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NOARA
Network of Organic Agriculture Researchers in Africa
RÉSEAU DES CHERCHEURS EN AGRICULTURE BIOLOGIQUE EN AFRIQUE
شبكة الباحثين في الزراعة العضوية بإفريقيا

PROCEEDINGS OF THE 2ND AFRICAN ORGANIC CONFERENCE (AFROREC)

AFROREC
AFRICAN ORGANIC RESEARCH CONFERENCE



Theme:

Strengthening Organic And Agroecological Farming In Africa Through Innovative Research

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Venue:
Heliopolis University of
Sustainable Development, Cairo, Egypt

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About the conference

African Organic Research Conference (AFROREC); an initiative of the Network of Organic Agriculture Researchers in Africa (NOARA) which had participation of diverse regional and international multi-stakeholder organizations (farmers/producers, researchers, manufacturers/marketers, policy makers, etc.) in organic and agroecology sectors. The 1st AFROREC, the maiden edition by NOARA and first of its kind in Africa took place in Ibadan Nigeria from 6-8th December, 2022 as an hybrid event (virtual and physical participation). The conference was a contribution of NOARA to the decision of the African Heads of States and Governments on organic farming [EX.CL/Dec.621 (XVII)] as well as the demand by stakeholders of the organic and agroecological sectors of Africa, for research interventions to improve their operations.

The importance of organic and ecological agriculture in national food security, health, biodiversity, environment conservation and fight against poverty is increasingly being recognized in Africa and all over the world. Despite on-going efforts of the African Union Commission led-Ecological Organic Agriculture (EOA) Initiative, Agence Française de Développement (AFD), Federal Ministry for Economic Cooperation and Development (BMZ) of German Government, Food and Agriculture Organization (FAO), Research Institute of Organic Agriculture (FiBL), IFOAM Organics International, Forum for Agricultural Research in Africa (FARA) and some others in the organic agriculture and agroecology sectors of Africa, there is still a gap of appropriate research interventions to strengthen efforts of these organizations in Africa. Thus, NOARA through the 1st AFROREC with the theme - Unfavorable Climate and Food Systems in Africa: Organic and Agroecology Solutions, provided a platform for multi- stakeholders (agencies, organizations, civil societies, projects and individuals) of organic and agroecological research in Africa to showcase their research results/innovations as solutions to stakeholders' challenges.

The conference also created interactive and networking opportunities, as well as information sharing among the diverse participants of the event. During the three-day event, there were interaction among participants through plenary speeches, research paper presentations, dialogue of researchers with farmers, producers and input merchants and policy makers, journalists, as well as exhibition of organic products and projects. The event also provided opportunities for regional and continental meetings related to organic agriculture and agroecology, as well as a field trip to a community of organic farmers for scientific interventions into their challenges. Moreover, there were diverse opportunities for consultation and Press conference during the event. The Network of Organic Agriculture Researchers in Africa (NOARA) as a major stakeholder in disseminating organic agriculture research outputs within and outside Africa was privileged to coordinate the important event.

Objectives of the conference:

* To showcase the potentials of organic agriculture and agroecology research in transforming national and regional economies, ecologies and livelihoods through income growth, climate change adaptation, food sovereignty and trade.
* Sharing knowledge, information, experiences and skills among all stakeholders of organic and agroecology sectors in Africa.
* To present scientific evidence on the capability of organic agriculture/agroecology in contributing to healthy living and transformation of national and continental economy, enhancement of systems resilience and mitigation of climate change, among others.

* Platform for uptake of organic/agroecology alternatives through interdisciplinary / collaboration, especially, in the sharing of experiences.
* Exhibition of organic produce and products to stimulate national, regional and international trade; linking producers to markets.
* To showcase and publicize benefits of organic agriculture and agroecology for consideration of policy makers, organic stakeholders and the general public.
* Platform for policy makers to interact with researchers and other stakeholders on organic and ecological issues.

2nd AFRICAN ORGANIC RESEARCH CONFERENCE (AFROREC) COMMUNIQUE

Over 214 participants (in-person and virtual) of the 2nd African Organic Research Conference, representing diverse stakeholders in Organic and Agroecological Agriculture from approximately 25 countries across Africa and beyond, met in Cairo, Egypt, on 24 & 25 November 2025.Hosted as the continental conference of the Network of Organic Agriculture Researchers in Africa (NOARA), the event aimed to deliberate on the theme 'Strengthening Organic and Agroecological Farming in Africa through Innovative Research'.Our participants included researchers, farmers, students, journalists, policymakers, and business actors. The conference featured a rich program, including 2 keynote addresses, 5 lead papers, 56 abstracts, panel discussions, thematic sessions, oral presentations, side events, and regional consultations on the Organic and Agroecology Research Agenda for Africa 2035 (OARAA 2035). Presentations covered the full spectrum of organic and agroecological agriculture, from production (crop, livestock, ecosystem services) to business aspects. The event was hosted by the SEKEM Group, Heliopolis University for Sustainable Development, Cairo, and the Egyptian Biodynamic Association.

WE ACKNOWLEDGE THAT

Innovative research in organic agriculture and agroecology in Africa is key to strengthening the farming system, which will, in turn, address the challenges of food insecurity, climate change, and improve the livelihoods of the continent's citizens.

We AGREED

That Organic Agriculture and Agroecology research significantly contribute across a broad spectrum of critical areas:

* Global and Continental Alignment: Directly support the realization of the African Union's Agenda 2063, advance progress towards the United Nations' Sustainable Development Goals (SDGs), and drive the transformation of national and regional economies.
* Environmental StewardA/ship: Positively informs and supports international conventions, including the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Biodiversity Conference, by providing sustainable practices for climate adaptation, mitigation, and biodiversity conservation.
* Sustainable Input Development: Drives the innovation and development of organic and agroecological inputs, such as biopesticides, biofertilizers, herbicides, animal feeds, syn/pro/pre-biotics, preservatives, and natural colorants.
* Technological Innovation: Fosters engineering and technological advancements applicable across the value chain-from production, harvesting, and weed management to mulching and processing of food, feed, and fiber.

* Quality Assurance and Market Access: Enhances quality control systems, including the refinement and scaling of Participatory Guarantee Systems (PGS) and third-party certifications, which underpin business development and economic advancements in the sector.
* Holistic Health Outcomes: Addresses interconnected health issues across entire systems: soil, plant, livestock, fishery/aquaculture, the broader environment, and human health.
* Educational Advancement: Informs the dynamics of educational studies and supports the development and integration of robust organic agriculture and agroecology curricula.
* Policy and Practice: Underpins essential policy studies, improves extension services, and facilitates crucial farmer-led research initiatives within the organic and agroecology domains.

WE APPLAUD the great efforts made by all international, continental, regional and national organizations working in support of the development of Organic Agriculture and Agroecology in Africa.

WE RESOLVE THAT

All African countries represented by the Network of Organic and Agroecological Research in Africa (NOARA) should strive to implement impactful and evidence-based research and innovation activities to develop solutions that strengthen organic and agroecological farming across the continent.

CALL FOR ACTIONS:

1. Regularly Showcase Innovations: Regularly showcase organic and agroecology research products and innovations at the continental, regional, and national levels for the purpose of upscaling the production of organic and agroecological produce/products across the continent

2. Uptake and finalize OARAA 2036: The work-in-progress Organic and Agroecology Research Agenda for Africa (OARAA 2036)based on need assessment of the stakeholders should be led and finalized by the Forum for Agricultural Research in Africa (FARA) in collaboration with regional agriculture research bodies in Africa, and support from the Continental Secretariat of the NOARA, FiBL Switzerland, and other strategic international partners.

3. Network Stakeholders: NOARA should work with FARA to network stakeholders of organic and agroecology research at regional and national levels in Africa to foster synergy of operations and collaboration.

4. Generate Research Templates: NOARA should work with FARA to generate templates for organic and agroecology research in Africa, including methodologies for market data gathering, true-cost accounting, ecoservices valuation, and farmer-friendly climate-smart economy models.

5. Compile Scientific Compendium: The West and Central African Council for Agricultural Research and Development (CORAF) should work with FARA, regional research bodies in Africa, and NOARA to periodically compile scientific evidence on the capability of organic agriculture/agroecology in contributing to healthy living, economic transformation, enhancement of systems resilience, mitigation of climate change, soil health, and food security in a Compendium for Organic and Agroecological Research in Africa on a three-year basis.

WE PLEDGE THAT

The organic agriculture and agroecology research sectors in Africa, as represented during the 2nd African Organic Research Conference (2nd AFROREC), commit to collaborating closely with all public and private stakeholders to effectively implement the conference's resolutions.

APPRECIATION

We extend our sincere gratitude to the Government of Egypt for providing an enabling environment for the successful hosting of the 2nd AFROREC. Our appreciation also goes to the SEKEM Group, Heliopolis University for Sustainable Development, and the Egyptian Biodynamic Association for their exemplary support and hospitality. We likewise acknowledge all speakers and contributors whose participation enriched the conference.We also thank the leadership of the Network of Organic Agriculture Researchers in Africa (NOARA), members of the Local and Continental Planning Committeesfor the successful organization of the 2nd African Organic Research Conference (AFROREC), with the support and participation the following: Friends of SEKEM, FiBL Switzerland, Knowledge Hub for Organic Agriculture (KCOA), GIZ/BMZ, Knowledge Hub of North Africa (KHNA), African Organic Network (AfrONet), Forum for Agricultural Research in Africa (FARA), the West and Central African Council for Agricultural Research and Development (CORAF), IFOAM Organics International, International Society of Organic Agriculture Research (ISOFAR), IFOAM Technology Innovation Platform, Federal University of Lavras (UFLA, Brazil), Bread for the World, Agroecology Europe, and other stakeholders.

During the event, distinguished participants from within and outside Africa AGREED that the 3rd AFROREC will be held in Zimbabwe in 2028.

