize the role of external factors in shaping rice yield consistency and underscore the need for targeted interventions, especially in high-variance years, to reduce instability and promote steady agricultural performance.

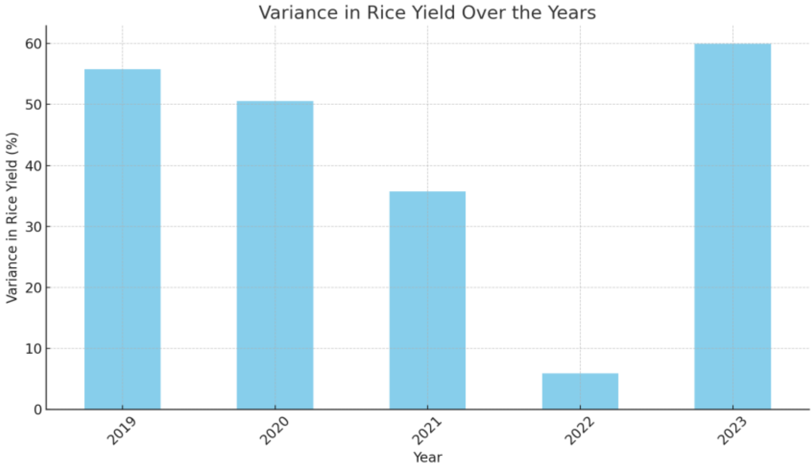

Figure 6: Variance in Rice Yield over the years

The box plot illustrates the year-on-year rice yield distribution across four LGAs: Awe, Lafia, Obi, and Doma, from 2019 to 2023. Awe consistently stands out as the top-performing LGA, with the highest median yields and greater variability in most years, particularly in 2019 and 2021. However, this high variability indicates fluctuations in its performance, likely due to external or environmental factors. Like all other LGAs, Awe experiences a significant decline in 2022 but rebounds strongly in 2023, reaffirming its position as the leading LGA in rice production. Lafia and Obi exhibit mid-range and relatively stable performance in most years, with narrower inter-quartile ranges indicating less variability compared to Awe. Lafia generally maintains steady yields, though it shows increasing variability in 2023, reflecting a more uneven recovery. Obi also displays stable performance in earlier years but demonstrates both higher yields and increased variability in 2023. In contrast, Doma consistently underperforms relative to the other LGAs, with lower median yields and narrower distributions. Despite its recovery in 2023, Doma's yields remain the lowest among the LGAs. A notable feature of the plot is the uniform drop in yields across all LGAs in 2022, accompanied by very narrow distributions, suggesting a widespread disruption that affected all regions similarly. This disruption is likely attributable to external factors such as adverse weather or economic conditions. The recovery observed in 2023 is uneven, with Awe and Obi showing the strongest rebounds, while Lafia and Doma recover at a slower pace.

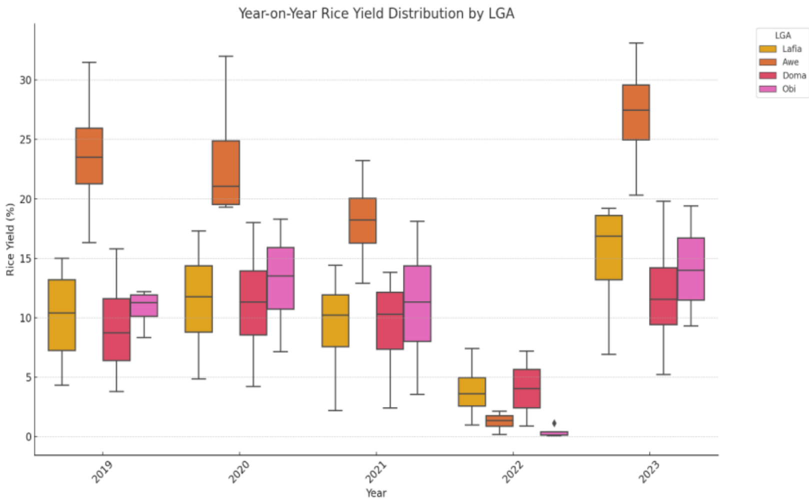

Figure 7: Box plot of year-on-year variance by LGA

4. Summary and Conclusion

This work reveals that introduction of agricultural subsidies and policies by the Government motivates peasant farmers to engage more in agricultural production that later boosts the quantity of food security, creating job opportunities, increasing the peasants per capital income and standard of living as well as growing the State's economy. In conclusion, the findings have evidently shown with clear results that agricultural subsidies have very significant impact on peasant farmers' productivities and to a very large extent the State's economy can fully rely on income generated from agricultural related activities.

5. Recommendations

The following were some recommendations made in line with the findings:

i. Formulation of agricultural policies by government agencies and other stakeholders that will make subsides available to empower peasant farmers and also train them on modern farming techniques as well as introduce hybrid seeds to them with loans.

ii. Infrastructural facilities should be created by the government of the day such as good markets, modern storage facilities; good road network, irrigation system, good health facilities and modern agricultural machineries which will help the large farmers get involved in contributing to the building of the nation's economy.

iii. Security of lives and properties should be upheld through formulation of proper conflict resolution policies and strategies that will enable the peasant farmers engage fully in the normal agricultural related activities.

iv. Government should also build industries and factories that will cover some raw agricultural products to finished goods that could be exported to countries were demanded as means of generating revenue.

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CHAPTER TWO

From Seeds to Sensors: The Unstoppable Rise of Internet of Sensing (IoS) in Modern Agricultural Technology

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Abstract

The integration of the Internet of Sensing (IoS) technology is revolutionizing modern agriculture, offering innovative solutions to address global challenges such as food security, resource scarcity, and environmental sustainability. IoS connects sensors, networks, and data analytics to create intelligent agricultural systems capable of optimizing productivity and efficiency. This chapter explores the applications, benefits, and challenges of IoS in agriculture, emphasizing its transformative potential. IoS technology facilitates precision farming by enabling real-time monitoring of crop health, soil conditions, and weather patterns. It supports advanced systems such as smart irrigation, autonomous machinery, and livestock monitoring, resulting in improved crop yields, resource conservation, and enhanced animal welfare. The technology also contributes to environmental sustainability by reducing water and chemical use and promoting energy-efficient practices. Despite its potential, IoS adoption faces challenges including infrastructure gaps, data management concerns, high implementation costs, and resistance to technological change. Overcoming these barriers requires investment in rural connectivity, the development of secure, user-friendly platforms, and collaborative efforts among stakeholders. Looking ahead, advancements in artificial intelligence, machine learning, block chain, and robotics will further enhance IoS applications, paving the way for innovations like autonomous farming, vertical agriculture, and transparent supply chains. These technologies promise to shape a sustainable and efficient agricultural future. This chapter concludes by highlighting IoS's critical role in meeting the global demand for increased food production while promoting environmental stewardship. By leveraging IoS, the agricultural sector can achieve a smarter, more sustainable, and productive future, essential for ensuring food security for a growing global population.

Keywords: Seeds to Sensors, Internet of Sensing, Agricultural Technology, artificial intelligence

1. Introduction

The world's population is projected to reach 9.7 billion by 2050, putting immense pressure on the agricultural sector to produce more food with limited resources. Climate change, soil degradation, and water scarcity further exacerbate the challenge. To meet this demand, farmers, researchers, and policymakers are turning to technology for innovative solutions. One such game-changer is the Internet of Sensing (IoS) technology, which is revolutionizing modern agricultural practices.

For centuries, farming has relied on traditional methods, often resulting in inefficiencies and wasted resources. However, the integration of IoS technology is transforming the agricultural landscape. By harnessing the power of sensors, networks, and data analytics, farmers can now optimize crop yields, reduce waste, and improve resource allocation. This fusion of agriculture and technology has given birth to a new era of precision farming, where data-driven decision-making is the norm [1, 2, 3, 4].

In this chapter, we will explore the unstoppable rise of IoS in modern agricultural technology, delving into its applications, benefits, challenges, and future directions. We will examine how IoS is empowering farmers to cultivate a more efficient, productive, and sustainable food future.

2. The Concept of Internet of Sensing (IoS)

According to Cömert & Akkaş [5], IoS is a system of interconnected physical sensors and devices designed to collect, transmit, and analyze data, enabling intelligent decision-making. Within agriculture, it involves the deployment of sensors, actuators, and data analytics to monitor crop health, soil conditions, weather patterns, and livestock behavior.

2.1. Key Components:

- **Sensors:** Measure environmental parameters such as soil moisture and temperature.
- **Networks:** Facilitate data communication via wireless, cellular, or satellite systems.
- **Data Analytics:** Process collected data into actionable insights.
- **Cloud Computing:** Provide scalable storage and management for agricultural data.

2.2. Applications Beyond Agriculture:

IoS extends to areas like smart cities, healthcare, and industrial automation, showcasing its adaptability and transformative potential.

3. Applications of IoS in Agriculture

Morchid *et al.* [6] reported that IoS has revolutionized agricultural practices through its diverse applications, which include:

3.1. Precision Farming:

- Monitoring soil moisture to optimize irrigation.
- Controlling temperature for crop health.
- Detecting pests, diseases, and nutrient deficiencies in real-time.
- Forecasting yields with high accuracy.

3.2. Livestock Monitoring:

- Tracking vital signs to ensure animal health.
- Analyzing behavioral patterns to optimize welfare.
- Automating feeding systems for improved nutrition.
- Using GPS technology to monitor grazing and prevent theft.

3.3. Smart Irrigation Systems:

- Adjusting schedules based on weather forecasts.
- Employing soil moisture sensors for precise water application.
- Reducing waste through automated controllers.

3.4. Crop Monitoring and Yield Prediction:

- Utilizing satellite imaging for large-scale monitoring.
- Deploying drones for localized assessments.
- Applying machine learning to predict outcomes and identify risks.

3.5. Farm Automation:

- Introducing autonomous machinery for planting and harvesting.
- Implementing robotics for tasks like weeding and pruning.

4. Benefits of IoS in Agriculture

IoS enhances productivity, sustainability, and profitability in agriculture [7]:

4.1. Increased Yields and Quality:

- Precision farming optimizes growth conditions.
- Real-time monitoring prevents crop stress.
- Data analytics supports strategic planning.

4.2. Resource Conservation:

- Smart irrigation reduces water usage.
- Targeted fertilizer application minimizes waste.
- Energy-efficient systems lower operational costs.

4.3. Improved Livestock Welfare:

- Health monitoring reduces diseases.
- Optimized living conditions enhance productivity.

4.4. Economic and Environmental Gains:

1. Higher yields boost revenues.
2. Reduced chemical use limits pollution.
3. Sustainable practices conserve biodiversity.

5. CHALLENGES AND LIMITATIONS

While promising, IoS adoption is not without hurdles [8]:

5.1. Connectivity and Infrastructure:

Rural areas often lack the connectivity needed for seamless data transmission and sensor operation.

5.2. Data Management and Security:

Data privacy, cybersecurity threats, and analytics complexity hinder widespread adoption.

5.3. Cost and Accessibility:

High initial costs make IoS systems less accessible for small-scale farmers.

5.4. Integration with Existing Practices:

Resistance to change, incompatibility with traditional methods, and training requirements remain obstacles.

5.5. Regulation and Standardization:

The absence of universal standards and unclear regulatory frameworks further complicate deployment.

6. Future Directions

Emerging technologies and trends are set to enhance IoS's impact on agriculture:

6.1. Artificial Intelligence (AI) and Machine Learning (ML):

AI-powered analytics will refine yield predictions and automate farming decisions.

6.2. IoT and Connectivity:

Improved integration of IoT devices will create more efficient farming systems.

6.3. Drone and Satellite Technologies:

These tools will offer unparalleled precision in crop monitoring and input application.

6.4. Blockchain:

Blockchain ensures secure, transparent supply chain management and data integrity.

6.5. Robotics and Automation:

Advancements in robotics will make autonomous farming a standard practice.

6.6. Urban Agriculture:

Vertical and indoor farming will address urban food needs sustainably.

7. Conclusion

The Internet of Sensing (IoS) has transformed agriculture from a resource-intensive sector into a precision-driven industry. By leveraging data and connectivity, IoS empowers farmers to enhance productivity, optimize resources, and adopt sustainable practices.

Despite current challenges, the future of IoS in agriculture is promising. With continued innovation, collaboration, and investment, IoS can help achieve global food security, foster environmental stewardship, and create a smarter agricultural landscape for generations to come.

This chapter calls for stakeholders across the agricultural value chain to embrace IoS as a critical tool in building a resilient and sustainable future.

8. Recommendations and Contributions to Knowledge

The integration of the Internet of Sensing (IoS) in modern agricultural technology represents a transformative shift toward precision farming, sustainability, and enhanced productivity. Based on the insights presented in this chapter, the following recommendations and contributions to knowledge are proposed to further advance the adoption and impact of IoS in agriculture:

1. **Investment in Rural Connectivity**:
   To fully realize the potential of IoS, governments and private stakeholders must prioritize the development of robust rural connectivity infrastructure. Expanding access to high-speed internet and reliable cellular networks in remote agricultural areas will enable seamless data transmission and real-time monitoring, ensuring that even small-scale farmers can benefit from IoS technologies.
2. **Development of User-Friendly Platforms**:
   IoS systems should be designed with user-friendly interfaces to encourage adoption among farmers with varying levels of technical expertise. Simplified platforms that integrate data analytics, visualization tools, and actionable insights will empower farmers to make informed decisions without requiring extensive training.
3. **Affordable and Scalable Solutions**:
   To address the high initial costs of IoS implementation, stakeholders should focus on developing affordable and scalable solutions tailored to the needs of smallholder farmers. Subsidies, grants, and public-private partnerships can help reduce financial barriers and promote widespread adoption.

4. **Data Security and Privacy Frameworks**:
   As IoS relies heavily on data collection and transmission, robust data security and privacy frameworks must be established. Governments and industry leaders should collaborate to create standardized regulations that protect farmers' data while ensuring transparency and trust in IoS systems.
5. **Capacity Building and Training**:
   Training programs and workshops should be organized to educate farmers and agricultural stakeholders on the benefits and operation of IoS technologies. By building capacity at the grassroots level, the agricultural sector can foster a culture of innovation and technological adoption.
6. **Integration of Emerging Technologies**:
   The future of IoS in agriculture lies in the integration of emerging technologies such as artificial intelligence (AI), machine learning (ML), blockchain, and robotics. These technologies can enhance predictive analytics, automate farming processes, and ensure transparent supply chains, further optimizing agricultural productivity and sustainability.
7. **Promotion of Sustainable Practices**:
   IoS should be leveraged to promote environmentally sustainable farming practices. By optimizing resource use, reducing chemical inputs, and minimizing waste, IoS can contribute to the conservation of biodiversity and the mitigation of climate change impacts.
8. **Collaborative Research and Development**:
   Collaborative efforts among researchers, policymakers, and industry players are essential to drive innovation in IoS applications. Funding for research and development should be prioritized to explore new use cases, improve existing technologies, and address the unique challenges faced by different agricultural regions.

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CHAPTER THREE

Assessment of the potentials of three tree species on soil nutrients in Shabu-Lafia, Nasarawa State, Nigeria

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Abstract

Tree plantation conserves the soil and increases its productivity. This study examined the effects of *K. senegalensis*, *G. arborea* and *T. grandis* plantation on soil nutrients in Shabu-Lafia, northern Nigeria. Twenty-five soil samples were randomly collected from each tree plantation from 0-15 cm depth. These 25 samples were mixed up to form five composite samples per plantation. Laboratory analysis was carried out on the soil samples to assess the effect of the three tree species on soil chemical properties including soil nutrients. The soil data were subjected to analysis of variance and correlation analysis. There were differences ($p < 0.05$) in the concentrations of soil pH, K, Na, Ca, total exchangeable base (TEB), effective cation exchange capacity (ECEC), base saturation (BS) and Pb content between *K. Senegalensis*, *T. grandis* and *G. arborea* in the study locations. It was evident that *K. senegalensis* enhanced the supply of soil nutrients. Significant ($p < 0.05$) positive correlations were found between soil pH and each of N, Available Phosphorus, K, Na, Mg, Ca, TEB, CEC and BS. Electrical conductivity showed significant ($p < 0.05$) negative correlation with N and Na. So, both positive and negative correlations were observed among the examined soil properties. The three tree species affected soil chemical properties differently. The study recommended that *K. senegalensis* should be adopted among the three tree species for agroforestry practice, afforestation and restoration programmes. To enhance soil conservation, maintain soil fertility and increase soil productivity, there is need for an awareness to integrate the planting of *K. senegalensis* trees in farmlands.

Keywords: soil nutrients, afforestation and restoration, soil fertility, *K. senegalensis*

1. Introduction

Deficiency in soil nutrient is the most central causes of low agricultural productivity, sustainability as well as profitability to peasant farmers in Nigeria. It is clear that maintaining soil quality is of paramount importance to ensuring sustainable land utilizations. Management of land as an elementary natural resource must focus on soil sustentation [1]. Decrease in soil productivity as a result of continuous farming and erosion is defined by increased bulk density, reduction in organic matter and availability of soil nutrients [2]. Variations in soil organic matter under plantations of different tree species can reflect in soil structure stability [3], which is a key index of soil productivity. With adequate soil humus, tropical humid forest can thrive on very poor soils. The presence of foliar humus in the soil creates soil voids which are conduits by which needed soil air reaches the roots of plants and also enhance the penetration of water in soils thereby stimulating plant growth [4]. Soil humus content affects soil properties and plants in several positive ways. Light-weighted spongy-textured humus increases soil water retention capacity and slows down runoff [5]. Humus provides habitats for many soil organisms that mix and concentrate nutrients in the soil; and most plants do well in humus-rich soils. The nutrients input of humus from decomposed leaves to soil fertility per unit area is much richer, cheaper and more readily available than plant nutrient from inorganic fertilizer [6].

The influence of tree canopies on soil resources can be of significant importance in forest ecosystem dynamics. Effects of different tree species plantations on soil nutrients are quite different on a global scale; for example, broad-leaved tree species promote soil available phosphorus (7-18%), while coniferous tree species cause uncertain changes in soil available phosphorus (–3%-16%) [7]. The impact of these different tree species on soil nutrients may be regulated by leave litter quantity and quality because litter plays an important role in soil nutrient cycling [8][9]. Large numbers of litter addition experiments have proved that the presence of leave litter has a positive impact on soil nutrients [10], and litter mixing experiments of different species showed that the chemical properties of leave litter were closely related to soil nutrients [11]. Therefore, the litter is the key to the nutrient cycling in the forest ecosystems [12]. The nitrogen and nitrogen-phosphorus ratio in litter affect soil nutrient properties by controlling litter decomposition rate [9]. The quality of litter of different species influences availability of soil phosphorus, with phosphorus-rich leaf litter releasing more phosphorus to increase its availability [10]. A close interaction exists between trees and soil. [13] Studied the competition between two heathland plant species, the dwarf shrub *Erica tetralix* L. and the perennial grass *Molinia caerulea* (L.). While the slow growing *Erica* was much more competitive at low N levels, the fast-growing *Molinia* dominated at high N levels. They concluded that these species could remain dominant, each at their own N level, because of positive feedbacks on soil N availability. *Erica* produced litter with low decomposability and therefore N availability in the soil remained low while *Molinia* produced litter of high quality keeping high levels of N in the soil.

Despite the increase in global land area used for forest plantations and their importance to human wellbeing, the implications of forest plantations on soil physicochemical properties remain an interesting topic in environmental studies. Some tree species are assumed to cause soil acidification, and consume high water quantity and soil nutrients, particularly in mono dominant stands [14][15][16] some others are known to improve soil fertility and hence agricultural productivity [17]. However, not much is known about the impact of *Khaya senegalensis*, *Tectona grandis*, and *Gmelina arborea* on soil nutrients. Thus, in the process of ecological restoration of plantations, it is important to clarify the effects of litter from different tree species on soil nutrients for the selection of afforestation tree species and the management of plantations for enhanced agricultural production and conservation of soil resources and biodiversity.