Signed

Dr. Ahmed Elshazly	Prof. Olugbenga AdeOluwa	Prof. Raymond Auerbach
Chair, Local Planning Committee	Continental Coordinator,	Chair, Governing Council
Heliopolis University for Sustainable Development, Cairo	Network of Organic Agriculture Researchers in Africa (NOARA)	Network of Organic Agriculture Researchers in Africa (NOARA)

ABOUT NOARA

The Network of Organic Agriculture Researchers in Africa (NOARA) was established to unite and coordinate African organic and ecological agriculture scientific and technical researchers within and outside Africa. The network is an African initiative. NOARA is a network independently established by African organic researchers that met at Modena, Italy, in 2005 but was later launched in 2009, during the 1st African Organic Conference in Kampala. During the 2nd African Organic Conference (2nd AOC) held in Lusaka, Zambia, in May 2012, a side event brought together participants from almost all regions of Africa and Europe to discuss how to develop organic agriculture research agenda. Research was underscored as a critical component of any initiative designed to promote ecologically sustainable development of agriculture in Africa. The 4th AOC in 2018 General Assembly at Saly, Senegal, recommended AfrONet to revive NOARA and probably re-organize the Network for effectiveness in its expected roles. A Coordinator was therefore appointed in March 2019 to build NOARA and ensure proper functionality of the Network.

NOARA VISION

Africa with zero hunger, poverty eradicated, improved livelihoods and sustained ecosystem through innovative organic and ecological agriculture research.

NOARA MISSION

To generate and disseminate sound evidence-based scientific organic agricultural knowledge that can ensure healthy, ecological, fairness and care of organic agriculture actors in Africa for sustainable livelihood and ecosystem, leading to food security, incomes and sustainable development.

NOARA SPECIFIC OBJECTIVES AND RESEARCH PRIORITIES

Thematic area 1: Research and Training

i. Lead research agendas on organic and ecological agriculture in Africa.
ii. Coordinate organic and ecological agriculture training and research in Africa.
iii. Support or initiate research activities that will contribute to the social, cultural and economic productivity of Africa's smallholder farmers, processors and marketers, particularly, women and youths who have been largely marginalized.
iv. Demonstrate success stories useful for up scaling organic and ecological agricultural practices.

Thematic area 2: Policy and Stakeholders' Engagements

i. Promote collaboration among organic and ecological agriculture researchers, practitioners, farmers and policy makers in Africa.
ii. Foster improved ecological organic agriculture database, to influence policy development in Africa.
iii. Advocate for the mainstreaming of organic and ecological agriculture into agricultural research and innovation to enhance food security in Africa.
iv. Engage organizations producing organic and ecological inputs in confirmatory and adaptive researc for possible recommendation of their products to end users in Africa and beyond.

Thematic area 3: Conferences and Information Dissemination

i. Organize conferences and meetings for the exchange of information on organic and ecological agriculture.
ii. Publish research and technical results on organic and ecological agriculture.
iii. Organise consortia of experts to address specific or emerging issues relating to organic and ecological agriculture in Africa.

Thematic area 4: Networking, Advocacy and Awards

i. Enhance partnerships for organic and ecological agriculture research in Africa and beyond.
ii. Map out like-minded organisations.
iii. Honour distinguished members as fellows of the network.
iv. Represent the interest of organic and ecological agriculture researchers within and beyond Africa.

NOARA KEY SERVICES

NOARA shall undertake functions appropriate to meeting the objectives cited in this constitution including to: (within and outside Africa)

a. Undertake lobbying and advocacy on organic and ecological agriculture research at high levels.
b. Support capacity building for key players in organic and ecological agriculture across the continent.
c. Mobilize resources for NOARA's endeavours in promoting organic agriculture on the continent.
d. Spearhead organic agriculture research, extension, training and value chains and market development.
e. Provide management and administrative consultancy to like-minded programmes and partners on organic agriculture research; and,
f. Undertake any other functions as deemed necessary to address NOARA's objectives.

The functions of the Network shall be conducted as much as possible by pooling and making use of members' own human, financial and technical resources. However, NOARA shall also make concerted effort to mobilize resources at various levels (local, national, regional, continental and international) to support research and networking activities, for a vibrant and successful Network.

Membership

NOARA is a membership Network that draws members from national, regional, continental and international organic agriculture organisations, associations, networks and companies within and outside Africa, but whose aims and goals are in support of organic and ecological agriculture.

AFRICAN JOURNAL OF ORGANIC AGRICULTURE AND ECOLOGY (ISSN: 2734-2913 (Prints) 2795-2223 (Online)

African Journal of Organic Agriculture and Ecology (AJOAE) is a journal of Organic Agriculture and Ecology published biannually to create an effective medium for dissemination of information on organic agriculture research findings in all areas of Agriculture, Food sciences and Ecology. The Journal International Standard Serial Number (ISSN) is 2734-2913.

Scope

Contributions may be on Agricultural Economics, Agricultural Engineering, Agricultural Extension, Agroforestry, Animal science, Crop/Environmental protection, Crop science, Environmental Sciences, Fishery/Aquaculture, Pharmacy, Soil science, Veterinary Medicine, Wildlife Management. Careful editing and scrutiny are required before sending manuscript to the editor as no room for alteration may exist once an article is accepted for publication based on reviewers' comments. Contributors are to send their manuscripts, not previously published or being considered for publication elsewhere to:

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Germination and Seedling Vigour of Maize as Influenced by Priming and Time of Seed Bio-Priming

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Abstract
Seed priming with bio-fertilizer is known to enhance germination and seedling vigour. However, priming time is crucial for germination and seedling vigour. Thus, two studies were carried out at the Federal University of Agriculture, Abeokuta, Nigeria, in 2020 to investigate the effect of bio-priming and time of bio-priming to promote seed germination and seedling vigour of maize plants. The germination and vigour trials had two factors each in common: Factor A comprised two levels of priming (hydro- and bio-priming) while Factor B consisted of twelve priming times (2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24 hours). In the germination experiment, twenty seeds obtained from each of the soaked seeds for each prescribed time interval were sown per Petri dish and replicated three times. The first two germinated seeds were picked up and transplanted into their corresponding 72 perforated pots, which contained well-watered topsoil, for the second trial. Results showed that bio-priming significantly reduced germination percentage. Hydro- and bio-primed seeds had 90.6% and 40.6% germination, respectively. Based on the significant interaction of priming and time of priming on seed germination, bio-priming should be limited to 4 hours for effective germination. Seedling vigour obtained from bio-primed seeds significantly reduced leaf greenness, number of leaves, and plant height at the earlier stage compared to their hydro-primed
counterparts but normalized as growth advanced. Conclusively, bio-priming significantly reduced germination percentage (40.6%) while hydro-priming increased it (91.6%). The time of bio-priming seeds should be limited to four hours. The performances of seedlings obtained from bio-primed seeds were initially lower in plant height; however, they levelled up as growth advances compared to those of hydro-primed.

Key words: Seed Treatment, Maize, Microbes, Priming, Germination

Résumé
L'amorçage des semences par un biofertilisant est reconnu pour améliorer la germination et la vigueur des plantules. Cependant, la durée de cet amorçage est cruciale. Ainsi, deux études ont été menées à l'Université fédérale d'agriculture d'Abeokuta, au Nigéria, en 2020, afin d'étudier l'effet de l'amorçage biologique et de sa durée sur la germination et la vigueur des plantules de maïs. Les essais de germination et de vigueur comportaient chacun deux facteurs : le facteur A comprenait deux niveaux d'amorçage (hydro- et bio-amorçage), tandis que le facteur B consistait en douze durées d'amorçage (2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22 et 24 heures). Dans l'expérience de germination, vingt semences, obtenues à partir de semences trempées pour chaque intervalle de temps prescrit, ont été semées par boîte de Petri, et l'expérience a été répétée trois fois. Les deux premières graines germées ont été prélevées et repiquées dans leurs pots perforés respectifs de 72 mm, contenant de la terre végétale bien humidifiée, pour le second essai. Les résultats ont montré que l'amorçage biologique réduisait significativement le taux de germination. Les graines amorcées par voie hydro- et biologique présentaient des taux de germination respectifs de 90,6 % et 40,6 %. Compte tenu de l'interaction significative entre l'amorçage et sa durée sur la germination, l'amorçage biologique devrait être limité à 4 heures pour une germination efficace. La vigueur des plantules issues de graines amorcées biologiquement était significativement réduite en termes de couleur verte des feuilles, de nombre de feuilles et de hauteur, en début de croissance, comparativement aux plantules amorcées par voie hydro-. Ces paramètres se sont normalisés au fur et à mesure de la croissance. En conclusion, l'amorçage biologique a significativement réduit le taux de germination (40,6 %), tandis que l'amorçage hydro- l'a augmenté (91,6 %). La durée de l'amorçage biologique des graines devrait être limitée à quatre heures. Les plantules issues de graines amorcées biologiquement étaient initialement plus petites en hauteur, mais elles se sont ensuite améliorées au fur et à mesure de leur croissance, comparativement aux plantules amorcées par voie hydro-

Mots clés: Traitement Des Semences, Maïs, Microbes, Amorçage, Germination

Introduction

Maize (Zea mays L.) is an important cereal crop that provides staple food to a large number of humans in the world. It has greater nutritional value, as it contains approximately 72% starch, 10% protein, 4.8% oil, 8.5% fibre, 3% sugar, and 1.7% ash (Adetiloye et al., 2006). Maize ranked 3rd among the 10 top crops produced in Nigeria (FAOSTAT, 2022). Besides, among the 20 top countries producing maize in the world, Nigeria ranked 13th with about 12 million tonnes (FAOSTAT, 2022).
Rapid, uniform germination and seedling emergence are the key factors for healthy seedlings, which is a main agricultural goal for improving maize yield (Rajjou et al., 2012). Seed vigour is usually used to evaluate these properties under a wide range of field conditions (Black et al., 2006). Therefore, any technology, such as seed priming, that can enhance rapid, uniform germination and seedling emergence with a view to improving grain yield is a welcome development.

The priming techniques that are most often used are osmo-priming (Chen et al., 2010; Badaruz Zaman et al., 2012), hydro-priming (Casenave and Toselli, 2007), solid matrix priming (Pandita et al., 2010), hormonal-priming (Yazdi et al., 2013), and bio-priming. Bio-priming is a process of biological seed treatment that refers to a combination of seed hydration and inoculation of the seeds with beneficial microorganisms (Prasad et al., 2016). It improves seed viability, germination, vigour indices, plant growth, and subsequent protection against diseases, and finally enhances yield. This study focuses on the use of bio-fertilizer priming, which has been reported to have great potential as these are renewable and environmentally friendly sources of plant nutrients; and are key components of Integrated Nutrient Management (INM) and Integrated Plant Nutrition Systems (IPNS) (Raghuwanshi, 2012).

The term biofertilizer represents everything from manures to plant extracts. Biofertilizers are those substances that contain living microorganisms and colonize the rhizosphere of the plant, increasing the supply or availability of primary nutrients and growth stimulusto the target crop (Miller, 2009). The general practice is that the seeds are soaked in water for hydration before being mixed with bacteria (Reddy, 2012). Sometimes the seeds are hydrated first and then dried at room temperature before being treated with microbial suspension (Saber et al., 2012). Perez-Jaramillo et al. (2016) reported that crop yield can be increased by 12-20 %.

There are numerous species of soil bacteria that colonize mainly in the rhizosphere of plants. These bacteria are collectively known as Plant Growth Promoting Rhizobacteria (PGPR). Some PGPR promote growth by acting as biofertilizers (Miller, 2009). Naturally grown bio-fertilizers not only give a better yield but are also harmless to humans and lead to better sustainable economic development for the farmers and their country (Mishra and Dash, 2014).

The Bezt DM microbes were purchased from Thailand to prepare biofertilizer using locally available fruits to prime seeds to promote germination and seed vigour. It is also used to accelerate compost decomposition of household and farm wastes (i.e., waste-to-wealth venture) to produce organic fertilizer for replenishing soil nutrients. However, an earlier study testing maize seeds bio-primed for 24 hours in the field resulted in a zero-germination percentage. Therefore, these laboratory studies were designed to determine the appropriate time needed to bio-prime seeds for optimal germination and seedling vigour. The study hypothesized that there is no difference in germination and seedling vigour among maize seeds subjected to varying priming times and techniques. The objectives were to determine: (1) the effect of priming on maize germination and (2) the optimal hours of soaking maize seeds in bio-fertilizer to enhance germination and seedling vigour.

Materials and methods

The study was carried out at the Federal University of Agriculture, Abeokuta, in 2020 to determine the effect of priming and the appropriate time of priming on seed germination, emergence, and vigour of maize seedlings. Two studies were carried out to investigate the effects of priming and time of priming on germination in petri-dish, while the second potted trial examined the effects of priming and time of priming on seedling vigour. The two trials had two common factors and levels. The two 2 by 12 factorial experiments were carried out using a Completely Randomized Design (CRD) and replicated 3 times each. Factor A comprised hydro-priming and bio-priming, while Factor B consisted of twelve levels of bi-hourly intervals (2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24 hours) for the two trials.

Reconstituted existing materials of liquid bio-fertilizer for priming: It was made from the combination of various locally available fruits (excluding lime and grapes due to high concentration of acid). The fruits majorly included: pineapple, pawpaw, avocado, banana, and oranges. Thirty kilograms of the fruit mixture were weighed and cut into ½ or ¼ pieces. This was placed in a permeable sack. A sachet of 100 g of Bezt DM microbes imported from Thailand was introduced

into the sack containing the fruits. The sack containing the cut bits of fruit mixture and microbes was placed inside a plastic tank of 150 litres capacity, and 100 litres of water was added. The tank was closed to allow decomposition to take place for 7 days. The decomposing material is infused into the water in the tank. The bag containing the fruit mixture and infused solution in the plastic container was stirred at 3-day intervals to increase decomposition. At the end of decomposition, the pieces of fruit were squeezed and filtered to release the liquid bio-fertilizer. The filtered fruit bits were added to compost materials.

Priming of seed and planting: The quantities of maize seed (SUWAN 1 variety) required for planting were divided into 2. Each half lot of seeds was soaked in 3 litres of bio-fertilizer and 3 litres of water in two separate buckets. At 2 hourly intervals, 60 seeds were collected from each primed bucket (hydro-primed and bio-primed bucket) and planted into 3 Petri dishes (at 20 seeds per Petri dish) which constituted 3 replicates for the 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22 and 24 hours, given total of 72 Petri dishes.

The Petri dishes were monitored daily for the number of seeds whose radicle had emerged. The first two seeds whose radicles emerged were picked up from each Petri dish per treatment per replicate and planted in their corresponding already prepared soil in 72 perforated polyethylene bags. The observation of the remaining 18 seeds left in each of the 72 Petri dishes for the germination study continued for a week. At the end of a week, the percentage germination was determined, while data collection for the potted experiment commenced on the 5th day and continued at 5-day intervals for 6 weeks.

Preparation of potted soil: Well-drained topsoil collected for the experiment was homogeneously mixed. One and a half kilograms (1.5 kg) of homogeneous topsoil were weighed and filled 72 perforated polyethylene bags to the brim.After adding water to the polyethylene bags to field capacity, an additional 200 grammes of well-decomposed compost was used to further fill the polyethylene bags to the brim. This additional compost was meant to boost the soil nutrients. The primed and germinating seeds from the Petri-dishes of the germination trial were planted into the corresponding 72 prepared and well-labelled polyethylene bags.

Data Collected includes Chlorophyll content using a LEAF CHL PLUS Chlorophyll meter, 131-50 version 1.0 (FT GREEN LLC, USA). It measured changes or trends in plant health status not visible to the naked eye. The plant height (cm) was measured using a calibrated ruler from the soil surface to the tallest leaf. The number of leaves was visually counted. These data were taken at every 5-day intervals. However, fresh shoot weight (g), dry shoot weight (g), root weight (g) measured using a sensitive balance (Mettler's balances), root length (cm), and number of roots were determined at 30 days after planting. The data collected were analysed using GENSTAT 12th edition software. The significant differences among treatments were separated using Duncan Multiple Range Test (DMRT) at 5%.

Results and discussion

The chemical composition of the prepared bio-fertilizer liquid is tabulated in Table 1. The bio-fertilizer liquid contained the following macro-nutrients: N (0.18%), P (2.74 mg/l), K (7.02 mg/l), Mg (15.4 mg/l), S (0.10 mg/l), and micro-nutrients: Zn (0.09 m/l), Fe (0.25 mg/l), Mn (0.11m/l), Cu (0.14 mg/l). It also had organic carbon (0.42%) and humic acid (0.11 mg/l). These nutrients and acids in the biofertilizer liquid were imbibed indiscriminately into the seeds during bio-priming. This corroborated the opinion of Srivastava et al. (2022), who reported the process of imbibition during bio-priming of seeds.However, the longer hours of imbibition of nutrients, and particularly humic acid, might be detrimental to germination, which is the initial and critical stage of the life cycle of plants

A significant effect of seed priming on maize germination was observed ($p<0.05$) (Table 2), with hydro-priming producing superior germination compared with bio-priming, which negatively affected germination. The higher germination percentage observed in hydro-primed seeds compared to bio-primed seeds confirmed the findings of Zulueta-Rodrigue et al. (2015) and Forti et al. (2020), who reported that both techniques improved germination rate. But Forti et al. (2020) expatriated further that while hydro-priming improved seed germination percentage, bio-priming resulted in improved seedling development. Seeds primed for 2 hours had a similar germination percentage to those of 4 hours, but significantly higher than the others. Seeds primed for 22 and 24 hours had the least germination percentage.

The greenness of the leaves, which is the measure of the plant health, as determined by the chlorophyll meter, pointed to the fact that the hydro-primed seedlings at 5 days after planting produce significantly greener plants than those of bio-primed. Although both bio-primed and hydro-primed seedlings had greenness values of 33.2 and 31.8, respectively, at 5 days after planting, below the critical value of 35. This was considered unhealthy according to the chlorophyll meter manufacturer's recommendation.

The greenness of the seedlings whose seeds were primed for 4 and 6 hours was the highest, while those of 22 and 24 hours had the lowest at 5 days after planting. Furthermore, seedlings whose seeds were primed for 4, 6, 10, 14, 16, and 18 had their leaves greenness above the critical value of 35, whereas the other were below. Conversely, as the seedlings of the various treatments progress in age, the healthiness improves and finally levels off with those hydro-primed at 25 days after planting. This agreed with Adornis et al. (2020), who reported that seed priming with micronutrients significantly increased chlorophyll content index.

The interaction of priming and time of priming on percentage germination was significant ($p<0.05$). It implied a differential response of germination to the two priming levels. Whereas 2 and 4 hours of the bio-primed were similar but significantly higher than the others. The reason for significantly lower germination observed from 6 hours and above for bio-primed seed could be due to excessive imbibition of certain substances or nutrients, acid inhibition, or altering the germination process. This agrees with the opinion of Chakraborti et al. (2022), who documented that priming induces alterations such as reconfiguration of key regulatory transcripts or protein levels, accumulations of substances in cells, metabolic reprogramme, and epigenetic systems. This further connotes that there is something unknown inherent in the bio-fertilizer whose cumulative concentration over time during priming could have been responsible for the preclusion of germination. It is therefore sufficient to suggest that bio-priming of seed with bio-fertilizer should be limited to 4 hours to optimize germination.