This study focused on chemical properties of soil, mainly the macro- and micronutrients, with respect to different tree species that mostly dominated as plantation in Nasarawa State of Nigeria. The trees are *K. senegalensis*, *T. grandis*, and *G. arborea*. The objectives of this study are: (i) to identify the variation of different soil chemical properties such as soil pH total N, available phosphorus, exchangeable bases, organic carbon, effective cations exchange capacity (ECEC) and exchangeable acidity as well as iron, zinc, copper, manganese and cadmium contents due to these tree species; and (ii) to determine the relationships between these assessed parameters.

2. Materials and Methods

2.1. Study location

The study was carried out at the Teak, Gmelina and Mahogany plantation sites belonging to the Department of Forestry & Wildlife Management, Faculty of Agriculture, Shabu-Lafia campus, Nasarawa State University, Keffi. Lafia is situated at 08°35' N and 08° 33' E in the Guinea savannah zone in the northern Nigeria at an altitude of about 177m above the sea level. The mean monthly maximum and minimum temperatures range from 35.06° C to 36.40°C and from 20.16°C to 20.50°C, respectively, while relative humidity and rainfall are 74.67% and 168.90 mm, respectively [18].

2.2. Sampling Procedure

Three lines parallel transects of 100 *m* running in a West to East direction in all the three plantations were established. At an interval of 25 *m*, a plot of size 4 *m* × 4 *m* was established along the line transect. In each line transect a total of five plots were established making a total of fifteen plots per plantation as adopted by [19]. Five plots were randomly selected per plantation making a total of 15 soil samples for the study.

2.3. Soil Sample Collection

Topsoil samples were collected at 0-15 cm depth with the use of soil auger as in [19]. Four of the five soils samples were collected at the vertex while one at the center; the collected soil samples was bulked to form one composite sample per plot and this was repeated throughout the plantation sample plots. The soil samples were stored in air-tight container for onward transportation to the laboratory for soil nutrients analysis.

2.4. Analysis of soil nutrients

Soil Ph was determined in 1:1 soil-H_2O suspension using Beckman zero metric Ph meter. Total n was determined by regular macro-Kjeldahl method and then titrated with acid. Available phosphorus was determined by the conventional method [20]. Exchangeable Ca and Mg were determined by the ethylenediaminetetraacetic acid (EDTA) titration method while K and Na were determined by flame photometry, organic carbon was determined by the potassium dichromate wet oxidation method [21]. Exchangeable acidity was determined by titration method. The micro elements – boron (B), iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) were determined using an atomic absorption spectrophotometer (model UNICAM 939).

2.5. Data analysis

Data were subjected to analysis of variance (ANOVA). Means were separated using the least significant difference at $p \leq 0.05$ ($LSD_{0.05}$). Correlation analysis was done to examine the relationships among the parameters.

3. Results and Discussion

The mean values of the assessed soil properties under the three tree species are presented in Table 1, while the result of the ANOVA performed on the data is presented in Table 2.

Soil Ph was higher under *K. Senegalensis* compared to *G. Arborea* and *T. Grandis*. Soil Ph is a key factor that controls soil nutrient availability and soil microbial activities. Consequently, the significant variation observed in this research could be attributed to variation in microclimate due to dense canopy, mineral content as well as the soil texture under *K. Senegalensis*. Soil Ph equal to 5.5 or lower tends to be acidic and can inhibit the growth of sensitive plant species, although it has a little effect on sensitive species even when as low as 4.0 [22]. With a soil Ph under *K. Senegalensis* of 7.04 (neutral), this tree species could be viewed as having the ability to cause a situation of desired acid-base balance in the soil. The implication of the increases in soil Ph observed under *K. Senegalensis* is that this tree species may not be able to support a wide distribution of epiphytes which prefer low soil Ph to thrive on forest trees [23].

Soil content of organic carbon was highest under *K. Senegalensis* and lowest under *T. Grandis*, though the differences under the three tree species were not significant. [24] reported similar observation under different tree species. The present variation was believed to be mainly due to decomposition of leaves [25, 26]. This variation could also be attributed to the ability of tree species to reabsorb the nutrients during senescence [27]. Soil organic matter is critical in maintaining long-term soil fertility since it is the reservoir of metabolic energy, which drives soil biological processes involved in nutrient cycling and availability [28].

Soil samples from *K. Senegalensis* showed the highest mean total n and available phosphorus and those from *G. Arborea* the lowest, though these differences were not significant. For an Alfisol in Samaru, Nigeria, [25] also reported variations in organic carbon, total N and available phosphorus contents due to complementary use of *azadirachta* and *parkia* foliage with NPK fertilizer. Nitrogen is released in the soil following organic matter decomposition by a process known as N mineralization [29]. The presence of good amount of N in the soil is required for better agricultural crops yield. Planting the trees of this study, especially *K. Senegalensis*, can help to reduce the cost of buying artificial fertilizer by the farmer. Similar results for available phosphorus were also reported by [30]. This can be attributed to solubilising behaviour of organic acids that are released into the soil during the decomposition of organic matter under the tree species.

The results further showed that *K. Senegalensis* had the highest mean values for soil contents of exchangeable K, Ca, Mg and Na while *T. Grandis* had the lowest, with the differences not being significant only for mg. The significant effect of the *K. Senegalensis* on soil contents of exchangeable K, Ca and Na may be as a result of rapid cycling of these elements in the organic litters and through tree fall. These results under *K. Senegalensis* are interesting particularly for exchangeable K known for its high mobility and hence frequently subject to leaching losses over time especially in high-rainfall tropical environments [31].

The duo of total exchangeable bases (TEB) and cation exchange capacity (CEC) of the soil showed higher mean values under *K. Senegalensis* compared to *G. Arboreal* and *T. Grandis*. The results agree with those of [32]. The high Ca, Mg, TEB and CEC values recorded at the *K. Senegalensis* site were due to high soil Ph levels under this tree species. Various plants have the ability to absorb Ca from the soil which will be retained in plant biomass in form of calcium oxalate [33][34]. The base saturation (BS) was highest under *K. Senegalensis* and lowest under *T. Grandis*. The high percent BS observed under *K. Senegalensis* was as a result of high Ph value. The BS is the saturation of CEC with base- forming cations. The BS has been considered a complex physiochemical variable that approximates the relationships between basic and acidic cations in relation to other soil properties and external factors such as organic matter content, vegetation, climate, texture, parent material, weathering stages, contamination and addition of mineral fertilizers, among others [35].

Generally, the results of this research indicated non-significant ($p > 0.05$) differences in soil contents of organic carbon, total N, available phosphorus, exchangeable Mg as well as Cr, Zn, and Cd contents between the tree species, although K. *Senegalensis* recorded the highest amount of these nutrients. However, exchangeable K, Na and Ca including TEB, CEC and BS showed significant differences between the tree species, with *K. Senegalensis* showing higher values of these parameters compared to *T. Grandis* and *G. Arborea.* The nutrients found in plant materials such as leave litters, flowers, roots, etc., are released to the soil after decomposition [27]. This implies that *K. Senegalensis* has less ability to re-absorb their nutrients during translocation and abscission before shading its leave, or it could be that its roots can absorb from the soil sufficient nutrients to the whole tree parts. This observation could further be explained by the effect of microclimate of the *K. Senegalensis* plantation. The result of this study agrees with that of [36] who reported that different trees species had the ability to affect the chemical properties of soils under them differently.

Table 1a: Mean Value and Duncan mean separation for soil chemical properties as influenced by the canopies of *Tectona grandis, Khaya senegalensis* and *Gmelina arborea*

Sources of variation	Ph	Ec (ds/m)	Organic Carbon (g/kg)	% O.M	N (g/kg)
Tectona grandis	6.1500±0.24269[a]	26.67±5.774[a]	1.7967±0.04041[a]	1.7967±0.04041[a]	0.2100±0.07000[a]
Khaya segegalensis	7.0400±0.41073[b]	20.00±0.000[a]	1.7500±0.13528[a]	3.0100±0.23065[a]	0.3500±0.07000[b]
Gmelina arborea	6.3967±0.10599[a]	20.00±0.000[a]	1.7333±0.06429[a]	2.9833±0.10786[a]	0.2333±0.04041[ab]
Total	6.5289±0.46697	22.22±4.410	1.7600±0.08261	3.0278±0.13998	0.2644±0.08413

Sources of variation	P (mg)	K (mg)	Na	Mg (mg)	Ca (mg)
Tectona grandis	6.3300±0.16523[a]	0.22700±0.039051[a]	0.13500±0.044576[a]	1.02467±0.094553[a]	1.18433±0.101854[a]
Khaya segegalensis	6.8400±0.55570[a]	0.37533±0.050846[b]	0.24267±0.030022[a]	1.27300±0.144094[a]	1.75267±0.344767[b]
Gmelina arborea	6.1733±0.09713[a]	0.27400±0.036497[a]	0.19533±0.014295[ab]	1.07733±0.057492[ab]	1.28833±0.058859[a]
Total	6.4478±0.42133	0.29211±0.075303	0.19100±0.054381	1.12500±0.145235	1.40844±0.319145

Table 1b: Mean value and Duncan mean separation for soil chemical properties as influenced by the canopies of *Tectona grandis*, *Khaya senegalensis* and *Gmelina arborea* (Cont.)

Sources of variation	E.A	T.E.B	C.E.C	B.S	Pb
Tectona grandis	0.9967±0.28868[b]	2.58100±0.268531[a]	3.57767±0.037978[a]	72.33±8.083[a]	0.30300±0.000000[a]
Khaya segegalensis	0.5000±0.17000[a]	3.64067±0.529859[b]	4.14367±0.385993[b]	87.67±5.132[b]	0.23433±0.068501[a]
Gmelina arborea	0.7767±0.09238a[b]	2.83200±0.165309[a]	3.61167±0.078233[a]	78.33±3.215[ab]	0.23433±0.068501[a]
Total	0.7578±0.27685	3.01789±0.570111	3.77767±0.338682	79.44±8.383	0.25722±0.059371
Sources of variation	Mn (mg)	Cr	Zn (mg)	Cu (mg)	Cd
Tectona grandis	1.26467±0.539320[a]	0.20267±0.062931[a]	8.62500±3.307189[a]	0.10467±0.006351[a]	69.59400±2.527583[a]
Khaya segegalensis	1.18867±1.029008[a]	0.23900±0.000000[a]	9.04167±4.732424[a]	0.11200±0.000000[a]	89.79800±3.727682[a]
Gmelina arborea	1.08500±0.362149[a]	0.20267±0.062931[a]	4.45667±3.609883[a]	0.11633±0.024420[a]	52.84667±37.851973[a]
Total	1.17944±0.613449	0.21478±0.048064	7.37444±4.051235	0.11100±0.013611	70.74622±24900271

Table 2: ANOVA for Soil Chemical Properties

		Ph		E.C		O.C		O.M	
Sources of Variation	D.f	F	Sig.	F.	Sig	F	Sig.	F	Sig.
Treatment	2	7.956	0.021*	4.000	0.079^{ns}	0.403	0.685^{ns}	0.401	0.686^{ns}
		N		P		K		Na	
Sources of Variation	Df	F	Sig.	F.	Sig	F	Sig.	F	Sig.
Treatment	2	4.429	0.066^{ns}	3.165	0.115^{ns}	9.503	0.014*	8.475	0.018*
		Mg		Ca		E.A		T.E.B	
Sources of Variation	Df	F	Sig.	F.	Sig	F	Sig.	F	Sig.
Treatment	2	4.668	0.060^{ns}	6.210	0.035*	4.616	0.061^{ns}	7.259	0.025*
		C.E.C		B.S		Pb		Mn	
Sources of Variation	Df	F	Sig.	F.	Sig	F	Sig.	F	Sig.
Treatment	2	5.792	0.040*	5.268	0.048*	1.507	0.295*	0.049	0.952^{ns}
		Cr		Zn		Cu		Cd	
Sources of Variation	Df	F	Sig.	F.	Sig	F	Sig.	F	Sig.
Treatment	2	0.500	0.630^{ns}	1.248	0.352^{ns}	0.492	0.634^{ns}	2.120	0.201^{ns}

NOTE: * = Significant at 5% probability level, ns = not significant at 5% probability level.
Key: D.F: Degree of freedom, F: Calculated value, Sig: Significance, E.C: Electric conductivity, O.C: Organic carbon, O.M: Organic matter, ns: Not Significant

Soil samples from *T. Grandis* showed higher mean Pb content than those from *K. Senegalensis* and *G. Arborea* for which values were similar. Soil contents of Mn, Cr, Zn, Cu and Cd did not differ under the three tree species. Meanwhile only C u appeared higher at the site of *G. Arborea.*

Out of the 20 chemical properties analysed in this study, 14 appeared to be more abundant under

K. Senegalensis, while five appeared more abundant under *T. Grandis*; only one namely cu tended to be more abundant under *G. Arborea.* Under *T. Grandis* and *G. Arborea*, the lightness of the leave may result to smaller litter accumulation as a result of wind blowing the leaves away, thus reducing their addition of nutrients to the soil. The data attained may also suggest greater ability of *T. Grandis* and *G. Arborea* to re-absorb the nutrient elements in the leaves before shading off their leaves. Tree plantation is known to have the potential to conserve soil, maintain soil fertility and increase soil productivity [37] by increasing organic matter, N fixation, nutrients uptake while also improving soil structure, soil moisture retention and water infiltration. Notably, indigenous tree species proved to perform better than the exotic ones in this study.

The result of correlation is presented in Table 3. There were significant positive correlations between each of soil Ph and total N, available phosphorus, exchangeable bases (K, Na, Mg and Ca), TEB, CEC and BS. However, significant negative correlation was observed between soil Ph and exchangeable acidity. This implies that as soil Ph increases, N, P, K, Na, Mg, Ca, TEB, CEC and BS increase. Soil Ph was expected to influence the abundance of nutrients in the soil. The positive relationships between soil Ph and these soil nutrients probably reflect rainfall amount in the study locations. [35] reported similar results.

The correlations between electrical conductivity and each of total N and exchangeable Na showed significant negative relationships. So, as electrical conductivity increases the amounts of total N and exchangeable Na decrease. Because of its influence on available nutrients in the soil, a positive correlation was expected between electrical conductivity and total N [38].

There was a significant positive correlation between OC and Pb. Although soil organic matter constitutes usually a small portion of soil, it is one of the most important components of ecosystems. Soil organic matter is a product of the decomposition of plant residues, roots and soil organisms whether living or dead organic matter has been termed as the lifeblood of soil. It has tremendous impact on the chemical, physical and biological properties of soil [39, 40].

Also, there were significant positive correlations between total N and each of available P, exchangeable bases (K, Na, Mg and Ca), TEB, CEC and BS.

However, the correlation between total N and exchangeable acidity was significantly negative. There were significant positive correlations between available phosphorus and each of exchangeable bases (K, Na, Mg and Ca), TEB, CEC and BS, a significant negative correlation was found between available phosphorus and exchangeable acidity. Available phosphorus also a significant negative correlation with Pb content of the soil.

Other significant positive correlations were between exchangeable K and the rest of the exchangeable bases as well as between exchangeable K and each of TEB, CEC and BS. Significant negative correlations existed between exchangeable K and exchangeable acidity. This pattern of relationship observed between exchangeable K and the cation exchange indices was also observed for exchangeable Na. Significant positive correlations existed between exchangeable mg and each of exchangeable Ca, TEB, CEC and BS, but a significant negative correlation was found between exchangeable Mg and EA. There were significant positive correlations between exchangeable Ca and each of

TEB, CEC and BS, but a significant negative correlation between it and exchangeable acidity.

A significant positive correlation existed between Cr and Cu contents of the soil. In general, if the soil Ph is below 7 the BS is less than CEC. At Ph 7 or higher, soil clay mineral and organic matter surface occupied by basic cation and thus BS is equal to CEC. Therefore, soils with a high percent BS are generally more fertile because they have little or no acidic cations Al^{3+} that are toxic to plants; they are more buffered against acid cations from plant roots and soil processes that acidify the soil (nitrification, acid rain) and they are more fertile, with more of especially the plant-nutrient basic cations (K^{+}, Ca^{2+} and Mg^{2+}). The availability of nutrients in soil depends on soil Ph, organic matter, adsorptive surfaces and other physical, chemical and biological conditions [41].

Table 3 Matrix of the correlations among the soil properties assessed

	pH	EC	OC	TN	AvP	K	Na	Mg	Ca	EA	TEB	CEC	BS	Pb	Mn	Cr	Zn	Cu	Cd
pH	-																		
EC	-0.545	-																	
OC	-0.419	-0.160	-																
TN	0.955**	-	-0.334	-															
AvP	0.927**	-0.507	-0.614	0.858**	-														
K	0.984**	-0.560	-0.326	0.968**	0.858*	-													
Na	0.948**	-	-0.232	0.986**	0.844*	0.955**	-												
Mg	0.905**	-0.377	-0.267	0.797*	0.823*	0.890**	0.801*	-											
Ca	0.989**	-0.486	-0.516	0.931**	0.956*	0.961**	0.910**	0.880*	-										
EA	-	0.612	0.308	-	-0.800*	-	-	-0.836*	-	-									
TEB	0.995**	-0.500	-0.422	0.935**	0.928*	0.979**	0.923**	0.936*	0.988**	-	-								
CEC	0.929**	-0.357	-0.465	0.816**	0.924*	0.893**	0.799**	0.909*	0.957**	-0.751*	0.951*	-							
BS	0.956**	-0.606	-0.290	0.958**	0.822*	0.966**	0.956**	0.882*	0.908**	-	0.945*	0.800*	-						
Pb	-0.543	0.167	0.866*	-0.537	-0.690*	-0.504	-0.450	-0.336	-0.618	0.467	-0.534	-0.530	-0.447	-					
Mn	-0.495	0.156	0.502	-0.484	-0.579	-0.439	-0.412	-0.569	-0.512	0.500	-0.530	-0.494	-0.517	0.346	-				
Cr	0.236	0.378	-0.364	0.132	0.167	0.298	0.053	0.283	0.275	-0.158	0.272	0.333	0.174	-0.505	0.121	-			
Zn	0.347	-0.431	0.190	0.530	0.044	0.473	0.513	0.149	0.260	-0.565	0.295	0.047	0.519	-0.058	0.076	0.098	-		
Cu	0.069	0.079	-0.376	0.109	0.089	0.128	0.035	0.047	0.083	-0.161	0.079	0.012	0.133	-0.640	-0.001	0.718	0.189	-	
Cd	0.536	-0.257	0.322	0.497	0.281	0.585	0.529	0.586	0.586	-0.477	0.545	0.530	0.525	0.329	-0.121	-0.038	0.385	-0.534	-

EC, Electric Conductivity; OC, organic carbon; N, nitrogen; AvP, available phosphorus; K, potassium; Na, sodium; Mg, magnesium; Ca, calcium; EA, exchangeable acidity; TEB, total exchangeable bases;
CEC, cations exchange capacity; BS, base saturation; Pb, lead; Mn, manganese; Cr, chromium; Zn, zinc; Cu, copper; Cd, cadmium

Conclusion and Recommendation

The results revealed that different tree species can affect soil chemical properties differently. It is evident that from this study that *K. Senegalensis* improved the supply of nutrients and lowered the soil content of such heavy metals as Pb better than the other two tree species. This *K. Senegalensis* was thus superior to *G. Arboreal* and *T. Grandis* as regards enhancing the fertility status of the soil.

From the result of this study, it is recommended that *K. Senegalensis* should be adopted among the three tree species for agroforestry practice. To enhance soil conservation, maintain soil fertility and increase soil productivity, there is need for an awareness on the potential ecological benefits of having *K. Senegalensis* tree stands in farmlands.

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CHAPTER FOUR

Physics in Agriculture

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Abstract

Agricultural activities have gone mechanized beyond what is used to be. This paper reviews the roles and importance of physics in modernizing agriculture. Different topics in physics address different mechanized areas of agriculture. Knowledge in physics can contribute more in the limitation of hazards in agriculture. It is not possible to engage in mechanized Agriculture without understanding elementary physics. Physics is a natural science which enable one to learn about nature's principle and the logic behind some natural incident.

Keywords: Physics, Agriculture, Electromagnetism, Atmospheric

1. Introduction

Physics is a branch of science which deals with matter and energy. It studies measurement and units. It is a quantitative science which relies on observations and experiments conscious of the fundamental principles, theory and hypothesis that explains the behaviour of matter and energy. Each of their characteristic behaviour can be studied under different topics in physics. Subsections in physics are; Mechanics, Thermodynamics, Electromagnetism, Optics and Waves [1]. Physics is considered to be a base for virtually all the applied sciences including Agriculture.

Agrophysics is one of the branches of natural sciences dealing with the application of physics in agriculture and environment. It plays an important role in the limitation of hazards to agricultural objects (soils, plants, agricultural products and foods) and to the environment. Soil physical degradation, gas production in soils and emission to the atmosphere, physical properties of plant materials influencing their technological and nutritional values and crop losses are examples of such hazards. Agrophysical knowledge can be helpful in evaluating and improving the quality of soils and agricultural products as well as the technological processes [2, 3].

This is one of the families of natural sciences dealing with the application of physics in the agriculture and environment. It is a science that studies physical processes and properties affecting plant production. The fundaments of agrophysical investigations are mass (water, air, nutrients) and energy (light, heat) transport in the soil-plant-atmosphere and soil-plant-machine-agricultural products-foods continuums and way of their regulation to reach biomass of high quantity and quality with the sustainability to the environment. Agrophysics is an integral part of environmental physics. It deals with the processes in lands in agricultural use, being under intensive human intervention, e.g. monoculture crops, water management and high level of chemical and mechanical treatments. Agrophysics is also concerned with plant raw materials as a source of high-quality agricultural products and food. It comprises physical processes and properties of soils, plants, agricultural products and food.

The soil physical degradation is involved in the wider definition of soil degradation. It is the general process by which soil gradually declines in quality and is thus made less fit for a specific purpose, such as crop production. This includes, soil erosion, soil compaction, surface seals or crusts, pans, desertification, and waterlogging.

In cold climates, the rate of germination, emergence and final stand establishment is slowed greatly by low seedbed temperature. The minimum temperatures for root growth are about 5 ^{0}C. in hot regions, however, emergence can be hindered by adversely high seedbed temperatures. In cold climates the rate of germination, emergence and final establishment is slowed greatly by low seedbed temperature. The maximum temperatures for root growth are from 35 to 40 ^{0}C. the temperatures can be influenced by mulching [4, 5].

2. Mechanics

Mechanics is a topic in physics where the knowledge of the use of machine is acquired. The efficiency, mechanical advantage and velocity ratio of mechanics are evaluated thereby making the user of machine acquire optimal performance and greater output. The operations are used for land preparation, crop and animal harvesting tools. They are used in harvesting of natural resources as in drying and commodity preservation.

The Green Revolution mechanized agricultural production, thus making farm work easier. Mechanization refers to the utilization of different types of equipment to plant, harvest, and do primary processing. It included the widespread introduction and use of equipment such as tractors, combine harvesters, and sprayers. An important factor of the Agricultural Revolution was the invention of new tools and advancement of old ones, including the plough, seed drill, and threshing machine to improve the efficiency of agricultural operations.

Plate 1: A farmer making use of physics knowledge to operate Sprayer on farm

3. Thermodynamics

Thermodynamics is the study of the relations between heat, work, temperature, and energy. Thermodynamics, science of the relationship between heat, work, temperature, and energy. Thermodynamics deals with the transfer of energy from one place to another and from one form to another. The key concept is that heat is a form of energy corresponding to a definite amount of mechanical work. The behaviour of these quantities is governed by the four laws of thermodynamics which convey a quantitative description using measurable macroscopic physical quantities, but may be explained in terms of microscopic constituents by statistical mechanics. Thermodynamics has a great potential in life sciences. Thermodynamics has been used in systems biology to analyse metabolic pathways and analyse metabolic strategies evolved by microorganisms. Thermodynamics is used more and more often in biology for analysis of microorganism cells and communities, as well as plants. Morowitz was the first to roughly estimate thermodynamic properties of ubiquitously present microorganisms using statistical thermodynamics. Afterward, the interest in bio thermodynamics increased, which motivated researchers to study the subject in more detail. Wang and Duboc [6] reported experimental enthalpies of combustion of microorganisms. The next great advance in the field was made by experimentally determining the entropy of Saccharomyces cerevisiae. Based on this data, Battley [7] has made a very detailed analysis of S. cerevisiae growth, determining the change in specific enthalpy, entropy, and Gibbs free energy for the process in both aerobic and anaerobic modes and on several substrates. Barros and Feijóo made a quantitative analysis of soil microorganism growth, describing it with a growth reaction. Multicellular and unicellular organisms represent a highly organized amount of substance, containing nucleic acid, proteins, lipids, and carbohydrates, characterized by specific elemental composition (empirical formula) and thermodynamic properties (enthalpy, entropy, and Gibbs energy). The conversion of energy by plants must be performed in full accordance with the general laws of thermodynamics. Plant growth rate is proportional to the product of the metabolic rate and the metabolic efficiency for production of anabolic products. Thermodynamics has been used to study plant growth and photosynthesis and sets a limit to the maximum possible energy yield of photosynthesis ηm. Thermodynamics do not permit functioning of a four-quantum mechanism for the lowest intensities of light encountered in practice in experiments on plant photosynthesis [5]. The maximum temperatures for root growth are from 35 to 40 ºC. the temperatures can be influenced by mulching [6].

4. Electromagnetism

During microwave or high frequency heating, many material properties affect the heating performance. Among the most significant are the electron magnetic properties, especially the dielectric properties of the food. In addition to these properties, geometry, packaging and the microwave oven itself affect the heating. There are the electromagnetic properties of Agricultural products; electronic atomic and orientation polarisation. The important mechanism at microwave frequencies is also ion conductivity (ion loss or polarisation) where hydrated ions try to move in the direction of the electrical fields and transfer energy by this movement. This is strongly temperature dependent [7].

5. Atmospheric

Practically all of the energy that reaches the earth comes from the sun. it is intercepted first by the atmosphere. A small part of it is directly absorbed, particularly by certain gases such as ozone and water vapor. Some energy is also reflected back to space by clouds and the earth's surface. Convection in the atmosphere includes large and small scale rising and sinking of air masses. The vertical motions effectively distribute heat and moisture throughout the atmosphere column and contribute to cloud and storm development where rising motion occurs and dissipation where sinking motion occurs. Where water vapor condenses onto a surface, a net warming occurs on that surface which makes the water molecule to bring heat energy with it. However, the temperature of the atmosphere drops slightly and condensation produces clouds, fog and precipitation especially when facilitated by cloud condensation nuclei.

Water vapor enhances the radiative balance and the hydrological cycle. It is the principal element in the thermodynamics of the atmosphere as it transports latent heat and contributes to absorption and emission in a number of bands. Water vapor condenses into clouds that reflect and adsorb solar radiation, thus directly affecting the energy balance. Atmospheric pressure is often affected by four major factors which are, temperature, altitude, water vapor in air and gravity of the earth.

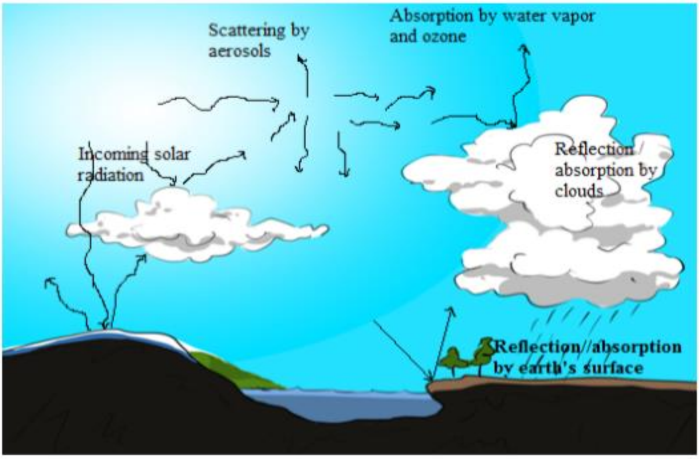

Plate 2: Illustration of interactions of solar radiations with different constituents of the atmosphere

6. Nuclear Radiation

Electromagnetic radiation emitted by the sun emits energy according to Planck's law at a temperature of 6000 K. The radiation ranges from infrared to ultraviolet. Radiations with shorter wavelengths are absorbed by gases in the atmosphere by the ozone layer. Solar radiation is the ultimate source of energy which is captured by the plants during the process of photosynthesis. One of the most important factors that influences plants development is the solar radiation intercepted by the crop. The solar energy brings energy to the metabolic process of the plants. The principal process is the photosynthetic assimilation that makes synthesize vegetal components from water, CO_2 and the light energy possible. Part of this energy is used in the evaporation process inside the different organs of the plants and in the transpiration through the stomas. Solar energy radiation provides the energy needed for fundamental physiological process such as photosynthesis and transpiration [14]. Plants intercept direct and diffuse sunlight. The upper leaves receive both types of radiation, while the lower leaves intercept a small portion of direct radiation. Solar radiation transmitted by the leaves is predominantly infrared. Visible radiation between the wavelengths of 400 and 700 *nm* is the most important type from an Eco physiological point of view as it relates to photosynthetically active radiation (PAR). 50 % of the incident radiation is used by the plant to perform photosynthesis [5]. The quantity of radiation intercepted by plant cover is influenced by a series of factors such as leaf angle, the properties of the leaf surface affecting light reflection, the thickness and chlorophyll concentration which affect the light transmission, the size and shape of the leaf phyllotaxis and vertical stratification and the elevation of the sun and distribution of direct and diffuse solar radiation. Out of 100 % total energy received by the leaf, only 5 % is converted into carbohydrates for biomass production later. Losses of energy are by non-absorbed wavelengths – 60 %. Reflection and transmission – 8 %. Heat dissipation – 8 % and Metabolism – 19 % [5] Maximum crop production requires complete capture of incident solar radiation and can only be achieved with supporting levels of water and nutrients [5]. The efficiency of radiation interception is also influenced by the levels of nutrients in plants, mainly by nitrogen [8]. The water deficit reduces the interception of solar radiation due to rolling up the leaves [9]. If the water deficit is prolonged, the number and size of leaves may be reduced or else the total leaf area may decrease, reducing the interception of radiation as a consequence [10].

The direct method for evaluating the percentage of intercepted radiation (LI) is to measure PAR both above and below the canopy at noon on completely cloudless days [5]

$$LI = [1- [\frac{PAR\ below\ canopy}{PAR\ above\ canopy})] \quad (15)$$

Commercially available linear photosynthetically active radiation (PAR) sensors are used to take these measurements which are based on PAR values registered by the sensor. These measurements can be taken either by locating sensors perpendicular to the crop rows [14] or by taking multiple measurements parallel to them [11]. The later method is obviously costly considering the number of measurements required to characterize the study area, especially in the case of low-lying crops where one may need to remove vegetation in order to place sensors under it. Using the percentage of shaded soil at solar noon to estimate the interception of solar radiation by a crop and the distribution of irradiance among each leaf [10].

These measurements can be taken either by locating sensors perpendicular to the crop rows [13] or by taking multiple measurements parallel to them [12].

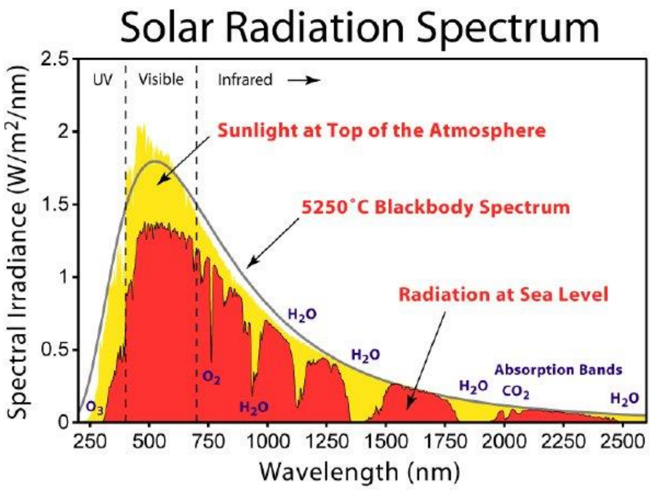

Figure 1: Spectrum of solar radiation above the atmosphere and sea level. prepared by Robert A. Rohde as part of the Global Warming Art project [13]

Some of the most innovative ways of improving agricultural practices involve nuclear technology. Using isotopes or radiation techniques in agriculture can control pests and diseases, increase crop production, protect land and water resources and ensure food safety. The FAO and the International Atomic Energy agency (IAEA) have been expanding knowledge and enhancing capacity in this area for than fifty years and recently strengthened this partnership by creating a joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture.

Five areas have been decided of how FAO and IAEA are improving agriculture and food security. The five areas are in

(1) Animal health
(2) Insect pest management
(3) Improved soil and water management
(4) Food safety and Control
(5) Plant Breeding and Genetics.

7. Conclusion

Physics is the basis of any science that needs a scientific explanation. Conventional physics used by planter's planter who cut short the long leaf with intention to avoid is physics, reducing evaporation also physical property of evaporation and imbibition, evaporation and virtual water come part of physics. No matter what you do in agriculture, there will always be situations that continually encounter physics. Physics helps to understand what is presently happening and what will happen next. Physics is a crucial requirement for a proper understanding of agriculture. The use of physical laws and modern measuring methods in agriculture and natural environment allows us to forecast, estimate, monitor, mitigate, resist and control unfavourable phenomena of physical degradation of soil environment and plant materials.

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CHAPTER FIVE

The Physicochemical Properties of the Nigerian Plant Seed Oils: Promoting Health and Food Security

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Abstract

The fats and oils are the most abundant lipids in nature, and non-volatile substances, insoluble in water but soluble in organic solvent. They constitute along with protein and carbohydrates, the major food stuffs and are widely distributed in nature. Oil serves as a good source of protein, lipid and fatty acids for human nutrition including the repair of worn-out tissues, new cells formation as well as a useful source of energy. Oilseeds are those seeds that contain considerably large amounts of oil. Oil can be extracted from oilseed by using traditional methods of extraction (on a very small scale), mechanical expression (hydraulic and screw presses) which can be manual, semi-automated or automated, and solvent extraction (e.g. hexane, fluid carbon dioxide) or a combination of two of these methods. Physicochemical parameters of the oils extracted from some Nigerian plant foods using standard analytical techniques were reviewed. The physicochemical properties of the plant oils reviewed were found to be at the range concentrations as follows: Saponification value (SV): 5.58 - 249.90 mgKOH/g, peroxide value (PV): 0.45 - 290.00 mEq O_2/kg of sample, acid value (AV): 0.34 - 68.88 mg KOH/g, iodine value (IV): 2.65 - 153.00 g I_2/100g sample, density (Ds): 0.9031 - 0.9208 g/cm^3, viscosity (Vs): 0.43 to 302.39 mm^2/sec, specific gravity (SG): 0.830 – 1.710, refractive index (RI): 0.147 – 1.792, free fatty acid (FFA): 0.14 – 34.65 % as oleic acid, ester value (EV): 0.54 – 241.04 mgKOH/g and heat of combustion (HC): 8904.25 – 11303.35 gcal/g. The result of the reviewed work confirms the Nigerian seed oils to be of good quality and can find application either in food industry as food additives or industrial purposes such as cosmetics, soaps, paint and even energy generation.

Keywords: Physicochemical parameters, seed oils, health, food security, Nigeria

1. Introduction

The term oil is used in generic sense to describe all substances that are greasy or oily fluid at room temperature [1]. Generally, fats are considered as extracted triglycerides/lipids that are liquid under the same condition. Fats and oils belong to a larger group of naturally occurring substances called lipids. Because lipids serve as a convenient means of rapid heat transfer, they have found increasing use in commercial frying operations [2]. Fats and oils are non-volatile substance insoluble in water but soluble in organic solvent. They constitute along with protein and carbohydrates, the major food stuffs and are widely distributed in nature. From chemical point of view, oils and fats are products of the reaction between a triol (glycerol) and three molecules of fatty acids. This type of reaction is commonly termed as esterification.

Oils/fats are obtained basically from two sources namely: animal and vegetable sources [3]. Animal fats and oils are derived both from terrestrial and marine animals. Marine fats include liver oils etc. Terrestrial fats and oils derived from animals include lard (from Swine), suet (from oxen or sheep), ghee (from cow or buffalo milk), etc. Vegetable oil is found in greatest abundance in fruits and seeds. Oils obtained from plant source are termed vegetable oils. These include: palm oil, cotton seed oil, ground oil, sunflower oil etc. Edible oils from plant sources are of interest in various food applications and industries. They provide characteristic flavours and textures to foods as integral diet components [4] and can also serve as a source of oleo chemicals [5]

Vegetable oils had made an important contribution to the diet in many countries, serving as a good source of protein, lipid and fatty acids for human nutrition including the repair of worn-out tissues, new cells formation as well as a useful source of energy [6-9].

Oilseed crops are major sources of lipids for human nutrition as well as for several industrial purposes. They are defined as those seeds that contain considerably large amounts of oil. The most commonly known oilseeds (conventional oil seeds) are groundnut, soybean, palm kernel, cotton seed, olive, sunflower seed, rapeseed, sesame seed, linseed, safflower seed, etc. [10-13]. There has been an increase in the world production of oil seeds over the last thirty years [14]. This would appear to be related to the products and by-products as oils seeds are primarily grown for their oil and meal. Vegetable oil is always at a higher price per ton than the cake, this is because the demand for oil is often higher than the cake.

Nut and seed oils are receiving growing interest due to their high concentration of bioactive lipid components which have shown various health benefits. Fats and oils, and their several lipid components can extensively be used in the food and also in cosmetics, pharmaceuticals, biodiesel paints and other. Oils from most edible oils seeds are used in the food industry, though there is growing emphasis on industrial utilization as feedstock for several industries with about 80% of the world production of vegetable oils for human consumption. The remaining 20% utilization is between animal and chemical industries. The ability of a particular oilseed fit into the growing industries depends on its utilization potential, rate of production, availability and ease of the processing technology.

Generally, oils and fats from seeds and nuts constitute an essential parts of man's diet. Fats and oil, together with proteins, carbohydrates, vitamins and minerals are the main nutrients required by the human body. The chief important of the vegetable oils lies in their food value. Vegetable oils derived from plant seeds have been playing vital roles to provide comfort in human lives in various aspects, they are essential in meeting global nutritional demands and are utilized for many food and other industrial purposes [15]. In the last few decades, there have been growing concerns over vegetable oils as source of material in preference to petroleum or mineral oil. The main factor for this concern is due to environmental issues that regard mineral oil as major contributor of volatile organic components which themselves are responsible for most of our present recalcitrant pollution problems threatening the ecology. Oilseeds are also used in animal feed because of their high protein content. Their seeds contain energy for the sprouting embryo mainly as oil, compared with cereals, which contain the energy in the form of starch [16].

There are two quality types of oil: (i) Edible oils, used as food grade oil, that is most often encountered as an odorless frying oil which is low in unsaturated fats, but, it is also an ingredient in many food products, especially where a healthy oil is required. (ii) Industrial oils (although some edible types are also used industrially) - which are not edible, but, have been bred to contain high levels of compounds critical for some industrial processes.

Edible fats and oils are similar in molecular structure; however, fats are solid at room temperature, while, oils are liquid. Fats and oils are essential nutrients, comprising about 40% of the calories in the diet of the average person. Edible vegetable oils are used as salad or cooking oils, or may be solidified (by a process called hydrogenation) to make margarine and shortening. These products supplement or replace animal products (butter, lard), supplies of which are inadequate to meet the needs of an increasing world population. While there are many uses for industrial vegetable oils, but, total world production is only about 3% of that of edible oils. Industrial applications are based on the properties of particular fatty-acid components of these oils. For example, flaxseed oil, rich in the unsaturated fatty acid linolenic, is a drying oil and is used in protective coatings (paints, varnishes). Vegetable oils are used in putty, printing inks, erasers, coating or core oils, greases, plastics, etc. The residue remaining after the oil has been extracted from oilseeds, is an important source of nutrients for farm animals. Oilseed meals from soybean, peanut, rapeseed and flaxseed are rich in protein; when mixed with other ingredients (cereal grains), and they provide nutritionally balanced feeds [17].