Elements (mg/l)	Content
N	0.18
P	2.74
K	7.02
Mg	15.4
Fe	0.25
Mn	0.11
Cu	0.14
Zn	0.09
Co	0.07
S	0.10
Humic acid	0.11
Organic Carbon	0.42

Table 2: Influence of priming and time of priming on germination and chlorophyll content (%)

Treatment		Number of days after planting					
	Germination percentage	5	10	15	20	25	30
Priming (p)							
Hydro-primed	91.6a	33.1a	38.2a	43.2a	46.1a	47.2a	46.8a
Bio-primed	40.6b	31.8b	37.8a	43.5a	47.2a	48.5a	48.0a
SE	14.65	1.27	0.80	1.34	2.06	2.14	2.09
Hours (h)							
2	95.7a	27.1d	35.4bc	43.7a	49.7a	50.4a	47.5a
4	88.5ab	37.9a	37.5ab	44.5a	38.5a	40.6a	40.3a
6	82.2bc	37.4a	40.6a	43.7a	47.2a	48.3a	47.8a
8	76.3cd	33.0c	38.2ab	43.2a	39.5a	42.1a	40.9a
10	72.8cd	36.4ab	40.3a	44.2a	49.1a	47.7a	46.0a
12	67.2de	32.9bc	39.7ab	46.5a	50.7a	49.3a	48.9a
14	59.3ef	35.3ab	39.9a	44.5a	48.3a	49.7a	49.4a

16	56.0efg	35.4ab	41.5a	47.5a	45.9a	45.8a	45.5a
18	51.8fg	36.2ab	40.9a	45.7a	50.3a	51.7a	51.1a
20	52.7fg	30.2cd	36.9ab	41.9a	45.8a	48.1a	51.3a
22	44.5g	23.9e	32.7c	41.5a	48.9a	49.9a	48.3a
24	46.3g	23.8e	32.3c	40.8a	46.2a	50.4a	51.8a
SE	13.67	1.55	1.95	3.29	5.05	5.24	5.11
H X P	S	NS	NS	NS	NS	NS	NS

Values with similar alphabets vertically are not significantly different

Table 3: Interaction of priming and soaking hour on percentage germination (%)

Treatment	2hrs	4hrs	6hrs	8hrs	10hrs	12hrs	14hrs	16hrs	18hrs	20hrs	22hrs	24hrs
Hydro-primed	97.3a	95.3a	96.0a	93.7a	92.7a	97.7a	94.3a	94.3a	88.0a	87.3a	81.0a	85.0a
Bio-primed	94.0a	81.7a	61.3b	59.0b	53.0b	36.7bc	27.7cd	17.7de	15.7de	18.0de	8.0e	7.7e
SE				12.5								

Values with similar alphabets vertically and horizontally are not significantly different

The number of leaves that accounted for the photosynthate of the seedlings was significantly influenced by priming and time of priming (Table 4). The observed number of leaves of seedlings whose seeds were hydro-primed was significantly higher than that of bio-primed seedlings at 5, 10, and 15 days after planting. This could be attributed to the stress induced by the bio-priming of the seed with biofertilizer at the early stage of seedling due to the alteration mentioned earlier. However, as the seedlings advance in age, the bio-primed seedlings equalize with the hydro-primed seedlings at 25 and 30 days after planting.

Maize seeds primed for the period of 2, 4, 6, 8, 10, and 16 hours had a higher number of leaves than their counterparts primed for 18, 20, 22, and 24 hours at 5 days after planting. Conversely, differences observed in the number of leaves among the seedlings whose seeds were bio-primed at different times narrow down as the seedlings advance in age. The leveling up of the number leaves as the seedling advances in age could be, perhaps, due to the imbibition of nutrient elements and the role of the inoculant (Bezt DM microbes in liquid) during bio-priming. According to Schikora et al. (2016), who reported that bacterial inoculum can boost plant development by facilitating mineral uptake, reducing infections through biological competition, and stimulating the plant defence system. Forti et al. (2020) similarly documented that bio-priming improved seedling development.

Bio-priming significantly reduced plant height at 5, 10, 15, and 20 days after planting compared to that of hydro-priming (Table 5). The plant height significantly varied across the time of priming at 5, 15, and 20 days after planting. The seedlings whose seeds were primed for 2 to 14 hours were similar in height but significantly taller than those of 18 to 24 hours at 5 days after planting. At 15 days after planting, seedlings whose seeds were primed for 12 hours had significantly taller plants than those of 18 hours, whereas others were comparable. Furthermore, seed primed for 12 hours produced significantly taller plants than those of 8 hours at 20 days after planting, while others had comparable plant height. However, the seedlings were similar at 25 and 30 days after planting, irrespective of the time of priming. This points to the fact that bio-primed seedling, which initially suffered from the detrimental effects of bio-priming because of the accumulated substances claimed by Chakrabori et al. (2022), could also enjoy the positive benefit accrued to it. This perhaps explained the reason why the seedlings that overcome the side effects of alteration could level up at 25 days after planting and thereafter. Thus, confirming the assertion of Forti et al. (2020), who reported that bio-priming resulted in improved seedling development.

The interactions of priming and time of priming on plant height were consistently significant for the whole period of the study (Table 6). This implied that the primed seed produced seedlings whose plant height responded differently to the time of priming. While the seedlings from hydro-prime were indifferent, those of bio-primed plants varied depending on the time of priming.

Table 4: Influence of priming and time of priming on the number of leaves

Treatment	Number of days after planting					
	5	10	15	20	25	30
Priming (P)						
Hydro-primed	2.94a	3.98a	5.81a	6.92a	8.11a	8.58a
Bio-prime	1.87b	3.29b	5.44b	6.78a	7.53a	8.36a
SE	0.31	0.60	0.13	0.21	0.34	0.38
Hours (H)						
2	2.56abc	3.78ab	5.67a	6.83a	8.17a	9.17a
4	2.72ab	4.22a	5.67a	6.00a	6.67a	8.00a
6	2.94a	4.33a	5.67a	6.67a	8.17a	8.83a
8	2.72ab	4.39a	5.67a	6.33a	6.67a	7.00a
10	2.72ab	4.50a	5.83a	7.50a	8.33a	8.50a
12	2.44abc	4.17ab	5.83a	7.50a	8.17a	8.67a
14	2.39abcd	3.28ab	5.83a	7.00a	7.83a	8.50a
16	2.50abc	4.11a	5.83a	7.33a	8.67a	8.67a
18	2.06cde	3.17ab	5.33a	6.83a	7.83a	8.83a
20	1.83e	2.78b	5.50a	6.83a	8.17a	8.67a
22	2.17bcde	3.17ab	5.67a	7.17a	7.67a	8.83a
24	1.83e	2.50b	5.00a	6.17a	7.50a	8.00a
SE	0.45	150	0.31	0.52	0.84	0.94
H*P	NS	NS	NS	NS	NS	NS

Table 5: Influence of bio-fertilizer and time of priming on plant height (cm)

Treatments	Number of days after planting					
	5	10	15	20	25	30
PRIMING (P)						
Hydro-primed	19.6a	42.3a	51.69a	62.1a	76.1a	104.0a
Bio-primed	12.5b	37.1b	47.39b	55.9b	72.0a	101.2a
SE	0.67	1.53	1.66	3.10	3.73	4.79
HOURS (H)						
2	17.3ab	39.5a	49.8abc	60.0abc	72.8a	98.2a
4	20.0a	38.8a	48.7abc	52.3bc	66.7a	91.7a
6	18.0ab	41.7a	52.2ab	67.5ab	75.7a	103.2a
8	18.3ab	40.8a	48.5abc	47.0c	59.7a	86.0a
10	17.3ab	42.3a	51.5ab	63.3abc	84.7a	111.0a
12	18.2ab	41.4a	56.7a	71.2a	85.8a	113.5a
14	17.3ab	43.9a	54.5ab	64.2abc	76.5a	118.2a
16	15.0bc	42.2a	52.0ab	66.7ab	82.7a	107.8a
18	12.7c	32.3a	41.8c	53.8abc	76.7a	107.3a

20	13.4c	38.6a	46.0bc	54.2abc	76.8a	103.7a
22	13.1c	38.4a	47.8abc	57.0abc	72.8a	101.3a
24	11.8c	36.0a	45.0bc	51.0bc	57.7a	89.7a
SED	1.65	3.74	4.06	7.60	9.13	11.73
H*P	S	S	S	S	S	S

Table 6: interaction between priming and soaking hour on plant height (cm)

Treatments	Number of days after planting					
	5	10	15	20	25	30
Hydro-primed						
2HRS	18.00a	39.0a	49.33a	58.0a	66.7a	91.3a
4HRS	20.33a	35.0a	41.67a	38.7b	49.7b	72.0b
6HRS	18.67a	43.7a	50.00a	62.3a	71.0a	96.7a
8HRS	19.33a	43.3a	50.00a	58.7a	75.0a	108.0a
10HRS	20.33a	40.5a	52.00a	64.7a	84.7a	114.7a
12HRS	18.67a	41.3a	56.33a	70.3a	84.3a	111.7a
14HRS	19.33a	47.0a	57.33a	68.0a	82.7a	120.3a
16HRS	21.67a	45.5a	55.67a	76.0a	87.3a	113.7a
18HRS	20.00a	42.3a	48.67a	60.3a	81.0a	117.0a
20HRS	17.33a	43.3a	58.67a	69.3a	93.0a	116.3a
22HRS	20.83a	43.3a	50.33a	61.3a	74.3a	101.0a
24HRS	19.77a	42.8a	50.33a	57.7a	63.7a	85.3a
Bio-primed						
2HRS	16.67a	40.0a	50.33a	62.0a	79.0a	105.0a
4HRS	19.67a	42.7a	55.67a	66.0a	83.7a	111.3a
6HRS	17.33a	39.7a	54.33a	72.7a	80.3a	109.7a
8HRS	17.33a	38.3a	47.00a	35.3b	44.3.0b	64.0b
10HRS	14.33b	44.2a	51.00a	62.0a	84.7a	107.3a
12HRS	17.00a	41.5a	57.00a	72.0a	87.3a	115.3a
14HRS	13.00b	40.8a	51.67a	60.3a	70.3a	116.0a
16HRS	10.00b	39.0a	48.33a	57.3a	78.0a	102.0a
18HRS	8.00b	22.3b	35.00b	47.3a	72.3a	97.7a
20HRS	6.00b	33.8a	33.33b	39.0b	60.7b	91.0a
22HRS	6.33b	33.4a	45.33a	52.7a	71.3a	101.7a
24HRS	4.67b	29.2b	39.67b	44.3a	51.7a	94.0a
SE	2.33	5.28	11.57	10.7	12.91	16.60

Values with similar alphabets vertically are not significantly different

The priming and time of priming did not influence above-ground biomass, root, and root-related parameters except root length (Table 7). The interaction of priming and time of priming on root-related parameters and above-ground biomass was not significant. This suggests that the above-ground biomass, root, and root-related parameters obtained from the primed seeds responded similarly to the time of priming.

Table 7: Influence of Bio fertilizer and time of priming on root and root-related parameters

TREATMENT	Root length (cm)	Root weight (g)	No. of Root	Above biomass weight (g)
PRIMING (P)				
Hydro-primed	54.1a	3.33a	21.50a	63.3a
Bio-primed	54.7a	2.89a	19.08b	57.7a
SE	3.70	0.25	1.13	3.80
Hours (H)				
2	54.3a	4.17a	19.67a	64.4a
4	46.3a	3.67a	16.67a	57.4a
6	47.7a	2.81a	20.67a	61.3a
8	52.2a	2.04a	16.67a	44.0a
10	59.2a	2.65a	25.50a	65.3a
12	57.3a	2.77a	21.17a	62.4a
14	58.3a	2.56a	18.83a	66.4a
16	56.5a	3.08a	20.83a	66.5a
18	56.7a	3.07a	22.50a	64.9a
20	51.5a	3.27a	20.67a	63.3a
22	62.8a	3.40a	21.00a	58.7a
24	49.9a	3.82a	21.83a	51.3a
SE	9.06	0.61	2.76	9.31
H X P	NS	NS	NS	NS

Values with similar alphabets vertically are not significantly different,
NS =non-significant, S = significant.

Generally, the process of bio-priming induced certain stress on the seeds, which not only suppressed germination as indicated earlier but also affected seedling vigour, which is obvious at the early seedling stage. The actual causes of the reduction in the performance (plant health, number of leaves, plant height, culm diameter) of the seedling at the early stage compared to their counterpart in hydro-priming could be attributed to the fact that biofertilizer contains some inherent substances that cause alteration to germination, plant health, and growth parameters. Although these alterations were overcome by the bio-primed seedling as the growth advanced, because of the presence of plant nutrients and beneficial bacteria in the biofertilizer, which also facilitated seedling development to catch up with their hydro-primed counterparts. This could be a result of the developed immunity as the plant grows. The significant interactions of priming and time of priming on the number of leaves and plant height implied the differential responses.

Conclusions

Seed priming with bio-fertilizer is known to enhance germination and seedling vigour. However, priming time is crucial for germination and seedling vigour. Thus, two studies were carried out to investigate the effective time of bio-priming to promote seed germination and seedling vigour of maize plants. The study shows that bio-priming significantly reduced germination percentage. The time of bio-priming the seed should be limited to four hours. The performance of seedlings obtained from bio-primed seeds was initially lower but levelled off as growth advanced compared to that of hydro-primed.

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Back to Basics: Mitigating the Harmful effects of Droughts for Efficient Livestock Productivity in the Grasslands of the Central Free State In South Africa

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Abstract
Rangelands'health is dependent on rangelands' productivity and effective livestock management practices,and is directly linked to proper animal stocking rates in extensive livestock farming systems. Thus, these two parameters are essential for healthy rangeland ecosystems. However, imprudent rangeland management exacerbates the impacts of catastrophic droughts, leading to fodder shortages for ruminant animals in extensive livestock farming systems. The latter subsequently increases the vulnerability of livestock to diseases, and thus, implicates low reproductive performance and high livestock mortalities in extensive farming systems. This results in exorbitant financial losses incurred by livestock farmers. Abysmal rangeland conditions inevitably lead to rangeland degradation and consequently minimize the ability of rangeland ecosystems to sequester more carbon. This tremendously decreases the inherent ability of these ecosystems to function optimally toenvironmental shocks and mitigate the harmful impacts of climate change. This study compares the findings of three trials with an identical theoretical framework, namely: 1. Stocking rates on land-reform farms during drought, 2. Rangeland management and reproduction performance of beef cattle and 3. Rangeland condition and soil chemical properties data were collected from nine extensive livestock land-reform farms. Post research trials comparison and scientific data analyses, the following was found: Imprudent rangelands management practices decrease the ability of rangelands to support livestock with fodder during drought, Execution of science informed sustainable grazing system increase livestock productivity during drought, Improper animal stocking rates leads to financial losses during drought, whereas proper animal stocking rates can increase income even during drought and Lastly, a significant difference between rangeland condition and soil carbon, demonstrating the essential role of good rangeland management in carbon sequestration was identified. It is thus concluded that knowledge regarding stocking rates and prudent rangeland management practices (condition and carbon sequestration) is paramount for sustainable livestock farming during climate change.

Keywords: Mitigating Droughts, Livestock Productivity, Grasslands

Résumé
La santé des pâturages dépend de leur productivité et de pratiques d'élevage efficaces, et est directement liée à des taux de chargement appropriés dans les systèmes d'élevage extensifs. Ces deux paramètres sont donc essentiels à la santé des écosystèmes de pâturages. Cependant, une gestion imprudente des pâturages exacerbe les effets des sécheresses catastrophiques, entraînant des pénuries de fourrage pour les ruminants dans les systèmes d'élevage extensifs. Ces pénuries augmentent la vulnérabilité du bétail aux maladies, ce qui se traduit par une faible performance reproductive et une forte mortalité dans ces systèmes. Il en résulte des pertes financières considérables pour les éleveurs. La dégradation des pâturages conduit inévitablement à leur dégradation et, par conséquent, réduit leur capacité à séquestrer le carbone. Ceci diminue réduitconsidérablement leur capacité intrinsèque à fonctionner de manière optimale face aux chocs environnementaux et à atténuer les effets néfastes du changement climatique. Cette étude compare les résultats de trois essais menés selon un cadre théorique identique, portant sur : 1. les charges animales dans les exploitations agricoles issues de la réforme agraire en période de sécheresse ; 2. la gestion des parcours et les performances de reproduction des bovins de boucherie ; et 3. l'état des parcours et les propriétés chimiques des sols. Ces données ont été collectées auprès de neuf exploitations agricoles extensives d'élevage issues de la réforme agraire. Après comparaison des essais et analyse des données scientifiques, les conclusions suivantes ont été tirées : des pratiques de gestion des parcours inappropriées diminuent leur capacité à nourrir le bétail en période de sécheresse ; la mise en œuvre d'un système de pâturage durable, fondé sur des données scientifiques, accroît la productivité du bétail en période de sécheresse ; des

charges animales inadaptées entraînent des pertes financières en période de sécheresse, tandis que des charges animales appropriées peuvent accroître les revenus, même en période de sécheresse ; enfin, une différence significative a été observée entre l'état des parcours et le carbone du sol, démontrant le rôle essentiel d'une bonne gestion des parcours dans la séquestration du carbone. En conclusion, la connaissance des charges animales et des pratiques de gestion des parcours (état et séquestration du carbone) est primordiale pour un élevage durable face aux changements climatiques.

Mots-clés : Atténuation des sécheresses, Productivité du bétail, Prairies

Introduction

The profitability and sustainability of extensive livestock farming enterprises are determined by various factors, including the health of rangelands and livestock reproductive performance (Van der Westhuizen *et al*., 2020). Avenant (2019) reported that the grassland biome of South Africa covers a total area of 32 534 079 ha (hectares), of which the available livestock grazing area is 21 560 559 ha and it is currently being grazed by 3 934 838 large stock units (LSU's). According to Meissner *et al*. (1983), a large stock unit is equivalent to an animal with a live body weight of 450kg, gaining 500g per day in weight on the pasture with a digestible energy (DE) concentration of 55%. In the Free State Province, the total grassland area is 12 982 516 ha with an available grazing area of 8 538 734 ha. grazed by 1 333 815 LSU's (Avenant, 2019), indicating an average stocking rate of 6.4 ha/ha /LSU. According to Mokhesengoane *et al*. (2021), rangeland resource planning and management depend on climatic variations such as rainfall and temperature, influencing the stocking rate adjustments.

However, over the past four consecutive decades, several research projects have highlighted weather events, such as El Niño-induced droughts, to have had detrimental implications on livestock productivity and will continue in the future (Thornton *et al*., 2009). A study by Van der Westhuizen *et al*. (2020), emphasised that increased climate variability and climate change significantly threaten essential grassland ecosystems with increased droughts, especially in semi-arid areas with unpredictable rainfall.

Additionally, poor rangeland management and overstocking can lead to financial and livelihood losses due to livestock mortalities in extensive livestock farming systems (Mokhesengoane *et al*., 2021). Natural rangelands management methods based on scientific research promote sustainable beef productivity and can decrease the adverse effects of droughts (Van der Westhuizen *et al*., 2020). The sustainability of livestock farming enterprises and grazing resources contributes to global food security, as the Food and Agriculture Organization (FAO, 2014) predicts an increase in the world's population growth from 7.2 billion to 9.3 billion by 2050.

The degradation of grasslands is a global concern, while ecosystem health also plays a role in hydrological disturbances, water quality, dust storms occurrence and severity, food security, poverty, rural development, and the social consequences of farming communities (Van der Westhuizen *et al*., 2022). Previous studies have identified a negative relationship between soil organic carbon (SOC) content, soil organic matter (SOM), and low rainfall occurrences (Fynn *et al*., 2009). Therefore, sustainable rangeland management practices should be implemented to reduce the carbon footprint. An agricultural extension can be essential to incentivise and support farmers to adopt sustainable livestock production systems.