The essential fatty acids contained in hemp seed oil are required in our diet more than any other vitamin, yet our bodies do not naturally produce them. They must be obtained from external sources in the food we eat. These are involved with producing life's energy throughout the human body and without them, life is not possible. Extensive studies have demonstrated that many common illnesses are related to deficiencies or imbalances of specific fatty acids in the body. Symptoms are often related to a lack of omega 3 and omega 6 fatty acids and their derivatives, the postaglandins. Most people eating a healthful diet, one that includes a balanced ratio of essential fatty acids, also have healthy skin and a strong immune system. Yet some individuals may experience shortages in specific fatty acids or their metabolites due to dysfunctional enzyme systems or other inhibitions in their metabolic pathways caused by genetic, immune-system-related, or even environmental factors. Hemp seed oil also provides an adequate supply of antioxidants (Vitamin E), carotene (precursor to Vitamin A), phytosterols, phospholipids and a number of minerals including calcium, magnesium, sulfur, potassium, phosphorus, along with modest amounts of iron and zinc. Oilseed rape is a very useful crop as the seed is typically 42% oil and the meal left after removing the oil is about 42% crude protein. Proteins serve a variety of functions in the human body such as acting as enzymes, antibodies, and the structural components of tissues, hormones and blood protein. The main function of dietary protein is to supply amino acids for the growth and maintenance of body tissue. Digestion disassembles proteins into their basic building blocks - amino acids. Furthermore, the oil is particularly of high quality and high in monounsaturates, and should logically be a premium product. Today’s certain varieties of oilseed rape have been bred to provide oil that is suitable for use in cooking and food processing. Known as

vegetable oil, the oil is widely used by the food industry and is now being increasingly processed for use as bio-diesel [18].
Mustard seeds have been highly prized medicinal as well as culinary spice being in use since ancient times. The seeds are obtained from mustard plant (*Brassica juncea*) which also include cabbage, broccoli, Brussels sprouts, etc. Generally perceived as health benefiting spice, mustard seeds are indeed very rich in phytonutrients, minerals, vitamins and anti-oxidants. Mustard greens are an excellent source of essential B-complex vitamins such as folates, niacin, thiamin, riboflavin, pyridoxine (vitamin B-6) and pantothenic acid. These vitamins are essential in the sense that body requires them from external sources to replenish. These B complex groups of vitamins help in enzyme synthesis, nervous system function and regulating body metabolism. Mustards are rich source of many health benefiting minerals. Calcium, manganese, copper, iron, selenium and zinc are some of the minerals especially concentrated in these seeds. Calcium helps to build bone and teeth. Manganese is used by the body as a co-factor for the antioxidant enzyme superoxide dismutase. Copper is required in the production of red blood cells while iron is required for the red blood cell formation and cellular metabolism [19]. Mustard seeds and its oil have traditionally been used to relieve muscle pain, rheuamtism and arthritic pain. The mustard oil is applied over scalp and is believed to stimulate hair growth. Its ground seeds act as a laxative, stimulant to gastric mucosa and increase intestinal secretion [20-21].
The protein quantity and quality, caloric value, and overall nutrient content of oilseeds are quite good. In many new oilseed protein sources, p henolic compounds are as important as unsaturated lipids, carbonyl compounds, and nonenzymatic browning in the development of adverse flavors and colours in food products. The free phenolic acids are of particular concern because of enzymatic oxidation too-quinones and subsequent binding to lysine and methionine in the proteins. Numerous free phenolic acids have been identified in all oilseed flours

with syringic, ferulic and vanillic being the major components in cottonseed, peanut and soybean flours. Gossypol in cottonseed, chlorogenic acid in sunflower, and sinapine in rapeseed are microconstituent phenolics which cause unique problems in the utilization of these defatted flours and their protein isolates in food applications. The roles of bound phenolics and tannins in the binding of essential nutrients or altering chemical and functional properties require further investigation [22].

The Cucurbitaceae seeds such as *Cucumeropsis mannii*, *Cucurbita maxima*, *Cucurbita moschata*, *Lagenaria siceraria* and *Cucumis sativus* and their defatted cakes are rich in proteins (28 to 40.49% and 61 to 73.59%, respectively). They also contain high lipid levels similar to those of the other oilseeds. These seeds can thus be considered as sources of proteins and oils [23]. Oilseeds and their constituents developed as functional foods or as sources of nutraceuticals provide benefits for consumers and food processors, and represent a significant opportunity for biotechnology and plant breeding companies. Researchers are applying molecular biology and biotechnology approaches to produce soy and canola oils enriched with sitostanols [24]. Vegetable oils containing 2 to 5% phytsterols/stanols have been generated by expressing the gene encoding the rate-limiting enzyme for sterol synthesis, hydroxymethylglutaryl-CoA reductase, in seeds of crop plants [25].

In Nigeria, the demand for vegetable oil has ever been widening as industrialist rely mostly on the popular vegetable oil such as palm kernel oil, soya bean oil, cotton seed oil and coconut seed oil for preparation of various products [26-27]. The characteristics of oils from different sources depend mainly on their compositions and no oil from a single source can be suitable for all purposes thus the study of their constituents is important.

2. Methodology

2.1 Extraction of oilseed's oil

Various techniques such as mechanical extraction, solvent extraction, traditional extraction and super critical fluid extraction are used to obtain the oil from the seeds. The solvent extraction has become the most popular method of extraction of oil because of its high percentage of oil recovery from seeds. Solvent extraction bridges the gap between mechanical extraction which produces oil with high turbidity metal and water content and supercritical fluid extraction which is very expensive to build and maintain its facilities.

Hexane is often used as solvent for oil extraction due to its lower boiling point for easy separation after extraction, its non-polar nature which makes it suitable for extracting vegetable oils which are generally non-polar, yet hexane has been categorized as hazardous air pollution (HAP) by the US Environmental Protection Agency and is included in the list of toxic chemicals [28]. The maximum permissible limit for hexane in oil and the meal are 5 ppm and 10 ppm, respectively [29]. These problems have attracted researchers to find a suitable alternative solvent. A number of solvents and their mixtures such as n-hexane, petroleum ether, alcohols, etc. have been study. Several parameters such as particle size, volume of solvent, operating temperature and extraction time has been found to affect the percentage yield of oil from seeds. Hence, the determination of the effect of these parameters on oil yields from seeds is important to minimize the loss of oil, the cost of extraction in general and the amount of energy expanded over time.

2.2 The role of moisture and temperature in oil extraction

Oil and water can each wet the solid components of oilseeds, though the two differ in affinity for the hydrophilic surfaces of particles. Water has a higher affinity and wets the surface of particles at a faster rate than oil due to its polarity and absorption ability. As such, the surface tension on the particles and water interface is insignificant while that of the oil interface is considerable. Research has proven that particles are selectively wetted by liquids with lower surface tension at the interface; hence water will tend to displace oil from the surface of particles. At a certain moisture content all the surface of the particles will be saturated by water and the oil will flow freely from the molecular forces. Thus, moisture increases the flow of oil through the pores of the press cake, hence reducing the amount of oil entrained in the cake and increasing the oil yield mostly in mechanical expression. High moisture content stops oil flow possibly because the structures of the finely milled particles have been altered (high aggregation). Moisture lubricates the pulp during pressing and causes a slower pressure increase and reduces oil yields [30].

Temperature is increased for oilseeds after pre-treatments such as cracking, dehulling, and milling by heating, roasting and steaming of oilseeds prior to extraction and is termed thermal treatment of oilseeds. Better extraction is achieved by heating, which reduces the oil viscosity and releases oil from intact cells, and also reduces moisture in the cells. Temperature plays an active role in the seed treatment for mechanical extraction and ensures an effective solvent process by heating the solvent which hastens the extraction process. At the right temperature and moisture content, the individual oil droplets unite to form a continuous phase and flow out maximizing oil yield.

2.3 Traditional extraction of seed oil

Traditionally, the commonest way of oil extraction is the water flotation process; oilseeds are thermally treated, crushed and milled into slurry (paste). With the aid of simple domestic utensils, oil is extracted by hand kneading. Water is added to the slurry and the mixture stirred and kneaded by hand until the oil separates to the top and sides of the utensils being used for the kneading. Water plays a vital role in hydrolyzing the paste, which displaces oil from hydrophilic surfaces in the slurry.

Under the traditional method, there are two ways of extracting oil; wet and water assisted extractions. This method is used, however, on a small scale, as it is labour- intensive, slow and tedious in operation compared to other methods but is assumed to produce high oil quality. In the wet extraction method, water is used in relatively large amounts to suspend the oilseeds such that the extracted oil floats on the top of the suspended oilseeds. Hot water flotation method of edible oil extraction is traditionally used in the rural areas of many developing countries. The water-assisted method involves the addition of small quantities of water to the slurry before the oil is extracted by manual kneading. The slurry is suspended in boiling water and boiled for at least 30 min with liberated oil floating on the surface. Further quantities of water are added after boiling to replace the lost water that occurred during evaporation, and to facilitate the floatation of the oil to the surface. The oil is carefully scooped from the surface of the water and boiled.

2.4 Mechanical Expression of Seed Oil

The main applications of mechanical expression are in the extraction of oils and juices. Expression is often combined with size reduction to maximize the yield of product. Components are extracted from plant parts either for direct use or for use in subsequent processing such as refining. In oil-bearing seeds, the oil is found inside cells in small droplets (10–80 μm) in diameter [31]. However, a single type of equipment is not suited to all oilseeds owing to variation in oil content, moisture content, porosity and solidity of the material, applied pressure, heating temperature, heating duration, particle size and shape, storage and handling practices, and the proportions of hulls in different oilseeds are factors influencing yield and quality of vegetable oil expressed [32].

Expression is achieved either in two stages (size reduction to produce pulp or slurry, followed by separation in a press) or in a single stage, which both rupture the cells and express the oil. In general, the single-stage operation is more economical, permits higher throughputs and has lower capital and operational cost but not suitable for hard nuts as the two stage of expression is more effective. The degree of effectiveness varies with the kind of oilseed and method of oil expression [33].

2.5 Solvent extraction of seed oil

Solvent extraction is the use of chemicals as solvents in the extraction of oil from oilseeds. Solvent extraction is known for its high yielding oil output, ease and swiftness to carry out; relatively cost effective, high overhead cost, and hazardous effects during and after operations. The use of this method requires a complete refining process to ensure traces of the solvents are removed totally. Solvent extraction of cleaned, cracked, dehulled and conditioned thin soy flakes (0.25–0.30 mm) with hexane is commercially practiced to extract oil [34-36]. Commercial solvent extraction does not include any pre-pressing operation due to the relative disadvantages of low oil content and slower oil recoveries. [37-38]. indicated that hexane, a petroleum-derived product has been extensively used as solvent for the oil extraction of soya beans and other oilseeds because of its low vapourisation temperature(boiling point 63 – 69^{o}C), high stability, low corrosiveness, low greasy residual effect, and better aroma and flavour productivity for the milled products. Hexane, however, is listed as a hazardous air pollutant by the United States Clean Air Act. Its use in the oilseed extraction plants can adversely affect workers' central nervous system, while its vapour ignites spontaneously with air at 25^{o}C [37-40]. Hexane is occasionally scarce and its price fluctuates depending on the supply and demand for gasoline [38]. [41] also reported that the use of hexane in small-capacity plants makes the processing expensive due to high operational losses. Research, however, is being conducted to find solvents that are safer and readily available than hexane. The ideal solvent must be easily removed from the meal and oil, non-flammable, stable, non-reactive with oil; meal or equipment, pure, only slightly soluble in water and readily available at low prices [38].

2.6 Determination of physicochemical parameters of seed oils

The determinations of physicochemical parameters of seed oils for refractive index, acid value, iodine value, saponification value, unsaponifiable matter, peroxide value, free fatty acid and specific gravity are always carried out according to the methods of [42].

3. Overview of the Physicochemical Properties of Seed Oils

The physicochemical properties of some Nigerian seed oils are presented in Table 1a – 1d. The refractive index range between 0.147 and 1.792 in groundnut and castor seed oils respectively. Refractive index of an oil is the ratio of speed of light at a defined wavelength to its speed in the oil/fat itself. This value varies with wavelength and temperature, the degree and type of unsaturation, the type of substitutions of component fatty acids and with accompanying substances. Refractive index is widely used in quality control to check for the purity of materials and to follow hydrogenation and isomerization [43]. Most of the seed oils reviewed have their refractive index values within the acceptable range of 1.4677 to 1.4707 for virgin, refined and refined-pomace oils according to Codex Standards for fats and oils from vegetable/plant sources [44]. The specific gravity ranges from 0.830 in pumpkin seed oil to 1.710 in almond seed oil. The result showed that most of the reviewed oils are less dense than water and therefore would be useful in cream production as it will make the oils flow and spread easily on the skin [45]. According to [46], specific gravity is commonly used in conjunction with other figures in assessing the purity of oil.

The density of the reviewed seed oils is found to be in the range of 0.847 in cotton seed oil to 1.160 in cashew nut seed oil. Density of seed/vegetable oils is dependent on their fatty acid composition, minor components and temperature [47]. The difference in the density of the reviewed oils may be due to the refined and unrefined characteristics of the oils. Viscosity increased with the molecular weight and decreased with increasing unsaturated level and high temperature [48]. The viscosity of the reviewed oils ranges from 0.43 to 302.39 in castor and almond seed oils, respectively. The more viscous oil is, the better its use as lubricant [49], hence pumpkin, jatroph curcas, cotton and almond seed oils will have high lubricating properties. Those oils with low viscosity value

indicate that they are light and so probably highly unsaturated; the high value might be as a result of suspended particles still present in the crude oil sample [50].
Acid value gives an indication of the quality of fatty acids in oil. From Tables 1a –1b, the acid values range from 0.34 to 68.88 in akee apple and luffa gourd oils, respectively. These values however accounted for the presence of free fatty acids in the oils as an indicator of the presence and extent of hydrolysis by lipolytic enzymes and oxidation [51]. Low acid value in oil indicates that the oil will be stable over a long period of time and protect against rancidity and peroxidation. This could be attributed to presence of natural antioxidants in the seeds such as vitamins C and A as well as other possible phytochemical like flavonoids. Acid value is used as an indicator for edibility of an oil and suitability for use in the paint and soap industries [52]. High acid value in oil (e.g. luffa gourd) showed that the oil may not be suitable for use in cooking (edibility), but however, be useful for production of paints, liquid soap and shampoos [52]. Also appreciable acid value of oils is an indication that the plant might be poisonous for livestock [52].
The saponification value is in the range of 5.58 to 249.90 for castor and palm kernel oils respectively. Saponification value is a measure of oxidation during storage, and also indicates deterioration of the oils. An increase in saponification value in oil increases the volatility of the oils. It enhances the quality of the oil because it shows the presence of lower molecular weight components in 1 g of the oil which will yield more energy on combustion [53]. The low saponification value is an indication that the oil may not be suitable for soap making, oil-based ice-cream and shampoos. It has been reported by [54] that oils with high saponification values contain high proportion of lower fatty acids. Therefore, the low saponification value of some oils under reviewed indicated that they contain high proportion of higher fatty acid and can be regarded as non-edible oils.

The iodine value is a measure of the degree of unsaturation and it is an identity characteristic of seed oils, making it an excellent raw materials for soaps cosmetics industries [55]. For the reviewed oils, iodine value ranges from 2.65 in almond seed oils to 153.00 in melon seed oil. The iodine value could be used to quantify the amount of double bond present in the oil which reflects the susceptibility of the oil to oxidation. Oils with iodine value less than 100 gI_2/100g of oil are non-drying oils correspondingly. [56] reported that the lower the iodine value the lesser the number of unsaturated bonds; thus the lower the susceptibility of such oil to oxidative rancidity. Therefore, non-drying oils are not suitable for ink and paint production due to their non-drying characteristics but may be useful in the manufacture of soaps [57] and can be regarded as liquid oil. A good drying oil should have iodine value of 130 and above. Thus, most of the oils in Tables 1a – 1b may not be suitable as alkyl resins for paint formulation or use as varnisher since they cannot be grouped as drying oil because of their iodine values. High iodine value is a pointer to the presence of high percentage of unsaturated fatty acids in the seed oil; as such amount of iodine that will be absorbed by the unsaturated acids would be higher [58], and oils with such characteristic may therefore be find useful as raw materials in the manufacture of vegetable oil-based ice cream [59].

Peroxide value (PV) is the most common indicator of lipid oxidation. The unrefined vegetable oils are characterized by greater PV, compared to refined oils. The PV of the oils under reviewed ranges from 0.45 in melon seed oil to 290.00 in bambara groundnut. High values of PV are indicative of high levels of oxidative rancidity of the oils and also suggest absence or low levels of antioxidant; certain antioxidants may, however, be used to reduce rancidity such as propygadlate and butyl hydroxyl anisole [93]. The [94] stipulated a permitted maximum peroxide level of not more than 10 mequivalent of oxygen/kg of the oils; therefore, some of the oils reviewed may not be suitable for consumption. The value for unsaponifiable matter is in the range of 0.837 to 41.780 for soy bean and luffa gourd seed seed oils respectively. High unsaponifiable matter content of fats and oils has been reported to be an indication of adulteration or contamination. This may be due to the presence of fuel or lubricating oils in the oil sample [95].

Free fatty acid is the percentage by weight of a specified fatty acid (e.g. percent oleic acid) [96]. High concentrations of free fatty acids are undesirable in crude vegetable oils because they result in large losses of the neutral oil during refining. In crude fat, free fatty acids estimate the amount of oil that will be lost during refining steps designed to remove fatty acids [97]. High levels of free fatty acids especially linoleic acids are undesirable in finished oils because they can cause off-favour and shorten the shelf life of oils. The quantity of free fatty acid in oil is an indicator of its overall quality. They may be formed through hydrolysis or in the advanced stages of oxidation. An excessive amount of free fatty acids lowers the smoke point of oil and will cause ‘popping’ of the oil during cooking. High quality oils are low in free fatty acids [98]. In refined vegetable oils, the lower the free fatty acid the more acceptable the oil is to man in terms of palatability. From the results of the reviewed oils, the percentage of free fatty acid ranges from 0.14 to 34.65 in castor and luffa gourd seed oils respectively. The heat of combustion value range between 8904.25 gcal/g and 11303.35 gcal/g with most of the reviewed oils having the value greater than the approximate value for edible oils 9500 gcal/g [99].