This study aims to present agricultural extension personnel with information to guide them in facilitating theadoption of sustainable rangeland management practices for efficient livestock productivity and rangelands' ecosystem health, concentrating on recent research results for the Bloemfontein area. Data collection included: (1) stocking rates of LSUs on land-reform farms during droughts (Mokhesengoane *et al*., 2021); (2) range land management and reproduction performance of beef cattle (Van der Westhuizen *et al*., 2020), and (3) assessment of rangeland condition and associated soil health collected on nine extensive livestock land-reform farms(Mokhesengoane, 2023).

Materials and Methods

2.1 Study area

The three studies evaluated in this present study were all conducted in the semi-arid grassland biome of the Bloemfontein area (1320 m to 1420 m above sea level), located in the Free State Province of South Africa. According to Van der Westhuizen (2003), the vegetation type can be described as sweet grass-veld, often dominated by the perennial The medatriandra (red grass) specie when grasslands are in a pristine, maintained condition. The average rainfall reported from the last 95 years for this area by ISCW-databank (2018) is ± 556 mm per annum. The most precipitation occurs in

the summer months (November to March), resulting in a 62% increase in vegetation growth (Van der Westhuizen, 2006). The Department of Agriculture, (2003) grazing capacity map recommends the grazing capacity norm of 6 ha per LSU for veld in good condition in this area.

2.2 Methods

Purposive sampling was utilised to select three recent research trials supporting ecological sustainability approaches in livestock management in the Bloemfontein area during drought periods. Previous studies reviewed based on their theoretical framework include:

i. stocking rates of LSU's on land-reform farms during droughts (Mokhesengoane et al., 2021);
ii. rangelands' management and reproduction performance of beef cattle (Van der Westhuizen et al., 2020), and
iii. An assessment of rangelands' condition and associated soil health was collected on nine extensive livestock land-reform farms (Mokhesengoane, 2023).

According to Mokhesengoane *et al*. (2021), twenty-nine livestock farmers reported a loss of 176.8 LSU during the 2018 and 2019 mid-summer drought period. In contrast, Van der Westhuizen *et al*. (2020), described increased livestock production during drought with minimal rangeland management input in the same district during drought. Whilst Mokhesengoane, (2023),quantified the benefits and limitations of sustainable rangeland management practices post two wet seasons preceded by droughts by comparing soil carbon content with rangeland conditions. Soil analyses were performed according to The Non-Affiliated Soil Analysis Work Committee (1990). Rangeland condition scores were determined for every site using the indicator species technique, developed and tested against a degradation gradient technique specifically for central Free State vegetation type (Van der Westhuizen, 2003).

3. Results and Discussions

Literature studies indicated the influence of stocking rate, rangeland management, and condition assessment on sustainable livestock production while mitigating the harmful effects of droughts and climate change.

3.1 Stocking rate

According to Mokhesengoane *et al*. (2021), the average stocking rate implemented by farmers representing land-reform projects in the Bloemfontein district during the 2018 and 2019 drought was 5.9 ha per LSU. Overstocking occurred on 31 % of the farms, and 38% of farmers reported fodder shortages. Despite the low feed resources, overstocking rates of over 300% (above the recommended 6 ha/LSU) and high mortalities were reported (Table 1). Total livestock mortalities reported for this trial were 176.8 LSU's equal to R 1 760 920.87 (ZAR) at R42.39/kg for an average B2/B3 carcass for November 2018.

In the study of Mokhesengoane et al. (2021), respondents were requested to compare the availability of natural fodder with that of their neighbours. (Table 1) shows a positive relationship between available fodder and stocking rate and a negative relationship between available fodder and mortality rate (Table 2). The stocking rate of the farms with less fodder available than their neighbours (stocking rate of 378%) contributed to forage shortages and higher mortality rates (22.4%).Furthermore, the influence of stocking rates during drought on beef production and reproduction is also emphasised by Van der Westhuizen *et al*. (2020). Reduced stocking and calving rates (not reduced lower than 18%) during drought outperformed the 6 ha/LSU for the study area with R 1 534 per cow (Table 3). Future studies could further investigate the practical implementation of the variable stocking rate. Due to the impact of climate variability on sustainable beef production, stocking rates should be determined according to assessments of rangeland potential.

3.2 Rangeland management

Van der Westhuizen *et al*. (2020) recorded a 32% calving rate without implementing rangeland management during the first year of the trial. In contrast, after a year of rangeland management implementation, the calving rate almost doubled to 59%, reaching the maximum of 82% in year four. These calving rates are more profitable than the lower calving rate of 34% reported for commonage farmers, 60% reported for commercial farmers (Scholtz & Bester, 2010), and 32% reported for Bloemfontein land-reform farms studied during drought (Mokhesengoane *et al*., 2021). Commonage and land reform small-holder farmers generally report lower calving rates due to their communal livestock farming background, where rangeland management and sustainable beef production practices are not usually implemented (Van der Westhuizen *et al*., 2020).

Additionally, poor livestock performance and degradation of natural resources are more evident in these systems (Van der Westhuizen et al., 2020). Weaning calf weights of 156 kg with no rangeland management inputs and 229 kg during

production year four of rangeland management implementation was recorded (Table 4). The implementation of a reduced stocking rate resulted in an increased calving rate, improved environmental health and potential income per cow, further emphasising the importance of a balance between natural fodder availability and livestock numbers (Mokhesengoane et al., 2021).

3.3 Rangelands condition

Rangeland condition assessment is crucial to ensure the sustainability and profitability of extensive livestock farming systems. The condition status of grazing resources indicates ecosystem health, production ability, and carrying capacity during drought (Van der Westhuizen et al., 2018). The risks associated withdroughts escalate if rangeland conditions deteriorate; for example, fodder shortage can increase to 48% for rangelands of average condition (50%) compared to only 5% for rangelands classified as an optimum condition in the Bloemfontein area (Van der Westhuizen, 2006).Where poor rangeland conditions are identified, the probability of forage shortages increases to more than 90%. Results from Trial three indicated significant differences ($p < 0.05$) between rangelands condition (minimum = 14%, maximum = 81%, average = 50%) and topsoil carbon content (Table 5) of land-reforms farms at 20 cm depth (for rangelands in very poor condition, 1% topsoil carbon content was recorded and for rangelands in a good condition, 3.1% topsoil carbon content was recorded). Rangelands in good condition can sequestrate three times more carbon than rangelands in poor conditions.

The grasslands biome covers approximately 50% of the global surface area (Mitchell, 2000), mainly utilised for livestock grazing. Grasslands are essential in carbon sequestration, absorbing atmospheric carbon dioxide during photosynthesis and transporting it through the root systems to be stored in the soil.Carbon (C) then strengthens the soil structure by increasing macro soil pores, substrate, and energy to support soil microbial activity, further promoting the storage of organic nitrogen (N), phosphorus (P), and other related soil nutrients.

Therefore, grassland maintenance through the implementation of management practices and adequate animal stocking rates increases the potential of the soil to store more C and, as a result, mitigate the effects of climate change (Fynn et al., 2009).

4. Conclusions

The collective findings of this comparison study illustrate that proper animal stocking rates and prudent rangelands management leads to ecological sustainability, high investment returns, and sustainable extensive livestock farming enterprises. These findings can further be summarised as follows to mitigate the adverse effects of droughts and climate change:

i. Overgrazing leads to higher livestock mortalities during droughts.
ii. Reduced livestock numbers during droughts decrease livestock mortalities.
iii. Reduced livestock numbers during droughts increase the production and reproduction rate of livestock.
iv. Production planning for sustainable rangelands utilisation increases livestock production and profitability.
v. With the execution of a sustainable grazing system, livestock production can be higher even during drought periods.
vi. Carbon sequestration for good-condition grasslands is three times higher than that for poor-condition grasslands.

In conclusion, properly managed grasslands and grazing resources, including controlled stocking rates, are effective tools for livestock farmers to mitigate the harmful influence of climate change on the environment. No mortalities were reported during Trial two, with similar environmental parameters to Trial one, reiterating the significance of implementing rangeland management practices and production planning based on scientific research. Trial three results illustrate that SOC and SOM increase as rangelands condition improves, highlighting the importance of grassland health for carbon sequestration and mitigating climate change impacts and a reduced carbon footprint.

5. Recommendations

The study recommends a paradigm shift to extension personnel by highlighting the significance of proper rangeland management and animal stocking rates in carbon sequestration to reduce climate change effects. Furthermore, the study recommends that the balanced application of stocking rates, in line with seasonal fodder availability fluctuations, is paramount for sustainable livestock productivity during variable climatic conditions. Knowledge of stocking rates and rangeland management is critical for profitability and environmental sustainability.

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Tables

Table 1: Mean mortality rate as a percentage of the stocking rate at 6 ha/LSU (± standard deviation); (Mokhesengoane *et al*.,2021).

Stocking rate	**Mortality %**
More than 130 % overstocked	32.7 ± 50^{a}
Rest of farmers	5.7 ± 7.6^{b}

a& b - Values in columns with different superscripts differ significantly

Table 2: Fodder availability compared to neighbouring farms with average stocking rate and average mortality rate during the drought of 2018-2019 (Mokhesengoane *et al.*, 2021).

Forage availability in comparison with neighbours	Frequency	Percent (%)	Stocking rate (%)	Mortality rate (%)
Better	12	41.4	88	6.5
Same	6	20.7	147	14.0
Worse	11	37.9	378	22.4
Total	29	100.0		

Table 3: Comparison of reproduction performance between fixed and variable stocking rate (%); (Van der Westhuizen *et al*., 2020).

Years after implementation of rangeland management	Fixed stocking rate	Reduced stocking rate due to drought
Calving rate (%)	58	76
Weaning weight (kg)	188	198
Income per cow mated *	R 4 034	R 5 568

* = Based on a weaner price of R37/kg

Table 4: Reproduction performance (calving rate % and weaning weight in kg) and rangeland condition over four production years (Van der Westhuizen *et al*., 2020).

Years after implementation	Calving % ± SD	Weaning weight (kg) 205 days ± SD	Simulated seasonal production
No rangeland management inputs	32^{a} ± 10	155.8^{a} ± 11.1	Normal
Year 1	59^{b} ± 19	215.8^{c} ± 6.7	Below normal
Year 2	60^{b} ± 12	214.4^{c} ± 10.1	Very high
Year 3	62^{b} ± 15	190.0^{b} ± 9.6	Very low Drought
Year 4	82^{c} ± 7	228.6^{d} ± 6.7	Normal

a, b, c, d - Values (mean ± SD) within a column followed by different superscript letters are significantly different ($p < 0.05$), SD = Standard deviation.

Table 5: Top soils' carbon content (%) for different rangelands condition classes (Mokhesengoane, 2023).

Rangelands condition	Very poor (≤ 20 %)	Poor to Moderate (21 - 60 %)	Good (> 60 %)
Carbon content ± SD (%)	1.0^{a} ± 0.43	1.9^{a} ± 0.73	3.1^{b} ± 1.08

a, b, c, d - Values (mean ± SD) within a column followed by different superscript letters are significantly different ($p < 0.05$), SD = Standard deviation.

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Abattoir Operations and their Ecological Footprint: Implications for Climate Resilience and Justice in Gwagwalada, Abuja, Nigeria

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Abstract
Background: Abattoirs in Gwagwalada, Abuja, Nigeria serve as critical hubs for regional meat supply, yet their operational practices pose significant environmental and public health risks. These practices directly impact food safety and climate resilience, raising critical climate justice concerns within the local food system. Purpose: This study assessed the ecological footprint of Gwagwalada abattoir operations and analysed their implications for climate resilience, food safety, and justice.
Methods: The authors employed observational techniques, visual aids, and conducted interviews with approximately fifty meat buyers and five producers/workers to document operational activities, infrastructure, and value chain dynamics.
Current practices reveal inadequate water supply, unsanitary slaughtering (e.g., tire-based skinning), and poor waste management (e.g., unmanaged processing effluents), leading to environmental contamination and inefficient resource use. Rudimentary transportation and storage exacerbate food safety risks. These deficiencies compromise ecological integrity, undermine meat supply chain resilience, and disproportionately expose vulnerable workers and communities to environmental degradation and health hazards, highlighting significant climate justice issues. Existing abattoir operations in Gwagwalada are unsustainable and detrimental to public health and environmental well-being. Urgent interventions are needed, including developing standardized, climate-resilient abattoir infrastructure with advanced waste and water management systems. We, the authors, advocate for modern meat preservation technologies and fostering value chain development, prioritizing ecological sustainability and equitable access to safe practices. Implementing such biotechnological and systemic improvements is crucial for enhancing food security, public health, and climate justice in the region.

Keywords: Abattoir, Ecological Footprint, Climate Resilience, Food Safety, Climate Justice, Gwagwalada, Nigeria.

Résumé
Les abattoirs de Gwagwalada, à Abuja (Nigeria), constituent des plateformes essentielles pour l'approvisionnement régional en viande. Cependant, leurs pratiques opérationnelles présentent des risques importants pour l'environnement et la santé publique. Ces pratiques ont un impact direct sur la sécurité alimentaire et la résilience climatique, soulevant de graves questions de justice climatique au sein du système alimentaire local. Objectif : Cette étude a évalué l'empreinte écologique des opérations de l'abattoir de Gwagwalada et analysé ses implications pour la résilience climatique, la sécurité alimentaire et la justice. Les auteurs ont utilisé des techniques d'observation, des supports visuels et ont mené des entretiens avec une cinquantaine d'acheteurs de viande et cinq producteurs/travailleurs afin de documenter les activités opérationnelles, les infrastructures et la dynamique de la chaîne de valeur. Les pratiques actuelles révèlent un approvisionnement en eau insuffisant, des abattages non hygiéniques (par exemple, le dépeçage à l'aide de pneus) et une mauvaise gestion des déchets (par exemple, des effluents de transformation non traités), entraînant une contamination environnementale et une utilisation inefficace des ressources. Le transport et le stockage rudimentaires aggravent les risques pour la sécurité alimentaire. Ces carences compromettent l'intégrité écologique, fragilisent la résilience de la chaîne d'approvisionnement en viande et exposent de manière disproportionnée les travailleurs et les communautés vulnérables à la dégradation de l'environnement et aux risques sanitaires, soulignant ainsi d'importants enjeux de justice climatique. Les opérations d'abattage actuelles à Gwagwalada sont non-durables et préjudiciables à la santé publique et

au bien-être environnemental. Des interventions urgentes sont nécessaires, notamment le développement d'infrastructures d'abattoir standardisées et résilientes face au climat, dotées de systèmes avancés de gestion des déchets et de l'eau. Nous, les auteurs, préconisons l'adoption de technologies modernes de conservation de la viande et la promotion du développement de la chaîne de valeur en privilégiant la durabilité écologique et l'accès équitable des pratiques sûres. La mise en œuvre de telles améliorations biotechnologiques et systémiques est cruciale pour renforcer la sécurité alimentaire, la santé publique et la justice climatique dans la région.

Mots-clés: Abattoir, Empreinte écologique, Résilience climatique, Sécurité alimentaire, Justice climatique, Gwagwalada, Nigéria1. Defining Abattoirs and Their Critical Role

Abattoirs, also known as slaughterhouses, are specialized industrial facilities where livestock is humanely slaughtered, processed, and inspected for human consumption. In the context of the Nigerian food system, and specifically Gwagwalada, abattoirs are pivotal nodes in the livestock value chain.
The Gwagwalada abattoir operates as a major hub for the slaughtering of cattle, the subsequent buying and selling of meat, and associated activities like cattle keeping and rearing on-site, as evidenced by the visual data (Figure 2).



These operations provide employment across various value chain segments—from herders and butchers to meat processors and transporters—underscoring its socioeconomic importance. A core function is meat inspection, which is meant to serve as a quality safeguard, reduce contamination risk, and protect public health.

2. Operational Activities and Associated Ecological/Health Risks

The operational practices observed at the Gwagwalada abattoir, as documented by this study's primary data and supported by prevailing literature on abattoir management in Nigeria, involve several activities that generate significant ecological and public health footprints.

A. Slaughtering and Processing

- **Practice:** The study documented unsanitary slaughtering methods, such as the use of tire-based skinning.
- **Risk:** This practice is a major source of cross-contamination, introducing pathogens, soot, and chemical residues from the tires directly onto the meat surface, thereby severely compromising food safety. Literature consistently highlights that such rudimentary processing techniques are a primary cause of microbial contamination (e.g., Salmonella, E. coli) in meat destined for markets (e.g., Ladele, 1991).

B. Water and Effluent Management

- **Practice:** The findings indicate inadequate water supply and the unmanaged discharge of processing effluents (blood, intestinal contents, wash water) directly into the environment. The image showing workers handling large jerry cans (Figure 1) visually supports the finding of water scarcity and reliance on non-integrated supply methods.
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- **Risk:** This practice is the single largest contributor to the abattoir's ecological footprint. The high organic load and pathogens in the untreated effluent pollute surface water bodies, contaminate groundwater, and generate foul odors, severely degrading the local ecosystem and increasing the risk of waterborne diseases in surrounding communities. Secondary data, including case studies across other Nigerian cities, consistently report effluent discharge as a major environmental challenge (Oke, 2023).

C. Waste Management (Solid and By-products)

- **Practice:** Poor handling of solid waste (e.g., bones, non-edible offal, and general refuse) and the absence of modern rendering or by-product utilization facilities.
- **Risk:** The waste attracts pests (flies, rodents), which are vectors for disease transmission. Accumulation of organic waste contributes to the release of methane, a potent greenhouse gas, thereby directly contributing to the abattoir's climate change footprint.

D. Value Chain and Logistics

- **Practice:** The findings note rudimentary transportation and storage methods for the processed meat.
- **Risk:** Lack of refrigerated transport and storage (the "cold chain") allows for rapid bacterial growth, which significantly exacerbates food safety risks before the meat reaches the final consumer. Public opinion, often reported in local newspapers, frequently voices concerns over meat quality and handling practices during market transportation.

3. Implications for Food Safety, Climate Resilience, and Climate Justice

The operational deficiencies translate directly into significant socio-ecological impacts:

A. Impact on Food Safety and Climate Resilience

The combined effect of contamination during slaughter, poor water management, and rudimentary logistics creates an unresilient meat supply chain. A sudden shock (e.g., a disease outbreak or a heavy rain event typical of climate change) could rapidly contaminate the entire local food supply, leading to a public health crisis and a collapse of the meat value chain. Climate resilience in the food system requires robust infrastructure and standards that can withstand such shocks; the current setup in Gwagwalada fails this test.

B. Implications for Climate Justice

The unsustainability of the current operations highlights profound climate justice issues. Climate justice addresses the fact that the poorest and most vulnerable are often the first and worst affected by climate change impacts and environmental degradation.

- **Disproportionate Exposure:** The findings state that these deficiencies "disproportionately expose vulnerable workers and communities to environmental degradation and health hazards." The workers (butchers, labourers) are directly exposed to unhygienic conditions and the risks of zoonotic diseases. The residential communities near the abattoir bear the burden of polluted air and water without having contributed significantly to the abattoir's poor management practices.

- **Equity and Public Opinion:** International communities and policies emphasize equitable access to safe food and a healthy environment. A review of newspaper reports (popular opinion) often reveals calls from residents for governmental intervention to clean up abattoirs, indicating a perceived injustice in the distribution of environmental benefits (cheap meat supply) and burdens (pollution, health risks).



4. International Context and Policy Gaps

In international communities, modernized abattoirs operate under stringent standards that treat waste and water as resources, not liabilities.