Table 1a: Physicochemical Properties of some Nigerian seed oils

Plant seed/Parameter	Colour	RI	SG	Ds	VS	AV	SV	IV	PV	USM	FFA	EV	HC	Authors
Melon seed oil *(Cucurbitaceae)*	Pale Yellow	1.350	0.913	-	5.89	7.09	220.19	114.94	20.00	-	4.51	213.10	9250.32	[60].
	White	1.470	0.920	-	-	4.77	197.00	150.00	5.63	-	1.80	192.23	9427.45	[61].
	Yellow	1.460	0.910	-	-	4.75	197.00	153.00	5.66	-	2.05	192.25	9424.45	[61].
	-	1.470	0.850	-	2.48	2.37	183.13	121.51	-	-	1.19[a]	180.76	9582.45	[62].
	-	1.470	1.51	-	-	8.02	8.00	3.45	1.72	-	4.03[a]	-	11303.35	[63].
	-	1.470	1.670	-	-	9.36	9.90	3.02	1.42	-	4.71[a]	0.54	11286.40	[63].
	Yellow	1.450	0.930	-	-	3.50	192.00	110.00	8.30	-	1.76[a]	188.50	9513.20	[64].
	-	1.460	-	-	-	2.02	208.10	114.30	0.45	-	2.15	206.08	9361.59	[65].
	-	-	0.910	-	-	3.40	148.50	74.50	2.80	-	1.71[a]	145.10	9946.73	[66].
	-	-	-	-	-	3.13	188.00	95.50	10.20	-	3.40	184.87	9564.30	[67].
	-	-	-	-	-	4.22	193.00	98.00	11.60	-	3.90	188.78	9516.05	[67].
	-	-	-	-	-	3.67	190.00	98.20	9.70	-	3.50	186.33	9543.30	[67].
	-	-	-	-	-	4.10	185.00	97.67	10.40	-	3.60	180.90	9589.58	[67].
	-	-	-	-	-	3.23	190.04	114.10	12.00	-	3.30	186.81	9527.03	[68].
	-	-	-	-	-	4.26	194.80	125.13	13.20	-	3.80	190.54	9472.45	[68].
	-	-	-	-	-	3.67	210.00	119.00	11.69	-	3.50	206.33	9339.50	[68].
Groundnut seed oil (*Arachis hypogeal*)	Light Yellow	1.462	-	-	-	4.63	227.49	38.65	-	-	2.33	222.86	9259.82	[69].
	-	1.472	-	0.903	-	-	-	-	1.18	-	0.67	-	-	[2].
	-	0.147	-	-	-	2.52	170.00	100.70	0.47	-	1.26	167.48	9723.80	[70].
	-	0.256	-	-	-	1.79	195.00	108.50	0.60	-	0.89	193.48	9487.25	[70].
	-	0.247	-	-	-	2.35	201.00	110.70	0.74	-	1.18	198.65	9430.15	[70].
	-	1.465	-	-	-	-	220.20	81.94	22.06	-	2.45	-	9283.23	[71].
	-	-	0.914	-	-	1.88	175.78	95.87	-	-	0.94	173.90	9675.74	[72].
	-	1.449	-	-	-	5.99	193.20	38.71	1.50	-	3.01	187.21	9573.51	[73].
	-	-	-	-	-	36.14	199.20	-	-	-	18.23	163.06	-	[74].
Castor (*Ricinus communis*) seed oil	Amber	1.469	0.959	-	9.42	1.15	185.83	87.72	-	-	0.58[a]	184.68	9591.94	[75].
	Amber	1.467	0.959	-	6.48	0.87	181.55	84.80	-	-	0.44[a]	180.68	9634.02	[75].
	-	1.792	-	0.948	0.43	14.80	180.77	58.64	158.64	-	7.40	165.97	9667.31	[76].
	-	-	-	-	-	2.39	123.30	76.93	-	-	1.20[a]	120.91	10174.88	[77].
	-	-	-	-	-	0.28	5.58	-	-	-	0.14	5.30	-	[74].

Table 1b: Physicochemical Properties of some Nigerian seed oils

Plant seed/Parameter	Colour	RI	SG	Ds	VS	AV	SV	IV	PV	USM	FFA	EV	HC	Authors
Pumpkin seed oil (*Telfairia occidentalis*)	Yellow	-	0.830	-	-	3.97	158.40	49.40	2.90	-	1.98	154.43	9881.24	[78].
	-	-	-	0.921	32.220	3.56	-	101.00	25.00	-	14.40	-	-	[79].
	Light Yellow	1.460	0.920	-	-	3.48	179.04	115.60	2.26	-	1.74	175.56	9626.18	[80].
	-	1.463	0.933	-	45.00	12.60	184.00	16.00	-	-	6.34[a]	171.40	9680.40	[81].
	-	1.461	0.928	-	44.70	62.60	187.00	15.80	-	-	31.49[a]	124.40	9653.15	[81].
	Yellow	1.476	0.911	0.911	119.00	4.77	162.69	123.83	-	-	2.40[a]	157.92	9767.56	[82].
Cashew nut seed oil (*Anarcadium occidentale*)	Yellow	1.654	0.964	-	-	0.82	168.30	44.40	3.10	-	28.40	167.48	9795.66	[83].
	-	1.470	0.900	-	-	12.66	17.60	136.89	2.94	-	0.73	4.94	11082.07	[84].
	-	1.470	0.910	-	-	22.72	10.01	115.01	1.60	-	1.18	-	11173.40	[84].
	-	1.458	0.962	-	-	10.70	137.00	41.30	-	-	5.40	126.30	10085.15	[85].
	-	-	0.960	-	-	10.70	137.00	41.30	7.95	-	5.40	126.30	10085.15	[86].
	Winsor orange	1.420	0.906	0.910	-	2.24	212.00	50.61	10.58	-	2.24	209.76	9389.59	[87].
	Yellowish	1.730	0.913	1.160	-	2.62	167.00	87.77	10.00	-	2.45	164.38	9764.18	[87].
Jatropha curcas seed oil (*Jatropha curcas* L.)	-	-	-	0.895	41.40	35.80	193.00	-	-	-	18.10	157.20	-	[88].
	-	-	0.901	0.886	20.49	18.76	240.53	20.30	56.00	-	9.39	221.77	9158.85	[49].
	-	-	0.896	0.881	76.18	23.87	230.71	26.09	44.00	-	11.94	206.84	9242.91	[49].
	-	-	-	-	-	1.20	122.49	73.46	-	-	0.60[a]	121.29	10185.76	[77].
	-	-	-	-	-	1.50	208.50	135.85	-	-	0.75[a]	207.00	9336.38	[26].
Sesame seed oil (*sesamum Indica* L.)	White	-	0.915	-	-	0.50	189.00	103.00	8.00	-	0.25[a]	188.50	9547.65	[89].
	Red	-	0.923	-	-	0.45	191.00	116.00	7.45	-	0.23[a]	190.55	9516.35	[89].
	Yellow	1.464	0.928	-	-	0.49	189.54	106.00	1.80	-	0.25[a]	189.05	9539.71	[90].
	-	-	-	-	-	2.48	-	121.40	7.50	-	1.30	-	-	[91].
	-	-	-	-	-	2.63	-	106.88	4.71	-	1.35	-	-	[91].
Almond seed oil (*Prunus amygdalus*)	Yellow	1.46	-	0.910	302.39	40.14	151.55	12.46	2.25	-	20.05	111.41	9980.86	[92].
	-	1.47	1.71	-	-	9.66	9.40	2.65	0.93	-	4.86	-	11291.34	[63].
	-	-	-	-	-	0.77	163.40	-	-	-	0.39	162.63	-	[74].

Table 1c: Physicochemical properties of some Nigerian seed oils

Plant seed /Parameter	Colour	RI	SG	Ds	VS	AV	SV	IV	PV	USM	FFA	EV	HC	Authors
African pear (*Dacryodes edulis*)	Dark yellow	-	0.87	-	-	5.56	246.60	40.20	21.23	-	2.78	241.04	9083.41	[100].
seed oil	-	-	-	-	-	5.61	179.52	31.50	20.00	-	2.81	173.91	9705.89	[101].
	-	1.458	0.882	-	17.27	5.96	193.89	130.96	5.40	2.62	3.00[a]	187.93	9474.95	[99].
Luffa gourd (*Luffa aegyptiaca*)	Yellowish green	-	0.920	0.91	-	20.62	168.00	130.00	280.00	3.98	10.36	147.38	9712.80	[102].
	Reddish brown	-	0.930	-	-	68.88	108.27	102.61	20.00	41.78	34.65	39.39	10286.72	[99].
Shea tree/Vitellaria seed oil	-	1.453	-	-	-	0.46	223.00	61.00	77.50	-	0.23[a]	222.54	9278.55	[93].
(*Butyrospermum parkii*)	-	1.464	0.895	-	-	4.30	224.40	68.08	-	-	2.16	220.10	9258.66	[103].
Kapok tree seed oil (*Ceiva pentandra*)	Light yellow	-	0.910	-	-	-	229.00	125.60	14.00	-	8.50	-	9159.05	[104].
	Brightly yellow	-	-	-	-	-	179.77	76.80	-	-	-	-	9658.30	[105].
Cotton seed oil	-	-	-	-	-	0.81	199.42	119.78	-	-	0.41[a]	198.61	9435.53	[106].
	Reddish brown	1.464	0.920	-	74.00	11.50	189.00	94.70	9.25	-	5.78	177.50	9555.95	[107].
	-	1.455	-	0.847	-	-	-	-	1.42	-	1.66	-	-	[2].
Horse Eye seed oil	-	1.466	0.915	-	-	0.90	195.01	108.98	11.06	5.87	0.45[a]	194.11	9486.68	[108].
(*Dioclea reflexa*)	-	1.465	0.913	-	-	0.98	206.09	113.88	10.13	6.20	0.49[a]	205.11	9380.40	[108].
	-	-	0.946	-	-	6.93	197.88	152.44	9.97	-	3.49[a]	190.95	9416.96	[110].
Moringa seed oil	-	1.470	0.910	-	-	7.09	180.31	55.02	15.96	-	3.57[a]	173.22	9675.14	[111].
(*M. oleifera*)	-	1.471	-	-	-	3.80	171.90	85.30	8.10	-	1.91[a]	168.10	9721.82	[112].
Africsan bush	-	-	-	-	-	-	256.50	8.20	0.50	-	2.72	-	9024.83	[113].
mango (*Irvingia gabonensis*)	-	1.430	-	-	-	20.10	202.90	7.90	1.20	-	6.97	182.80	9515.57	[65].
Soy bean seed oil (*Glycine max*)	Golden yellow	1.466	-	-	-	19.21	228.19	73.02	-	-	9.66	208.98	9219.04	[69].
	-	1.457	0.906	-	17.99	4.28	192.30	136.81	3.50	0.837	2.15	188.02	9483.65	[102].

Table 1d: Physicochemical properties of some Nigerian seed oils

Plant seed /Parameter	Colour	RI	SG	Ds	VS	AV	SV	IV	PV	USM	FFA	EV	HC	Authors
Palm kernel seed oil	-	-	0.910	-	-	10.71	249.90	20.70	4.36	-	5.90	239.19	9072.72	[86]
	-	1.473	-	-	-	6.20	210.50	34.74	13.40	-	3.12	204.30	9419.19	[112]
	-	-	-	-	-	0.83	191.98	-	-	-	0.42	191.15	-	[74]
Bambara groundnut seed oil (*Vigna* subterrenea)	Pale yellow	-	0.880	-	-	0.92	124.80	121.00	286.00	2.35	4.85	123.88	10117.08	[52]
	Yellow	-	0.885	-	-	0.98	140.50	120.00	290.00	2.25	4.80	139.52	9974.43	[52]
African star apple seed oil (*Chrysophyllum alibidum*)	Pale yellow	-	0.920	-	-	3.56	126.30	31.06	1.80	-	1.76	122.74	10193.30	[100]
	-	1.400	0.900	0.711	-	2.86	195.82	33.22	1.98	-	1.42	192.96	9555.03	[10]
	-	1.396	0.895	0.708	-	2.82	194.07	33.20	1.98	-	1.41	191.25	9571.06	[10]
Sunflower seed oil (*Helianthus annuus L.*)	-	-	0.915	-	-	0.95	182.14	119.92	6.32	-	0.042	181.19	9593.50	[114]
	Pale yellow	1.464	0.921	-	-	-	188.51	78.45	0.89	-	0.22	-	9576.68	[115]
	Pale yellow	1.471	0.919	-	-	-	190.61	82.50	0.89	-	0.19	-	9553.42	[115]
Koto/Pterygota seed oil (*Pterygota macrocarpa*)	-	1.493	0.930	-	-	4.12	43.85	93.31	6.07	1.23	2.16	39.73	10885.46	[116]
	-	1.455	0.928	-	-	3.98	17.88	49.68	4.87	1.02	2.05	13.90	11166.72	[116]
Bottle gourd	White	1.510	0.940	-	-	5.21	221.00	98.70	6.58	-	2.60	215.79	9259.15	[61]
	Yellow	1.490	0.930	-	-	4.59	225.10	100.32	6.62	-	2.30	220.51	9220.02	[61]
Rattle box seed oil (*Crotalaria retusa L.*)	Yellow	-	0.880	-	-	1.10	161.28	46.34	5.26	1.92	0.55	160.18	9857.95	[117]
Khaya senegalensis seed oil	Golden yellow	1.458	-	0.053	-	2.69	195.58	88.40	-	-	1.35[a]	192.89	9502.04	[118]
Calabash seed oil	Yellow	1.490	0.900	-	-	5.92	159.00	4.02	5.60	-	2.96	153.08	9921.13	[61]
Akee apple seed oil (*Blighia sapida*)	-	1.449	-	-	-	0.34	261.00	87.60	135.00	-	0.17[a]	260.66	8904.25	[90]
Black turtle bean (*Phaseolus vulgaris* L.)	–	–	0.959	–	8.12	10.4	190.5	146.4	3.2	3.62	–	–	–	[119]
Tigernut (*Cyperus esculentus*)														.
Blood plum (*Haematostaphis barteri*)	–	–	0.91	–	8.42	9.12	180.30	57.30	7.50	0.50	4.59	171.18	9672.96	
	–	—	0.92	–	10.62	24.0	189..40	122.42	9.20	2.54	12.07	166.22	9517.07	[56]
Desert date (*Balanites aegyptica* (L)Del)	–	–	0.93	–	2.12	26.35	162.40	55.20	3.82	–	13.25	136.05	9838.84	[120]
	–	–	0.93	–	1.41	26.35	162.40	55.20	3.82	–	13.25	136.05	9838.84	[121]kernel
	–	–	0.92	–	1.39	15.60	198.60	142.50	5.90	–	7.85	186.0	9420.31	[121]pulp

RI = Refractive Index, **SG** = Specific Gravity, **VS** = Viscosity, **AV** = Acid Value, **SV** = Saponification Value, **IV** = Iodine Value, **PV** = Peroxide Value, **FFA** = Free Fatty Acid, **Ds** = Density, **USM** = Unsaponifiable Matter, **EV** = Calculated Ester Value [saponification value – acid value]; **HC** = Calculated Heat of Combustion [11380 – iodine value – 9.15 (saponification value)], [a]**FFA** = Calculated Free Fatty Acid [0.503(acid value)], – = Not available

4. Conclusion

There has been an increase in the world production of oilseeds over the last thirty years; this would appear to be related to the increasing demand for oilseed products and by-products as oilseeds are primarily grown for their oil and meal. Vegetable oil is always at a higher price per ton than the cake, this is because the demand for oil is often higher than the cake. Generally, oils and fats from seeds and nuts constitute an essential part of man's diet. Fats and oils, together with proteins, carbohydrates, vitamins and minerals, are the main nutrients required by the human body. Fats and oils are rich sources of energy, containing two and a half times the calories of carbohydrates (per unit weight). In addition to being a source of vitamins A, D, E and K, fats and oils also contain essential fatty acids. These essential fatty acids are not manufactured by the body and must be obtained from diets, with oleic, linoleic and linolenic acids as examples of unsaturated fatty acids.

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CHAPTER SIX

Sources of Lithium Exploration in Nasarawa: An Analytical Approach Using Lingo Software

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Abstract

Lithium is found to be the 25th most abundant element in the earth's crust, covering one-quarter of the earth. Nigerian, as the largest black African country has over 35 mineral resources spread around the country naturally. These resources if harnessed well contribute immensely to the growth and development of any country. Lithium constituents extracted in Nigeria consist mostly of Kunzite followed by Spodumene, Lepidolite, Petalite, and Amblygonite. Economic growth and gross domestic product (GDP) of different countries depend solely on the exploration of these God given natural resources for sustainability. This research work used the Financial Market Theory of Development revealing that foreign investors should have access to "well-regulated" financial markets which would provide the "surest path" to economic development. Break-Even-Principle (BEP), called the Break-Even cutoff grade method was used to modify a model for comparison of the revenue earned to the costs incurred to generate the revenue. The model was run using lingo software and the five sources of lithium were analysed to obtain the expected rate of return. The findings revealed that, Spodumene is the highest source of Lithium in Nasarawa State with objective function value of 0.03; production quantity of over 1,500 *metric tons* of Lithium daily from Endo. Many challenges hindering the production processes and marketing were identified including lack of mutual agreement or memorandum of understanding; Incessant land disputes, communal clashes, tussle for individual and community land ownerships; lack of good government policies for production and recommendations were made.

Keywords: Endo, Grade, Lingo, Lithium, Return, Spodumene

1 Introduction

For over 20,000 years ago, Mining industries and its works were discovered as one of the oldest production industries [7]. These industries today generate over US$700 billions' of revenue in the world by a few mining companies [7, 2]. The mining work itself over time has culminated to very demanding affair and high optimal production planning because of the greater depth, low-grade, limited resources, and complex geo-mining conditions [1].

The research conducted by Pratima *et al*. [10] estimated Lithium to be the 25th most abundant element in the earth's crust, implying that Lithium covers one-quarter of the earths' crust. Nigerian, the largest country in black African has over thirty-five (35) mineral resources spread around the country naturally [7]. These industrial mineral resources if harnessed very well could contribute immensely to the growth and development of the country, Nigeria specifically and the African continent at large [2]. These industrial mineral resources vary from crude oil to coal, gold, bitumen, columbite, zinc and lithium ore etcetera. Abam and Salisu [7] revealed that Lithium Ore is one of the thirty-five (35) mineral resources deposited in many Lithium-bearing pegmatites. For Kathryn *et al*. [9], "the lithium constituents extracted in Nigeria consist mostly of Kunzite that is easily extracted. This is closely followed by Spodumene, then Lepidolite, Petalite, Amblygonite and many more yet to be discovered. The five listed sources of lithium ore in Nigerian deposits are as follows: Kunzite, Spodumene, Lepidolite, Petalite and Amblygonite. However, the beautification and characterization serve as the basic means of identifying the real deposits of Lithium ore in Nigeria as well as recovering the lithium since it multiplies the value and revenue generation of the country [8].

Globally, Ayeni and Nsien [5] revealed that the economic growth, gross domestic product (GDP) and the value of different countries depend solely on the exploration of the God given natural resources before considering other means of sustainability. Records from the United States Geological Survey [13] revealed that the need and demand for Lithium is increasing geometrically with a projection of about 10% annual consumption growth [7]. Meanwhile Pratima *et al.* [10] opined that the advancement in the technological driven devices and new energy industry has enhanced the consumption, need and high demand for lithium. Rudnick *et al*. [11] asserted that some Lithium occur in magmatic crystalline rocks with the possession of industrial and commercial values including lepidolite, spodumene, petalite, amblygonite-montebrasite, and zinnwaldite. Over the years, the outputs and results from mining industries and companies has helped positively in solving the challenges encountered by the Sustainable Development Goals (SDGs); however, in recent decades, the industry has made significant advances on minimizing and managing impacts by improving how companies manage both their social and environmental impacts [3]. From the backdrop, there is a great need to analyse the impacts of the five sources of lithium ore extraction in Nasarawa Local Government Area of Nigeria using lingo software.

2 Theoretical and Conceptual Framework

The Financial Market Theory of development is an economic theory that uses private flows of capital in new stock markets to encourage domestic development in developing countries. This theory was put forward by the World Bank's World Development Report for 2000. According to Abam and Akeremale [2], the theory states that foreign investors should have access to "well-regulated" financial markets which would provide the "surest path" to economic development. Businesses in low-income countries would gain direct access to the private capital from industrialized countries.

3 Methodology

The methodology chosen for this research is the Break-Even-Principle (BEP) also called the Break-Even cutoff grade that deals with the comparison of the revenue earned to the costs incurred to generate the revenue. This implies that, each grade is greater than the break-even calculation which in turn generates greater costs. The BEP is a one-dimensional process that basically looks into financial parameters. However, some mining industries and companies that use the BEP do not provide the expected rate of return (ERR).

3.1 Model Notations

The seven (7) Mining Cost Components consist of the mine plan, drilling, blasting and smoke cleaning, mucking and loading, supporting, Ore and waste hauling and back filing. The ten (10) Processing Cost Components include the crushing and separation, fine separation, milling, leaching and adsorption, elution, electro-winning, smelting, thickening, destruction and waste water treatment while the ten (10) Mining and Financial parameters include maximum capacity mined (Max min), maximum capacity of processing (Max Pro), maximum capacity refined (Re), cost of mining (m_c), cost of processing (CP), cost of refining (p_c), recovery (a), fixed cost (f), selling price (SP) and discount rate (r_d).

The notations used for the model formulation as contained by Abam and Isah [7] are stated below.

V(i,j,k) = Value of the grades of the (i, j, k)th blocks in percentages.

SP = Selling price of the mineral Ore (dollar per ton).

CP = Processing cost for the Ore (dollar per ton).

CM = Mining cost for the Ore (dollar per ton).

MB = Single block tonnage.

N_x = Number of blocks in the x-direction.

N_y = Number of blocks in the y-direction.

N_z = Number of blocks in the z-direction.

m_x = Minimum number of blocks in the x-direction in one stopping block.
m_y = Minimum number of blocks in the y-direction in one stopping block.
m_z = Minimum number of blocks in the z-direction in one stopping block.
GC = Grade cutoff marks for a particular type of Ore.
Min_m = Minimum tonnage needed to be mined in one period.
Max_m = Maximum tonnage needed to be mined in one period.
Min_p = Minimum tonnage needed to be processed in one period.
Max_p = Maximum tonnage needed to be processed in one period.

3.2 Decision Variable

$$y_{i,j,k} = \begin{cases} 1 & if \quad (i,j,k)^{th} \quad block \quad is \ in \quad stope \\ 0, & otherwise \end{cases} \tag{1}$$

3.3 Objective Function

From Abam, Oladejo and Emmanuel [4], every company strives to maximize performance capabilities. Similarly, the output and performances of company's workforce was modelled by [6] revealing that, the very essence of companies like mining industries is to maximize the net profit cash flow from single stope with blocks of mineral ore as well as minimize the cost of production. From Abam and Isah [7], the modified Gangawat economic function model to a profit for a single block model resulted to:

$$e_i = a_i * u_i * (f_i * r * s - c) * \rho_i \tag{2}$$

where i = blocks, a_i = blocks density, u_i = volume of blocks, f_i = average grades of blocks, r = level of recovery, s = selling price per unit, c = mining and processing costs per unit and ρ is the stope stability determinant strength factor given as:

$$\rho_i = \frac{Rock \quad mass \quad strength}{Induced \quad factor} \tag{3}$$

The present value of the cost gotten at each period is denoted as W_m

$$W_m = \frac{M}{(1+i)^P} \tag{4}$$

where M = the amount of money received, i = rate of interest, p = index time period.

From equations (1) to (4) we have the objective function aimed at maximizing the cash flow single stope given as:

$$\max h(Y) \sum_{i=1}^{N_x} \sum_{j=1}^{N_y} \sum_{z=1}^{N_z} \{[(W_m * \frac{V_{(i,j,k)}}{100} * SP - CP) - CM] * y_{(i,j,k)} * MB\} \tag{5}$$

where $y_{(i,j,k)}$ is the decision variable.

The equation (5) above represents the economic function model for lithium ore extraction including the five different identified sources of lithium ore in Nasarawa State.

The model was tested for its acceptability and adaptability as well as the performance of each source using a Lingo Mathematical Software and the raw data got from the sites.

4 Data Presentation, Analyses and Discussion

Table 1: The Quality and Quantity of Lithium in Nasarawa

Minerals	Onda	Opa	Endo	Gidan Kwanu	Kama Otto
Kunzite Quality Quantity	NIL	5% and above 10 – 15 tons per day	NIL	4% and above Approx. 8.6 tons per day	7% and above Approx. 12.8 tons per day
Lepidolite Quality Quantity	NIL	0.45 at most Less than a ton per day	NIL	NIL	NIL
Spodumene Quality Quantity	2% and above At least 40 tons per day	NIL	2.5% and above At least 1,500 per day	NIL	NIL
Petalite Quality Quantity	NIL	6% and above. At least 35 tons per day	NIL	8% to 10% At least 42.3 tons per day	NIL
Amblygonite Quality Quantity	NIL	2 – 4% At least 1 ton per day	NIL	NIL	NIL

Source: Abam and Isah [7] field data

Table 2: Lingo Codes and the Calculation Results for the Lithium Ore Exploration Model

The LINGO Code	The calculation results
model:	
$$\max h(x)\sum_{i=1}^{N_x}\sum_{j=1}^{N_y}\sum_{z=1}^{N_z}\{[(W_m * \frac{V_{(i,j,k)}}{100} * SP - CP) - CM] * y_{(i,j,k)} * MB\}$$	
local optimal solution found	
sets:	Objective value I: 0.02
	Objective value II: 0.01
	Objective value III: 0.03
	Objective value IV: 0.01
	Objective value V: 0.01
K/K1,…,K5/:Mineral Goal;! Kunzite;	Objective deviation: 5.44 metric tons
L/L1,…,L5/:Mineral Goal;! Lepidolite;	Objective deviation: 0.4435 metric tons
S/S1,…,S5/:Mineral Goal;! Spodumene;	Objective deviation: 2.7 metric tons
P/P1,…,P5/:Mineral Goal;! Petalite;	Objective deviation: 8.63 metric tons
A/A1,…,A5/:Mineral Goal;! Amblygonite;	Objective deviation: 4.27 metric tons
links (K, L, S, P, A):x;	Total Solver iterations: 48
endsets	Elapsed runtime seconds: 0.10
	Model Class: CoMEPEMoL
max=@sum(K(i): Kunzite (i)* d(i))+	Total variables: 10
max=@sum(L(i): Lepidolite (i)* d(i))+	Linear variables: 10
max=@sum(S(i): Spodumene(i)* d(i))+	Total Indices: 5
max=@sum(P(i): Petalite (i)* d(i))+	Linear Indices: 5
	Total Parameters 10
	Linear Parameters 10
max=@sum(A(i): Amblygonite (i)* d(i))+	Total Constraints: 10
@sum(N(i): Constraints (i)*)>=10;!constraints	Total non-zeros: 25
@for K(j):@sum(N(i);x(i,j))=1);	Linear non-zeros: 10
@for L(j):@sum(N(i);x(i,j))=1);	
@for S(j):@sum(N(i);x(i,j))=1);	
@for P(j):@sum(N(i);x(i,j))=1);	
@for A(j):@sum(N(i);x(i,j))=1);	
@for Mineral Goals 1-5(j):@for(N(i):@bin(x(i,j)))));!0-1 constraints	
@sum(Ki):Kunzite(i)*d(i);! Kunzite max;	Variable Goal value Reduced Value
	Kunzite (K1) 0.02 0.000000
	Kunzite (K2) 0.005 0.000000
	Kunzite (K3) 0.002 0.000000
	Kunzite (K4) 0.002 0.000000

```
                                 Kunzite (K5)       0.056         0.000000
@sum(L(i) Lepidolite(i)*d(i);! Lepidolite max; Variable Goal value   Reduced Value
                                 Lepidolite (L1)    0.01          0.000000
                                 Lepidolite (L2)    0.002         0.000000
                                 Lepidolite (L3)    0.002         0.000000
                                 Lepidolite (L4)    0.002         0.000000
                                 Lepidolite (L5)     0.005        0.000000
@sum(S(i):Spodumene(i)*d(i);! Spod. max; Variable Goal value  Reduced Value
                                 Spodumene (S1)     0.03          0.000000
                                 Spodumene (S2)     0.02          0.000000
                                 Spodumene (S3)     0.03          0.000000
                                 Spodumene (S4)     0.02          0.000000
                                 Spodumene (S5)     0.006          0.000000
@sum(P(i): P(i)*d(i);!Petalite max;      Variable  Goal value       Reduced Value
                                 Petalite (P1)    0.001         0.000000
                                 Petalite (P2)     0.002        0.000000
                                 Petalite (P3)     0.005        0.000000
                                 Petalite (P4)     0.004        0.000000
                                 Petalite (P5)     0.008        0.000000
@sum(A(i):Ambly. (i)*d(i);! Ambly. max; Variable    Goal value   Reduced Value
                               Amblygonite(A1)   0.01           0.000000
                                 Amblygonite (A2)    0.002          0.000000
                              Amblygonite (A3)     0.002          0.000000
                                 Amblygonite (A4)    0.005          0.000000
                               Amblygonite (A5)    0.005          0.000000
data:
kunzite=0.35, 0.85, 0.002, 0.002, 0.56, 0.003, 0.58, 0.003, 0.50;
lepidolite=0.35, 0.002, 0.002, 0.002, 0.005, 0.56, 0.56, 0.003, 0.003;
spodumene= 0.35, 0.002, 0.852, 0.002, 0.56, 0.001, 0.56, 0.003, 0.003;
petalite=0.35, 0.002, 0.005, 0.004, 0.038, 0.0045, 0.002, 0.003, 0.001;
amblygonite=0.35, 0.002, 0.002, 0.85, 0.005, 0.001, 0.001, 0.85, 0.003;

enddata                   Goal case Y (K1)          544,143.100 tons
end                       Goal case Y (K2)          864,093.200 tons
                          Goal case Y (K3)           501,125.300 tons
                          Goal case Y (K4)          1,504,143.100 tons
                          Goal case Y (K5)           130,246.500 tons
                          Goal case Y (L1)           0.443 metric tons
                          Goal case Y (L2)           1.433 metric tons
                          Goal case Y (L3)           0.425 metric tons
                          Goal case Y (L4)           0.418 metric tons
                          Goal case Y (L5)           0.433 metric tons
                          Goal case Y (S1)           40.750 metric tons
                          Goal case Y (S2)           2.452 metric tons
                          Goal case Y (S3)         1,500.653metric tons
                          Goal case Y (S4)           2.045 metric tons
                          Goal case Y (S5)           2.200 metric tons
                          Goal case Y (P1)           8.443 metric tons
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Goal case Y (P2)	35.633 metric tons
Goal case Y (P3)	8.258 metric tons
Goal case Y (P4)	42.418 metric tons
Goal case Y (P5)	8.339 metric tons
Goal case Y (A1)	0.000 metric tons
Goal case Y (A2)	4.250 metric tons
Goal case Y (A3)	1.230 metric tons
Goal case Y (A4)	1.200 metric tons
Goal case Y (A5)	2.270 metric tons
Goal case Y (Obj value1)	0.025
Goal case Y (Obj value 2)	0.010
Goal case Y (Obj value 3)	0.030
Goal case Y (Obj value 4)	0.010
Goal case Y (Obj value 5)	0.010

5 Discussion of Results

The data got from the field revealed that there is a quantitative value of more than 40 tons of low grades of Spoudumene per day with a 2% quality above lithium concentration is mined from the Angwan Mada, Onda village site daily. This site experienced a drop in production due to legal issues and disagreements between the community and the mining company. At Opa village, a high grade of kunzite of 5% - 8% of lithium concentration is mined every day. A quantity of not less than 10 to 15 tons of lithium from kunzite is mined daily with high grade value. Similarly, 30 to 40 tons of high grade petalite is mined from Opa village daily. Also, at Opa village, 2 – 4% quality of concentration of amblygonite is mined daily making a 1 to 2 tons of lithium containing amblygonite. Endo village is the largest lithium site in Nigeria with a low grade spodumene of 2.5% above in concentration and between 50 to 100 truck-loads containing between 30 to 45 tons each of this lithium source mined per day. Endo happens to be the busiest lithium mining site producing highest quantity of the mineral of more than 1500 tons per day in Nasarawa Local Government Area and Nigeria at large. Be that as it may, mining work has been stopped due to legal issues between the companies, communities and the government of the day. Gidan

Kwanu village produces two to three trucks of high-grade kunzite of lithium concentration of 4% and above per week which accounts for 8.6 *tons per day*. In the same site, a high grade of petalite of 8% - 10% is mined from this site with one truck in quantity per week which accounts for 4.2 *tons* of the high-grade minerals mined at the site. At Kama Otto, a high-grade kunzite of 7% and above of lithium concentration is mined at the site daily with a quantity of at least 3 to 4 trucks load of the mineral which accounts for 1.28 *tones* of the mineral per day.

6 Summary, Conclusion and Recommendations

Kunzite as a mineral is produced to a capacity of over 15 *metric tons per day* at Opa village; 8.6 *metric tons* at Gidan Kwanu and 1.28 *metric tons* from Kama Otto village as the largest quantity respectively. The Lingo programme runs revealed that there exists an objective function value of 0.02 while Lepidolite has an objective function value of 0.01 predominantly found at Opa village with a quality value of 0.45 and not less than 1 *ton production per day*. Spodumene occurred highly at Endo village with the highest quantity of over 1,500 *metric tons* daily produced summing up to a quality production of over 2.5%. it also existed at Onda village with a daily minimum of 40 *tons* making 2% quality which revealed the highest objective function value of 0.03 as shown in table 2 above. This implies that Spodumene is the highest source of Lithium Ore in Nasarawa State and Nigeria as a whole. Petalite was found in Opa village and Gidan Kwanu with a quality value of about 6% and 10% respectively. Each site produces over 35 *tons* and 42 *tons* per day respectively revealing an objective function value of 0.01. For Amblygonite, table 2 reveals that this source of lithium only occurs in Opa village qualitatively with a 2.45 value and over 1 ton per day production yielding a 0.01 objective function value.

Conclusively, Spodumene stands as the highest source of Lithium Ore in Nasarawa State and Nigeria as a whole with an objective function value of 0.03 and production quantity of more than 1,500 metric tons of Lithium Ore per day from Endo village. However, there are many challenges hindering the production processes, marketing and converting of the minerals into finished goods as well as to the state of a high economic value. These include: lack of mutual agreement or memorandum of understanding or production between the mining companies and the Government of the day as well as the host communities; Incessant land disputes, communal clashes, tussle for individual and community land ownerships; lack of government policies and laid down rules, bargaining agreement between host communities and the mining companies as well as the government of the day.

The following Recommendations were made:

1. The outstanding legal issues should be redressed out of court and a memorandum of understanding/production or a deed of assignment signed so as to benefit all parties involved.
2. The State and Federal Governments should wade into the communal land clashes and disputes in order to bring lasting solutions to the peaceful coexistence of all parties.
3. Government of the day in conjunction with the mining companies should beef up security at the mining sites in order to maintain a secured environment for mining activities.
4. Both the State and Federal Government should enact good laws, bills and policies regarding Mineral Exploration or extraction generally so as to serve as a means of revenue generation to the Nigerian economy thereby enhancing economic growth.
5. Mining companies should provide the basic social amenities to the host communities and also make employment available to indigenous youths so as to improve the standard of living of the host communities in order to measure up with the 2030 SDGs.

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CHAPTER SEVEN

Biochemical Innovations: Pioneering Solutions for Climate Change Mitigation

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Abstract

Climate change represents a critical global challenge, necessitating innovative solutions to mitigate its adverse effects. This review examines biochemical approaches as viable strategies for reducing greenhouse gas emissions, highlighting their role in enhancing carbon sequestration, mitigating methane emissions, and producing sustainable biofuels. It discusses the significance of biochemistry in understanding climate dynamics and developing effective remedies, including the processes of photosynthesis and soil management for carbon capture. Additionally, it explores the potential of synthetic biology and engineering biology (EngBio) in optimizing biochemical solutions, such as gene editing for improved nitrogen-fixing microorganisms and the innovation of designer microorganisms for biofuel production. The review also explores the challenges involved in implementing these biochemical methods, such as economic constraints, technical limitations, and social barriers. Additionally, it offers strategic recommendations for policymakers to facilitate the effective adoption and integration of these methods. Emerging trends in biochemistry, including advances in carbon capture technologies and enzymatic solutions for pollution control, are highlighted as critical components in the fight against climate change. The review concludes by emphasizing the need for interdisciplinary collaboration, supportive policies, and international cooperation to realize the full potential of biochemical approaches in creating a sustainable, carbon-neutral future.

Keywords: Climate change, Biochemical approaches, Carbon sequestration, Methane emissions, Sustainable biofuels, Synthetic biology

1. Introduction

Climate change represents an unparalleled global challenge, necessitating innovative and integrative approaches to mitigate its far-reaching impacts. The core objective is to avert catastrophic disruptions to the delicate climate system, as highlighted by initiatives such as the United Nations Framework Convention on Climate Change (UNFCCC) [1]. Achieving the required reductions to limit global warming is still elusive, despite initiatives like the Kyoto Protocol. This underlines the urgent need for comprehensive risk management plans and emphasis on removing structural obstacles, such as a lack of legally binding commitments, stalled international negotiations, and unfulfilled reduction goals. A comprehensive and sustainable solution is required due to the intricate interactions between social, economic, and environmental factors and climate change.

Using low-carbon and renewable energy sources like nuclear, wind, and geothermal energy instead of fossil fuels is one of the main ways to combat climate change [2]. Nevertheless, the government's current commitments fall well short of what is needed to reduce emissions. Alongside geoengineering interventions like solar radiation management, creative solutions have been put forth in response, such as carbon capture technologies like deep ocean sequestration and geological storage. These include the use of spacecraft as sunshades and the application of seawater seeding or sulfate aerosols to alter cloud albedo [3]. In addition, biogeoengineering—an approach based on biology—offers tremendous potential to mitigate and repair the effects of climate change.

The rapidly advancing field of engineering biology (EngBio) offers transformative potential in this regard. Employing techniques such as gene editing, synthesis, and biomolecular engineering, EngBio provides innovative pathways to reduce greenhouse gas emissions and adapt to climate challenges [4]. EngBio could become a cornerstone of climate mitigation strategies with appropriate policy frameworks. Current gaps in its integration within climate policy, particularly in key scenarios outlined by the Intergovernmental Panel on Climate Change (IPCC), warrant urgent attention. A more comprehensive evaluation of EngBio's contributions is essential, particularly in supporting international commitments like the Paris Agreement, which aims to cap global warming at 1.5 °C [5].

Biochemical approaches also present promising avenues for addressing the multifaceted challenges of climate change [6]. Biochemistry is pivotal in understanding the complex processes that drive climate dynamics. By exploring biochemical mechanisms and pathways, we can uncover how biological systems can actively contribute to mitigating the impacts of climate change. As the demand for innovative and sustainable solutions to global challenges grows, biochemistry-based approaches stand out for their ecological sustainability and efficiency. The limitations of existing strategies highlight the pressing need for new, adaptable methods, with biochemistry offering a comprehensive framework to address the evolving challenges posed by climate change.

This review examines global efforts and challenges in combating climate change, focusing on the essential roles of biochemical stategies, interdisciplinary collaboration, and policy interventions. It highlights the potential of biochemistry-based strategies, providing an overview of their applications and exploring how they can be leveraged to mitigate climate impacts. The discussion also delves into the utilization of biological systems and emerging technologies, showcasing innovative solutions that biochemistry offers for a sustainable future.

2. Methodology

A summary of the many biochemical strategies for reducing the effects of climate change globally can be found in this article. An extensive literature review was conducted using government reports, academic journals, conference proceedings, and reliable databases such as PubMed and Google Scholar. The most frequently searched keywords were "enzymatic solutions," "carbon sequestration," "methane emissions reduction," "biochemical approaches," and "sustainable biofuels. Preference was given to publications that focused on biochemical approaches to climate change mitigation from the last two decades, focusing on empirical studies while excluding speculative or unsupported claims. Four main themes emerged from the literature: enzymatic pollution control, carbon sequestration, methane emission reduction, and sustainable biofuel production. The efficiency, scalability, and sustainability of these biochemical methods were evaluated through a comparative analysis, and new developments in engineering biology and synthetic biology were also examined. Along with an analysis of current policies pertinent to biochemical innovations, challenges including social, technical, and economic barriers were identified. The findings' synthesis highlights the potential of these biochemical approaches to combat climate change, emphasizing the need for interdisciplinary cooperation and increased policy support to promote their development and application.

3. Carbon Sequestration Overview

Innovative and sustainable solutions are essential in response to the increasing greenhouse gas emissions causing climate change. One promising approach is a biochemical method, carbon sequestration, which is a complex process involving the capture and long-term storage of carbon dioxide (CO_2). Toensmeier [7] emphasizes that reducing human-induced climate change hinges on effective carbon sequestration. This section emphasizes the complexity of this transformative process by highlighting the complex interactions between biological, geological, and physical processes in the global carbon cycle. According to this concept, there are opportunities for enhanced carbon capture by natural and bioengineered means through photosynthesis, a major biochemical process, photosynthesis [8].

There is great promise in photosynthesis, the ingenious mechanism by which bacteria, algae, and plants use sunlight to convert CO_2 into organic compounds [8]. By examining its metabolic complexity, carbon sequestration systems could be improved [9]. A deeper understanding of its metabolic intricacies could lead to optimized carbon sequestration strategies [9]. Beyond photosynthesis, soil serves as a vast carbon reservoir, playing a pivotal role in global carbon dynamics [10]. Effective soil carbon storage relies on complex interactions among organic matter, microbial communities, and root-soil dynamics, presenting opportunities for innovative soil management practices [11]. Given the interdependence of different biochemical pathways, it is critical to create sustainable carbon sequestration solutions holistically, keeping in mind that modifications made in one area may have an impact on other areas.

The third-largest carbon pool in the world is found in soil, which has 2,500 petagrams of carbon down to a depth of one meter much more than the atmosphere [12]. Although there is a chance that increased microbial decomposition brought on by climate change could turn soils from carbon sinks to sources, proactive management may enable soils to sequester significant amounts of carbon, estimated to be between 0.4 and 1.2 Pg C per year [13]. No-tillage farming, turning arable land into permanent grasslands, and using cover crops are methods for increasing soil carbon [14]. The long-term effectiveness of these strategies in many ecological contexts remains uncertain, but research has shown that nitrogen fertilizers also increase organic matter, which paradoxically promotes the breakdown of carbon, but they may also help store it [15]. While reduced tillage techniques can improve soil fertility and structure, they also have disadvantages, such as increased nitrous oxide emissions [16] Additionally, it has been demonstrated that increasing grassland diversity improves carbon storage, highlighting the importance of biotic interactions in the dynamics of soil carbon [17].

4. **Biochemical Mechanisms for Carbon Capture**

Studying biochemical pathways for carbon capture reveals key strategies for a holistic response to climate change. The contributions of soil and microbes become crucial components that elucidate the intricate processes within ecosystems [18]. The focus on soil emphasizes its importance as a carbon storage reservoir, emphasizing the interaction of organic matter dynamics, plant interactions, and microbial processes [19]. The significance of acknowledging soil as a crucial component in reducing carbon emissions is highlighted by this study, which promotes a comprehensive strategy for carbon capture that incorporates soil management techniques. According to Yu *et al.* [20], novel methods of photosynthesis represent a frontier in carbon capture technology, providing promising paths to improve carbon sequestration. Synthetic biological systems and artificial photosynthesis offer potential ways to overcome traditional constraints and more successfully combat climate change [21]. By pushing the limits of technology and knowledge, scientists hope to use these new photosynthetic techniques to maximize carbon capture and support environmentally friendly practices. Microalgae become essential factors in carbon capture initiatives, especially when carbonic anhydrase (CA) is active [22]. The remarkable capacity of microalgae to fix carbon and the role that CA plays in facilitating CO_2 sequestration make them important contributors to sustainable energy solutions [23]. The ability of microalgae to produce biofuel from captured CO_2 highlights their adaptability in meeting energy needs and climate change [24]. Ongoing studies on CA isoforms and carbon concentration mechanisms, ecological concerns, and difficulties with large-scale algal production, however, underscore how biochemical approaches to carbon capture are changing [25]. These difficulties highlight the necessity of ongoing development and study to maximize the effectiveness and sustainability of carbon capture technologies based on microalgae.

5. **Carbon Concentrating Mechanisms (CCMs)**

According to Giordano *et al.* [26], cyanobacteria, algae, and some plants use carbon concentrating mechanisms (CCMs) to raise CO_2 levels around ribulose–1,5-bisphosphate carboxylase/oxygenase (RuBisCO), which reduces oxygenation and improves carbon assimilation. Genetically introducing CCMs into C3 plants is a practical way to increase photosynthetic efficiency and reduce carbon emissions [26].

While improving natural carbon fixation pathways, synthetic methods provide creative ways to combat climate change. The creation of novel CO_2 fixation routes is intended to address the shortcomings of existing pathways, including their energy requirements and oxygen sensitivity. Synthetic processes such as the reductive glycine pathway and the CETCH cycle (crotonyl-CoA/ethylmalonyl-CoA/hydroxybutyryl-CoA) have the potential to convert CO_2 into desired chemicals more efficiently and adaptably [27]. Integrating CCMs and synthetic pathways into industrial applications, such as biofuel production and carbon capture technologies, signifies a major step forward in climate change mitigation efforts. Advancing these technologies through interdisciplinary collaboration holds promise for achieving a sustainable, low-carbon future. Genetic engineering and biotechnology advances facilitate more effective carbon fixation. Furthermore, synthetic biology techniques aim to engineer non-photosynthetic bacteria with carbon-fixing pathways, creating novel opportunities for carbon capture and utilization [28].

6. The Use of Carbon-Fixing Enzymes in Enzymatic Approaches to Climate Change Management

Given the enormous threat that climate change poses to global stability, creative ways to lessen its effects must be investigated. Enzymatic solutions are one of the most promising approaches to address the issues caused by the increasing levels of carbon dioxide in the atmosphere. Our detailed analysis of the role of enzymes in carbon fixing demonstrates their importance in addressing climate change. Carbon fixation, a crucial process that converts atmospheric carbon dioxide into organic compounds, is at the core of the carbon cycle [29]. Since it is an essential mechanism for removing carbon from the atmosphere, this process is a pillar in the fight against climate change. Carbon-fixing enzymes, which function as biological catalysts coordinating the transformation of carbon dioxide into organic molecules necessary for life support, are at the heart of carbon fixation. Phosphoenolpyruvate carboxylase (PEPC), ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO), and other important enzymes are among the remarkably diverse group of carbon-fixing enzymes [30]. In many different organisms, but especially in photosynthetic organisms like plants and algae, these enzymes are essential. Because these enzymes initiate the process of biomass formation, they significantly contribute to efforts to sequester carbon. Environmental factors such as temperature and nutrient availability impact the efficiency of these enzymes, further highlighting the complex interplay between biological and environmental processes in carbon fixation [31]. Genetic engineering approaches offer viable avenues to enhance carbon sequestration and mitigate climate change. The goal is to alter the properties and expression of carboxylases and other carbon-fixation enzymes to increase the efficiency of carbon-fixation pathways in microorganisms and plants. Techniques that could help carbon sequestration efforts include increasing the specificity of enzymes, overexpressing key enzymes, and optimizing RuBisCO catalysis. Enzymatic solutions present promising ways to enhance carbon fixation processes to combat climate change. Through the use of synthetic pathways, genetic engineering approaches, and elucidating the role of carbon-fixing enzymes, scientists hope to improve carbon sequestration efforts and mitigate the impacts of growing atmospheric carbon dioxide levels. Enzymatic solutions offer hope for a sustainable future in the face of climate change issues by fostering interdisciplinary innovation and collaboration.

7. Methane Mitigation

Understanding and addressing the complex dynamics of methane, a powerful greenhouse gas, has become a key focus in the unrelenting quest for effective climate change mitigation. Methane plays a major part in the list of factors that cause global warming because it can trap far more heat in shorter amounts of time than carbon dioxide [32]. This paper explores the complex and urgent role that methane plays in greenhouse gas emissions and highlights the difficulty of reducing its effects. According to Karakurt *et al*. [33], methane can originate from a variety of sources, such as the digestion of livestock, rice paddies, landfills, and the extraction of fossil fuels. The difficulties posed by each source add to the difficulty of reducing methane emissions. Anthropogenic and natural sources interact, making it even more urgent to include methane in all-encompassing climate change plans. Mitigating methane emissions is crucial because it highlights the effects of global warming from the Arctic tundra to the ocean floor [34].
A puzzling trend has emerged in the atmospheric dynamics of methane over the past 15 years [35]. After a period of relative stability, methane concentrations have surged exponentially since 2007, contradicting the mitigation trajectories outlined in the Representative Concentration Pathways (RCP)[36]. This acceleration, particularly under RCP 8.5, highlights the increasing impact of methane on global warming, especially when compared to the slower growth rates of CO_2 and nitrous oxide during the same period [37]. Both natural and anthropogenic sources play significant roles, as evidenced by the global methane budget, which tracks the balance between sources and sinks [38]. In tropical and mid-latitude regions,

human activities such as agriculture and waste management are primarily responsible for two-thirds of global emissions from tropical sources, especially wetlands [39]. However, discrepancies in estimates of emissions linked to fossil fuels, biogenic contributions, and biomass burning have made it challenging to pinpoint the exact sources behind the atmospheric increase in methane since 2007 [40]. Scientific advances are required to reduce uncertainties in the methane budget. To improve bottom-up modeling, direct methane flux measurements, process-based models for different sources, and dynamic global maps are crucial [41]. Improvements in measuring methane and its isotopes, as well as better observations of tracers unique to methane sources, like isotopic concentrations and emission signatures, are essential [42]. Furthermore, improved constraints on models of atmospheric transport and chemistry are necessary for precise flux estimates derived from inversion. Despite these doubts, the recent increase in methane concentrations points to a substantial human role [43]. This is crucial for shifting emissions toward lower trajectories like RCP6 or RCP4.5 since it presents opportunities for climate change mitigation [44]. Since methane has a short atmospheric lifetime and a strong potential for global warming, mitigating it is a quick fix for climate change [45]. Reducing methane emissions benefits not only the climate but also human health, agricultural output, and employment opportunities [46]. Coal mine venting and flaring, identifying and fixing natural gas leaks, covering landfills to produce biogas, and putting farm bio-digesters into place are just a few of the many different types of mitigation techniques [47]. Current studies investigate novel strategies such as changing the diets of ruminants and the methods used in rice farming [48]. These tactics are essential for lowering methane emissions in areas with high emissions, especially in the waste and agriculture sectors [49].

8. Biochemical Methods for Methane Reduction

Biochemical strategies for methane reduction explore the intricate mechanisms involved in enhancing methane oxidation efficiency and inhibiting methanogenesis, aiming to mitigate methane emissions and combat climate change. Key enzymes required for methane production in methanogenic archaea must be disrupted to inhibit methanogenesis [50]. Strategies to prevent methane emissions at their source, especially in anaerobic environments like wetlands, cattle farms, and wastewater treatment plants, can be developed with an understanding of the biology of methanogenesis [51]. This inhibition typically targets the enzymes that are essential to methanogenesis, such as methyl coenzyme M reductase (MCR), which catalyzes the last stage of methane production from methyl coenzyme M and coenzyme B [52]. Methane emissions from various sources can be effectively reduced by inhibiting MCR or other enzymes associated with methanogenesis [53].

However, to use methanotrophic bacteria for methane oxidation, it is necessary to comprehend the biochemical processes that allow these bacteria to convert methane to carbon dioxide [54]. The primary enzyme in charge of methane oxidation, methane monooxygenase (MMO), is found in methanotrophic bacteria [55]. Each of the two forms of MMO—soluble MMO (MMO) and particulate MMO (pMMO) has unique traits and catalytic qualities [56]. The bacterial membrane incorporates pMMO, whereas the cytoplasm produces sMMO. Methane is converted by these enzymes to methanol, which is then oxidized to formaldehyde, formate, or absorbed into cellular biomass [57]. Methanotrophic bacteria work to enhance methane oxidation efficiency by optimizing environmental conditions and substrate availability, thereby maximizing methane consumption rates. Investigating the microbial communities associated with methanotrophs can reveal cooperative interactions that further boost methane oxidation in diverse environments.

Biochemical engineering approaches are instrumental in developing innovative methane mitigation strategies, harnessing the metabolic capabilities of methanotrophs and the biochemical processes that drive methane oxidation [58]. Building designed systems like biofilters and bioreactors are necessary to effectively reduce methane emissions using these biochemical principles. Optimizing reactor topologies and parameters is necessary to overcome problems with limited solubility of gaseous substrates and limitations in gas-to-liquid mass transfer, ensuring optimal product production while maintaining microbial growth and metabolic activity.

9. Biochemical Techniques for Biofuel Production

Biochemical processes used to produce biofuel offer a direct way to combat climate change by reducing greenhouse gas emissions and promoting sustainable energy practices. By utilizing renewable biomass resources and decreasing dependence on fossil fuels, biofuel production plays a significant role in cutting carbon dioxide emissions and facilitating the transition to a low-carbon economy [59]. Moreover, incorporating biofuels into existing energy infrastructures supports the decarbonization of the transportation sector, a major driver of global warming. Additionally, the integration of biofuels into existing energy systems facilitates the decarbonization of the transportation sector, which is a major contributor to global warming.

Fermentation, one of the primary methods for creating bioethanol highlights the significance of microbial biochemistry in the synthesis of biofuel. Sugars from biomass are converted into ethanol in this process by the metabolic activities of microorganisms. Yeast and other key microbial catalysts enable the effective conversion of carbohydrates into biofuel precursors, highlighting the role of microbial metabolism in the generation of sustainable energy [60]. Enzymatic conversion serves as an accurate method of turning complicated organic resources into biofuel precursors using enzymes to catalyze biological reactions. This route has significant promise for optimizing substrate use and increasing the efficiency of biofuel generation. By using enzymes to tailor biofuel synthesis to specific feedstocks, it is possible to exploit a wide range of biomass sources while minimizing environmental impact [61].

10. Enzymes that Degrade Environmental Contaminants

According to Malhi *et al.* [62], environmental pollution is a major threat to the delicate ecosystem balance and exacerbates the problem of climate change. Discover how nature's biochemical catalysts can be used as effective tools to break down environmental pollutants through the process of enzymatic degradation. Several classes of enzymes are covered in this section, each with a special ability to target particular pollutants and catalyze their conversion into less dangerous or even benign compounds. The efficiency and specificity of these enzymes in degrading pollutants must be well understood to develop targeted and effective solutions for pollution management and climate change mitigation.

The narrative continues by talking about the various ways that enzymatic degradation can be used to reduce pollution and slow down climate change. According to Demarche *et al.* [63], utilizing enzymes' power provides a sustainable and eco-friendly method of reducing the adverse effects of pollutants on the environment, in addition to aiding with more comprehensive climate change mitigation techniques. Enzymatic solutions are used in a variety of environmental compartments, including soil, water, and air [64]. In wastewater treatment, enzymes are also essential because they degrade stubborn contaminants that are difficult to eliminate using traditional techniques.

12. Some Unique Strategies for Enhancing Carbon Sequestration and Climate Mitigation

Reforestation reduces CO_2 levels in the atmosphere, making it one of the best strategies to slow climate change. Large-scale afforestation could lower CO_2 levels by about 79 parts per million and global temperatures by about 0.74 degrees Celsius by 2050, according to simulations of global climate models [65]. However, several negative feedback mechanisms may limit its effectiveness. For instance, increased biomass could lead to a loss of soil carbon as CO_2 levels decline because net primary output would decrease [66]. The albedo effect, which can result in unintended warming rather than cooling, can also be influenced by forestry activities [9]. This is particularly true in high-latitude regions where snow cover reflects sunlight. Afforestation is not the only promising approach; ocean fertilization is another. The goal of this strategy is to raise ocean primary productivity to increase CO_2 drawdown, while simultaneously raising crops' albedo to reflect more sunlight and lower temperature increases [67]. Though theoretically promising, these strategies need more investigation to assess their viability and potential ecological effects, such as those on ecosystems and agricultural productivity.

Negative feedback mechanisms limit benefits, making increasing carbon sequestration a difficult task. For instance, winter albedo in high-latitude forests frequently decreases, which causes warming as opposed to cooling [68]. Afforestation in tropical areas may provide some cooling benefits, while afforestation in boreal regions may worsen warming effects, according to research [69]. Surface temperatures may be lowered via methods to increase crop albedo, such as increasing the reflectiveness of agricultural surfaces. Geo-engineering methods have also been proposed to mitigate warming, such as increasing cloud-top albedo by introducing saltwater aerosols into marine clouds [70]. The significant technical challenges and potential ecological consequences of these geo-engineering techniques underscore the intricacy of effectively tackling climate change with these strategies.

13. Overview of Effective Biochemical Solutions for Climate Change

Numerous initiatives that use biological processes to address climate change issues are covered in this review. These initiatives show how biological methods could change how environmental problems are addressed. Anaerobic digestion for waste conversion into electricity, enzymatic pollution control, and carbon sequestration through reforestation are significant examples [71]. The use of reforestation initiatives to produce carbon sequestration through plant photosynthesis is one noteworthy success story. Trees and plants take up carbon dioxide from the atmosphere through the process of photosynthesis, which stores it in their biomass. This supports biodiversity and ecosystem health in addition to reducing greenhouse gas emissions [72]. Anaerobic digestion (AD), which turns organic waste into bioenergy, is another effective use of biochemical principles [73]. AD produces biogas, a renewable energy source, and treats organic waste economically and effectively. AD contributes to lowering methane emissions and slowing down climate change by keeping organic waste out of landfills and using it to generate energy. Enzymes are biological catalysts that can transform pollutants into harmless compounds, making it easier to restore ecosystems affected by pollution. This approach is safe for the environment, can be tailored to target specific pollutants, and is a sustainable solution to environmental degradation. These successful initiatives underscore the importance of utilizing biochemical processes to combat climate change and offer scalable and sustainable ways to lessen the effects of global warming by leveraging the inherent capabilities of biological systems.

14. International Projects for the Development of Biochemical Solutions

International projects focused on biochemical solutions to climate change underscore the growing importance of global collaboration. Initiatives like the Paris Agreement, the Kyoto Protocol, and regional partnerships reflect nations' commitment to collective action [74]. These efforts, which include biofuel research, reforestation, and enzymatic pollution control, highlight the interconnected nature of climate change and the need for a unified response driven by biochemical innovation [74,39].

15. Collaborative Strategies for Climate Change Mitigation

As the study progresses, it uncovers the essential role of collaborative strategies in successfully addressing climate change. For biochemical solutions to be effectively applied worldwide, collaboration through technology transfer, information sharing, and joint funding initiatives is vital. This section examines international research projects that transcend geopolitical boundaries by harnessing the collective expertise of diverse scientific teams. For example, the **IEA Bioenergy Technology Collaboration Programme** advances biofuels and bioenergy technologies, offering renewable alternatives to fossil fuels, thus reducing greenhouse gas emissions and supporting cleaner energy [75]. Similarly, the **Carbon Sequestration Leadership Forum (CSLF)** promotes the development of carbon capture and storage (CCS) technologies, which prevent CO_2 emissions from entering the atmosphere [76]. The **EU Horizon 2020 program** also funds projects like **BioDegradation**, which develops enzyme-based solutions to tackle industrial waste, reducing pollutants and CO_2 emissions while fostering cleaner industrial practices [77]. Together, these initiatives strengthen technologies that reduce emissions, promote sustainability, and contribute to climate change mitigation.

16. Policy Frameworks, Prospects and Difficulties

Policymakers must strategically support various applications according to their technological and political feasibility in reducing climate change [78]. For the production of biofuel, each biochemical process presents unique opportunities and challenges. Stakeholders must oversee several complex aspects, such as feedstock selection and process optimization, to ensure both environmental sustainability and economic viability. Reducing adverse environmental effects and maximizing energy production requires addressing issues like land use change, water use, and biodiversity conservation. By modifying microorganisms for increased productivity and efficiency, synthetic biology has the potential to completely transform the production of biofuel [79]. Through the optimization of metabolic pathways and the engineering of microbial catalysts, synthetic biology provides a route to a sustainable energy future. Through interdisciplinary cooperation and technological innovation, stakeholders can fully realize the potential of biofuels as a competitive fossil fuel substitute. One of the most important ways to alleviate the environmental problems caused by greenhouse gas emissions in the fight against climate change is through carbon-neutral energy. The core of this effort is a thorough investigation of biochemical pathways, whereby the complex workings of living things present exciting opportunities for energy production without increasing the atmospheric carbon burden [80].

A key component in the quest for carbon-neutral energy is photosynthesis. The basis for sustainable energy production is laid by this natural process, primarily seen in plants and algae, and transforms solar energy into chemical energy. Photosynthetic organisms sequester carbon and lessen its environmental impact by converting carbon dioxide into organic compounds using the power of sunlight [81]. Beyond photosynthesis, there are concrete routes to carbon-neutral energy through biomass conversion and biofuel synthesis. Methods such as fermentation and anaerobic digestion provide creative ways to recycle organic waste and produce energy [82]. By reducing carbon footprints and creating chances for sustainable resource use, these biochemical pathways help to solve the twin problems of waste management and energy production. But even though biochemical pathways hold out hope for producing carbon-neutral energy, several obstacles still need to be overcome. Economic barriers prevent bioenergy technologies from being widely commercialized, especially when it comes to biomass production. Furthermore, to remove obstacles and enable the smooth incorporation of bioenergy into climate change mitigation plans, policy changes, and technological developments are essential.

Climate change mitigation through the seamless integration of bioenergy is a crucial part of the broader strategy to combat global warming. Bioenergy, which comes from biological sources, works in dynamic harmony with initiatives to slow down climate change. This integration shows the versatility of bioenergy as a carbon-neutral solution and is investigated from several angles, such as power generation and transportation fuels [83]. The analysis looks at the potential for a gradual transition to carbon-neutral alternatives by analyzing how bioenergy might be integrated into existing energy systems. The cofiring of biomass in conventional power plants, usage of bioethanol and biodiesel in transportation, and biomass power plants are specific examples of this integration. Beyond these uses, bioenergy's potential in carbon capture and storage (BECCS) can be investigated. To prevent the release of carbon into the atmosphere, BECCS absorbs and stores the carbon released during the burning of bioenergy Applications that offer both commercial and environmental benefits, such as nitrogen-fixing microorganisms and synthetic proteins, are likely to attract private investment, whereas those that are purely focused on lowering emissions may require special regulatory interventions to encourage development [84]. Advanced Public sector support for EngBio is still scarce, despite programs like the U.S. Research Projects Agency-Energy (ARPA-E) acknowledging its potential and frequently focusing on basic research rather than real-world implementation [85]. This reveals a serious weakness in strong policy frameworks meant to successfully distribute and commercialize EngBio technologies. Lawmakers must take into account elements like the effects on land use, the possibility of uprooting current industries, and social equity issues to support mitigation-focused EngBio projects. Applications of EngBio may encounter resistance when they vie for land with more traditional agricultural uses [4]. Current industries may also have political clout that prevents the adoption of technologies that pose a threat to their interests [86]. Consequently, policies ought to be created to encourage sustainable practices and address stakeholder concerns [86]. Furthermore, because regulatory barriers and the difficulty of reaping social benefits might lead to less than optimum development rates, EngBio technologies' appropriability and market access difficulties must be handled.

In addition to the IPCC's decarbonization strategies, EngBio offers a range of climate mitigation strategies. Some main contributions include replacing carbon-intensive products, reducing emissions during production, producing biofuels from sustainable sources, and enhancing carbon sequestration. For instance, biofuels can lower emissions without requiring significant changes to the infrastructure, and novel methods can absorb CO_2 from industrial operations [87]. Reducing livestock methane emissions can also be facilitated by the development of synthetic proteins as an alternative to animal proteins [88]. However, concerns regarding the environmental impact of genetically modified organisms necessitate thorough investigation and public participation. Targeted policy development is essential to maximizing EngBio's potential. This includes frameworks that strengthen research capacity in the Global South and promote cooperative worldwide efforts to set meaningful climate mitigation targets.

17. Current Difficulties

In this critical analysis, the current challenges are examined, with particular attention paid to the economic and technical obstacles as well as the social and political ramifications that influence the application of biochemical solutions. The path to biochemical approaches is paved with obstacles, both financial and technical. Although there is great potential for using biological processes, there are obstacles in the way of their practical implementation at the nexus of technology and economics. This section explores the complexities of creating and implementing biochemical solutions, looking at obstacles like financial and technological limitations [89].

The efficiency of enzymatic processes, the scalability of biofuel production, and the optimization of biochemical pathways for carbon sequestration are among the significant technical challenges [90]. To get past these technological obstacles, advancements in carbon fixation, bioenergy, and enzymatic remediation need to be continuously improved. Simultaneously, economic factors such as market dynamics, investment needs, and the cost-effectiveness of biochemical technologies become crucial factors in determining their viability. It takes careful balancing and strategic navigation to strike a balance between the need for cutting-edge technology and economic viability.

The intricate interplay of social and political implications inherent in the adoption of biochemical approaches for climate change mitigation is also explored in the section on challenges and prospects [91]. This section examines the ways that political will, policy frameworks, and societal attitudes affect the efficacy and acceptability of biochemical solutions.

The degree to which society accepts bioenergy efforts depends on several factors, including perceived environmental benefits, public awareness, and the impact on the local community. A wide range of topics influenced by public opinion such as biodiversity, land usage, and potential rivalry with food production are discussed in this study Political backing and legislation play a significant role in the expansion of biochemical activity. Biochemical remedies can be integrated into more complete climate change initiatives because of the complex rules needed to balance social fairness, environmental preservation, and economic prosperity. The political and sociological implications make it abundantly evident that successful integration of biological approaches requires alignment with political goals and cultural norms.

18. Emerging Trends

With the ongoing study on biochemical solutions for climate change, the narrative turns to the fascinating topic of Emerging Trends. Technological developments in biochemistry are continually evolving and expanding the realm of what is practical for climate change mitigation. This section goes into great length about the scientific and technical advancements that are profoundly changing how we approach climate issues. Bioenergy innovations are at the forefront, with the development of designer microorganisms for improved biofuel production resulting from advances in synthetic biology [92]. Customized solutions for pollution control are made possible by the incorporation of artificial intelligence and machine learning into enzymatic processes, which opens up new possibilities for accuracy and efficiency [93]. Additionally, improvements in carbon sequestration technologies such as increased weathering and direct air capture show how creative scientists may be in developing novel methods to absorb and store carbon at scale [94]. There are previously unheard-of opportunities for genetic manipulation of biological systems. In the fight against climate change, biochemical technique advancements are encouraging, such as the development of microbes that can sequester carbon more efficiently or carbon-fixing plants with enhanced photosynthetic powers.

19. Conclusion

Innovations in biochemical techniques were included in the inquiry, which captures promising breakthroughs in mitigating climate change. These developments move beyond the laboratory and show the promise of scalable and sustainable solutions that can revolutionize our collective response to climate concerns. Third-generation biofuels derived from algae are among the most promising advancements in the production of bioenergy; they are more productive than traditional biofuel sources and have a smaller environmental impact [95]. BECCS, or the combination of bioenergy and carbon capture and storage technologies, is becoming more popular as a practical way to attain zero emissions [96]. The design of enzyme cocktails that can degrade a wider range of pollutants has advanced, addressing the problems associated with recalcitrant contaminants in enzymatic pollution control solutions [97].

In the end, biochemical methods' revolutionary potential is essential to the future of climate change mitigation. When the importance of the listed recommendations in creating a sustainable response to climate issues is recognized, it becomes imperative to implement them. This commitment to biochemical innovation offers a path to a resilient and carbon-neutral future where these techniques are crucial for addressing the urgent problems brought on by climate change.

A comprehensive analysis of biochemical strategies, including carbon sequestration, methane mitigation, and mechanisms like suppressed methanogenesis, significantly contributes to global climate efforts. Emphasizing carbon-neutral bioenergy pathways and enzymatic pollutant degradation, the essential role of international collaborations is highlighted. Despite facing social, economic, and technical barriers, these strategies offer precise, effective greenhouse gas reduction while maintaining sustainability standards. Future recommendations underscore the importance of interdisciplinary collaboration, addressing social and political issues, scaling up successful initiatives, enhancing technological innovation, and establishing ongoing monitoring and assessment programs for long-term success. Herein lies our collective path towards a more sustainable and resilient planet.

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CHAPTER EIGHT

A Semigroup-Theoretic Approach to Sustainable Agriculture

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Abstract

Agricultural systems are complex and dynamic, influenced by both natural processes and human interventions. This work explores the application of semigroup theory as a mathematical framework to model and advance agricultural practices, particularly focusing on crop growth dynamics and pest control strategies. We construct semigroup structures to represent sequences of agricultural transformations, control measures, and natural evolutions. By leveraging the properties of semigroups, evolution semigroups, and semi-direct product semigroups, we develop models that enhance predictive capabilities, optimize intervention strategies, and promote sustainable agricultural practices. Our results demonstrate that semigroup theory not only provides a rigorous foundation for analysing agricultural systems but also offers practical tools for systematic improvement and innovation in agricultural management. This study paves the way for future research in applying abstract algebraic methods to real-world agricultural challenges.

Keywords: Semigroup Theory, Agricultural Modelling, Pest Control Dynamics

8. Introduction

Agriculture has long been the backbone of human civilization, and with the continuous growth in the world's population, ensuring food security remains a global priority. Modelling agricultural processes, such as crop growth and pest control, has become an indispensable tool for optimizing yields, improving resource management, and minimizing environmental impact. Traditionally, mathematical models in agriculture have employed differential equations, statistical methods, and systems theory. However, in recent decades, *algebraic structures*—particularly *semigroup theory*—have emerged as powerful frameworks for understanding the dynamics of biological and agricultural systems [1,2].

Semigroup theory, a branch of abstract algebra, studies sets equipped with an associative binary operation. Although originally developed for purely mathematical purposes, semigroups have found diverse applications across computer science, physics, biology, and now increasingly in agricultural science. In the context of agriculture, semigroups can model time-evolution processes such as the stages of crop growth, pest population dynamics, and intervention strategies for pest control. The algebraic nature of semigroups allows for a compact representation of complex biological interactions, offering new insights into systems that are otherwise difficult to model using classical continuous methods.

This introduction aims to present an overview of how semigroup theory can be applied to modelling crop growth dynamics and pest control in agriculture. We will first discuss the mathematical foundations of semigroups and their relevance to dynamic systems. Subsequently, we will explore how semigroup actions can model growth processes and biological interactions in crops and pests. Finally, we will discuss existing literature and propose future directions for integrating semigroup theory more deeply into agricultural modelling.

Mathematical Background: Semigroups and Dynamic Systems

A *semigroup* is an algebraic structure consisting of a non-empty set S together with a binary operation $\cdot$ such that $(a \cdot b) \cdot c = a \cdot (b \cdot c)$ for all $a, b, c \in S$ [1]. Unlike groups, semigroups do not necessarily require an identity element or inverses. This flexibility makes them particularly suited for modelling irreversible processes, such as the stages of plant development or pest infestation cycles.

In dynamic systems, states evolve over time according to specified rules. These evolutions can often be captured by transition functions or operators. If the set of all possible transitions forms a semigroup under composition, we obtain a semigroup representation of the system's dynamics. In biological modelling, semigroups naturally model the *non-reversible progression* of biological processes, where, for example, a plant cannot revert from maturity back to the seedling stage.

A particularly useful construction is the *semigroup of transformations* or *flow operators* over a state space, which describe how a state at time t evolves to a state at time $t + \tau$. This is foundational in *evolutionary semigroups* and *one-parameter semigroups* of operators, widely used to model time-dependent phenomena.

Semigroup Theory in Modelling Crop Growth Dynamics

Crop growth is a complex, multistage biological process influenced by environmental conditions, genetic factors, and agricultural practices. Traditional crop growth models such as the Logistic Growth Model, Gompertz Model, and Richards' Model capture the sigmoidal nature of crop biomass accumulation over time. However, these models often rely on continuous time differential equations and may not easily accommodate discrete interventions such as fertilization, irrigation, or pest outbreaks.

By contrast, *semigroup models* can discretize the growth process into stages (e.g., germination, vegetative growth, flowering, fruiting, senescence), each associated with specific transformations. These stages can be represented as elements of a semigroup where the binary operation describes the transition from one growth stage to another under specific conditions.

Suppose *S* is a semigroup whose elements are growth states, and the operation represents biological development over a unit time step or an environmental influence (such as fertilizer application). Then, sequences of operations model the complete growth cycle of a plant. Such a representation facilitates the inclusion of *nonlinear*, *stochastic*, or *external factors* (such as pest attacks or climatic events) as perturbations in the semigroup action, providing a robust and flexible modelling framework.

Moreover, *order-preserving transformations*—a subset of semigroup transformations—can model systems where the progression of growth must maintain a certain developmental order [1]. For instance, a plant cannot fruit before flowering, a constraint naturally encoded in order-preserving maps.

Semigroup Theory in Pest Control Dynamics

Pests significantly affect crop yields, necessitating effective control strategies. Pest population dynamics are inherently nonlinear and often exhibit threshold behaviours: small populations may go extinct naturally, while large populations may cause devastating outbreaks. Traditional pest models, such as the Lotka-Volterra equations, model predator-prey dynamics using differential systems [4].

However, semigroup approaches offer a different perspective by considering pest population states and control interventions as elements and actions within a semigroup framework. In this setting:

- Pest states (low, moderate, high infestation) can be treated as elements of a state space.

- Biological interactions (e.g., reproduction, natural death, migration) are transformations acting on these states.
- Control strategies (e.g., pesticide application, biological control) are external operations modifying the evolution dynamics.

This structure is particularly well-suited for *impulsive control models*, where interventions occur at discrete times rather than continuously. By defining a semigroup of transformations between pest states, interspersed with control actions, one can predict the long-term behaviour of pest populations under different management scenarios.

For instance, let P be a set representing pest states, and T a semigroup of transitions (natural growth and decay). Control actions can be modelled as external operators that reset or adjust pest populations, thus interacting with the semigroup structure in a *semi-direct product* formation. This algebraic view captures the dynamic interplay between natural biological progression and human intervention in pest control.

9. Preliminaries

In this section, we provide fundamental definitions and concepts essential for understanding the application of semigroup theory to modelling crop growth dynamics and pest control.

Definition 2.1. *[1] A semigroup is an algebraic structure* $(S, \cdot)$ *consisting of a nonempty set* S *equipped with a binary operation* $\cdot : S \times S \to S$ *that satisfies the following property:*

- *(Associativity) For all* $a, b, c \in S$,

$$(a \cdot b) \cdot c = a \cdot (b \cdot c).$$

Definition 2.2. *[1] A transformation semigroup is a semigroup* $(T(X), \circ)$ *where* $T(X)$ *is the set of all functions from a set* X *to itself, and the operation* $\circ$ *is the composition of functions.*

Definition 2.3. *[1] Let* $(X,\leq)$ *be a partially ordered set. A function* $f\colon X \to X$ *is called order-preserving if for all* $x, y \in X$*,*

$$x \leq y \Longrightarrow f(x) \leq f(y).$$

The set of all order-preserving transformations on X *forms a subsemigroup of* $T(X)$*.*

Definition 2.4. *[3] An evolution semigroup is a family of operators* $\{U(t)\}_{t\geq 0}$ *on a Banach space such that:*

- $U(0)$ *is the identity operator.*
- $U(t + s) = U(t)U(s)$ *for all* $t,s \geq 0$.
- *The mapping* $t \to U(t)x$ *is continuous for each fixed* x*.*

Evolution semigroups are used to model time-dependent processes where the state evolves continuously or discretely over time.

Definition 2.5. *In the context of pest population modelling, a pest state space* P *is a finite or infinite set where each element represents a discrete state of the pest population (e.g., low, moderate, high infestation levels).*

Definition 2.6. *[4] A control action is an operation applied to the pest or crop system intended to alter its state in a desirable way. Control actions can be modelled as external transformations acting on the state space, which may or may not preserve the semigroup structure.*

Definition 2.7. *An impulsive control model involves discrete interventions at specific moments that instantly change the system's state. Mathematically, it can be described as a* *sequence of semigroup evolutions interrupted by instantaneous transformations.*

Definition 2.8. *[2] Given two semigroups $(S, \cdot)$ and $(T, *)$ and an action of T on S, the semi-direct product $S \rtimes T$ is the set $S \times T$ equipped with the operation*

$$(s_1, t_1) \bullet (s_2, t_2) = (s_1 \cdot (t_1 \cdot s_2), t_1 * t_2),$$

where $t_1 \cdot s_2$ denotes the action of t_1 on s_2. This structure is useful for combining natural growth and control actions in a unified model.

10. Main Results

Theorem 3.1. *Let G be the set of all agricultural growth stages influenced by natural processes and human interventions. If each agricultural practice induces a transformation $g: G \to G$, then $(G,\circ)$ forms a semigroup whose structured composition can be optimized to enhance crop yield.*

Proof. The composition of two agricultural practices results in another valid growth transformation, ensuring closure. Associativity holds due to the sequential nature of agricultural practices. Through the semigroup structure, one can model and optimize the sequence of interventions to maximize agricultural output. □

Theorem 3.2. *Let P denote the pest population states and C the set of control measures as transformations on P. If C forms a semigroup under composition, strategic compositions of controls can be systematically designed to eradicate or minimize pest populations effectively.*

Proof. Each control measure transforms the pest population to a more desirable state. Composing multiple control measures yields another control action, and associativity follows from sequential application. Utilizing the semigroup structure allows for systematic pest management strategies to be developed. □

Theorem 3.3. *Let* $\{U(t)\}_{t\geq 0}$ *represent the natural evolution of the crop-pest system over time. If* $U(t+s) = U(t)U(s)$ *and* $U(0) = I$, *then* $\{U(t)\}$ *forms an evolution semigroup. This framework supports predictive modelling and long-term planning in agriculture.*

Proof. The semigroup property $U(t+s) = U(t)U(s)$ captures the temporal evolution of the system. The identity element $U(0)$ ensures initial conditions are maintained. Using this framework, agriculturalists can predict system behaviour and plan interventions more effectively. □

Theorem 3.4. *Consider a crop-pest dynamic system evolving via an evolution semigroup* $\{U(t)\}$, *subjected to discrete impulsive interventions* I_k *at times* t_k. *The combined system evolution can be modelled as*

$$x(t) = U(t - t_n)I_nU(t_n - t_{n-1})I_{n-1} \cdots U(t_1 - t_0)I_0(x_0),$$
$$\text{for } t_n \leq t < t_{n+1}.$$

Proof. The system evolves naturally between impulses and experiences instantaneous changes at intervention points. This alternating process remains associative, allowing the modelling of scheduled interventions to strategically improve agricultural outputs and resilience.□

Corollary 3.5. *The combination of natural evolution and strategic interventions can be encapsulated in a semi-direct product semigroup* $G \rtimes C$, *offering a comprehensive mathematical model for advancing modern agriculture.*

Proof. Since C acts on G and both are semigroups, the semi-direct product $G \rtimes C$ naturally models the interactive dynamics. This structure provides a robust framework for designing, implementing, and analysing agricultural strategies for sustainable advancement. □

11. Conclusion

The application of semigroup theory to agricultural systems presents a powerful and elegant framework for understanding and advancing crop growth dynamics and pest control strategies. By modelling agricultural operations and natural processes as semigroups, we are able to systematically capture the temporal and transformational aspects of agricultural evolution. Through the establishment of semigroup structures on crop growth transitions, pest control interventions, and their combined dynamics, we have shown that agricultural activities can be optimized, predicted, and controlled with mathematical rigor. The introduction of impulsive controls within the semigroup framework further enables strategic interventions that enhance system performance and resilience. Moreover, the use of semi-direct product structures unifies natural evolution and external actions into a single comprehensive model, offering a rich analytical tool for researchers and practitioners alike. This unified semigroup-based model not only improves the efficiency of current agricultural practices but also provides a foundation for developing innovative solutions to future agricultural challenges. Overall, semigroup theory offers a transformative approach to modernizing agriculture, providing clarity, structure, and optimization capabilities that are essential for sustainable agricultural advancement in an increasingly complex and demanding global environment.

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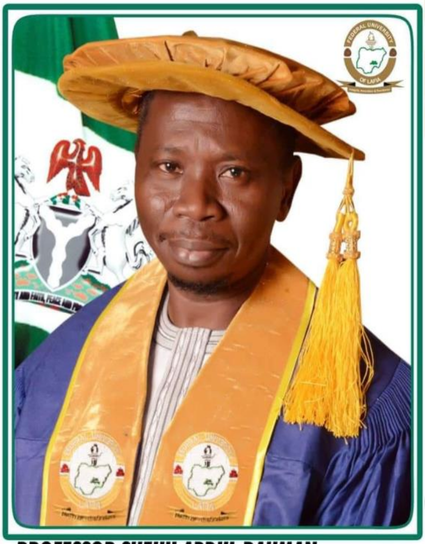

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