- **Best Practice in Developed Nations:** Modern abattoir operations employ advanced technologies like anaerobic digestion to convert highly polluting abattoir waste (paunch manure and effluent) into biogas (a renewable energy source) and nutrient-rich bio-fertilizer. This closed-loop system mitigates the environmental impact, reduces the facility's carbon footprint, and improves operational efficiency and resource use.

- **Policy Challenge:** The Gwagwalada abattoir's current challenges are often a result of a policy-to-practice gap. While Nigeria may have policies guiding abattoir standards, the implementation often lags due to insufficient investment in infrastructure, lack of enforcement, and reliance on outdated, labor-intensive methods. Policy guarding the use of abattoir waste for value addition (e.g., bone meal, biogas) is critical but appears absent or ineffective in this context, leading to the severe challenges identified.

5. Conclusion and Recommendation Summary

The Gwagwalada abattoir's operations are ecologically unsound and pose a direct threat to public health and the resilience of the local food system. The observed deficiencies compromise food safety and disproportionately impact the environment and vulnerable local communities, raising critical issues of climate justice.

The key recommendation aligns with the need for urgent interventions: Developing standardized, climate-resilient abattoir infrastructure with advanced biotechnological solutions for waste and water management (e.g., effluent treatment and biogas production) is the best practical way forward for operational and environmental safety. This is the surest path to enhancing food security, improving public health, and achieving climate justice in Gwagwalada.

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Biochar-based Native Microbial consortium for Crop Quantity and Quality Improvement in Cameroon

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Abstract
It is increasingly recognized that modern, high-productivity farming methods are not sustainable and that the world, particularly Africa, needs innovative solutions to provide safe and secure food for future generations. This study aimed to evaluate the collaborative effects of biochar and bacteria lendophytes to improve the growth, yield, and nutrient uptake (N,P,K) of maize (Zea Mays L.). Biochar used in this study was produced by slow co-pyrolysis of coconut fiber and cow dung (30:70). The consortium consisted of two bacterial strains: Bacillus velezensis and Glutamicibacter nicotianae. The experiment followed a fully randomized block design with five treatments: uninoculated control (C); chemical treatment (NPK); biochar; endophytes (Endo);andacombinedbiochar-endophytes(Bio).Growth,yield,andgrainnutrient uptake were evaluated. The results showed that all treatments improved maize growth and yield compared to the control. The NPK treatment achieved the highest plant height (149,29cm) and yield (9.6t/ha), whereas the Bio treatment obtained slightly weaker results (6,94 t/ha), representing 125% increase over the control. Fortunately, the Bio treatment significantly improved nutrient uptake, increasing N, P, and K uptake in grain by 78%, 90%, and 115%, respectively, relative to the control. Principal Component Analysis (PCA) indicated that improving yield does not ensure better nutritional content of the grains. These results highlight that the bio fertilizer based on endophytes and biochar can contribute to the improvement of the quantity and quality of maize and thereby reduce the use of chemical fertilizers.

Keywords: Amendment; biochar; consortium; crop; quantity; quality.

Résumé
Il est de plus en plus admis que les méthodes agricoles modernes à haut rendement ne sont pas durables et que le monde, et notamment l'Afrique, a besoin de solutions innovantes pour garantir une alimentation saine et pérenne aux générations futures. Cette étude visait à évaluer les effets combinés du biochar et d'endophytes bactériens sur la croissance, le rendement et l'absorption des nutriments (N, P, K) du maïs (*Zea mays L.*). Le biochar utilisé a été produit par co-pyrolyse lente de fibres de coco et de bouse de vache (30:70), et le consortium bactérien était composé de deux souches : *Bacillus velezens*is et *Glutamicibacter nicotianae*. L'expérimentation a suivi un dispositif en blocs aléatoires complets avec cinq traitements : un témoin non inoculé (C) ; un traitement chimique (NPK) ; un traitement au biochar ; un traitement aux endophytes (Endo) ; et un traitement combinant biochar et endophytes (Bio). La croissance, le rendement et l'absorption des nutriments par les grains ont été évalués. Les résultats ont montré que tous les traitements amélioraient la croissance et le rendement du maïs par rapport au témoin. Le traitement NPK a permis d'obtenir la plus grande hauteur de plante (149,29 cm) et le meilleur rendement (9,6 t/ha), tandis que le traitement Bio a donné des résultats légèrement inférieurs (6,94 t/ha), soit une augmentation de 125 % par rapport au témoin. Ce traitement Bio a toutefois amélioré significativement la teneur en nutriments, augmentant l'absorption d'azote (N), de phosphore (P) et de potassium (K) par les grains de respectivement 78 %, 90 % et 115 % par rapport au témoin. L'analyse en composantes principales (ACP) a indiqué que l'amélioration du rendement ne garantit pas nécessairement une meilleure valeur nutritive des grains. Ces résultats soulignent que le biofertilisant à base d'endophytes et de biochar peut contribuer à l'amélioration de la quantité et de la qualité du maïs et ainsi réduire l'utilisation d'engrais chimiques.

Mots-clés : biochar ; consortium ; amendement ; quantité ; qualité ; cultures.

1. Introduction

Biochar is an activated-carbon (C) soil conditioner that is developed from the combustion of biomass in anaerobic conditions at temperatures below 1000°C through the process of pyrolysis or dry carbonization (Naba *et al*.,2019). Biochar has attracted considerable attention for ameliorating soil health, soil cation exchange capacity (CEC), soil moisture content, and augmenting crop productivity in rice (Naeem *et al*., 2017); it is typically high in ash, pH, and surface area (Akhtar *et al*., 2015). Nowadays, waste biomass is used extensively to produce biochar because of its cost-effectiveness and food security advantages (Ouyang et al., 2013). The direct mechanism of biochar is the enhanced availability of essential nutrients in the soil, such as K^+, and the lessening of Na^+ absorption(Chintalaetal.,2014). The indirect mechanism involves the enrichment of soil physicochemical properties, biological properties, and soil enzymatic activity, all of which increase the plant water status. (Chintala et al., 2014, Akhtar et al., 2014) reported that biochar greatly increased the water holding capacity of soil, chlorophyll content, stomatal conductance, photosynthetic rate, and relative water content under water deficient conditions. Moreover, biochar application enhanced plant growth of various crops (Egamberdieva *et al*.,2016; Egamberdieva *et al*.,2019). Such positive effects of biochar application were often explained by enhanced diversity of soil microbial communities, which exhibit plant-beneficial traits, and their improved activities involved in nutrient cycling (Egamberdieva *et al*., 2017; Egamberdieva *et al*., 2017). Due to carbon and nutrient concentrations in biochar types, soil microbial activity may vary in response to biochar addition (Song *et al*., 2020).

Reports have indicated that biochar could mitigate water deficit in cereal crops when added with PGPR (Liu *et al*., 2017). Inoculation of biochar with *Azosprillum sp*. further improved the growth, yield, nitrogen (N), and phosphorus (P) uptake under water-deficient conditions compared to microbial inoculation only (Egamberdieva *et al*., 2017). The plant beneficial bacteria Bacillus *amyloliquefaciens* combined with biochar application produced from compost showed a positive effect on spinach(Zafaretal.,2020). Corresponding findings area vailable for *Paenibacilluspolymyxa*, combined with wood biochar on switchgrass (Shanta *et al*., 2016), and for *Pseudomonas fluorescens* and pinewood biochar on cucumber (Nadeem *et al*., 2017). Indeed, the use of the beneficial properties of microorganisms associated with plants is important for: increasing production yields; stimulating the assimilation of soil nutrients; acting as an abiotic stress agent and activator of drought tolerance; controlling plant diseases or pests; adapting plants to appropriate growing conditions or for reforestation activities (Nwaga *et al*., 2010; Deshmukh *et al*., 2018).

The synergistic use of microorganisms with biochar, especially in Africa and notably in Cameroon, is not well documented. Consequently, the current investigation was assumed with an intent to assess the synergistic use of biochar for crop quantity and quality improvement. It is projected that the study results will be beneficial for formulating novel management strategies for improving growth and plant productivity.

2. MATERIALS AND METHODS

2.1. Biochar

Biochar application in this investigation was prepared through slow co-pyrolysis of coconut fibres and cow dung (30:70) at 350°C under an oxygen depleted condition with a mean residence time of 4hours This biochar was chosen due to the in potential applications in the field or green house for crop production. It was obtained from the Regional Laboratory for Biological Control and Applied Microbiology. The initial physical and chemical properties of the biochar are given in the table 1.

Table1. Physico-chemical properties of the biochar

Parameters	pH	Ash	Ca	Mg	K	Na	CO	N	P	CE	C/N
Units	-	%								uS/cm	-
	9.3	0.66	3.26	1.85	1.73	0.97	23.25	2.55	1.20	536	9.1

2.2. Microbial consortium preparation

The microorganisms in the study are plant growth-promoting bacteria (Endo) previously isolated from cowpea crops in Cameroon. These were identified as Bacillus velezensis and *Glutamicibacterni cotianae*. The mentioned strains were selected for their potential to solubilize P and their N-fixation efficiency.
The microbial consortium's preparation included incubating strains for 48 h at 30°C.A mixture of used strains (1:1)waspreparedasinoculum,30mlof108CFU/mlfromeachculture per 500 g of the sterilized carrier and spread over a plastic sheet away from direct sun for 20 min before application.

2.3. Experiment design

Field experiments were conducted at the Regional Laboratory for Biological Control and Applied Microbiology of the Mbalmayo Agricultural Research Centre of the Institute of Agricultural Research for Development (IRAD) in Cameroon (Latitude:3°87'Nand Longitude:

11°52'E). The intent was to study the synergistic impacts of plant growth-promoting bacteria (B. velezensis and G. nicotianae.) and biochar on yield and nutritional value of maize (Zea mays, CMS 8704) in soil. This study used a randomized complete block design, comprising four replications in three blocks, each including all treatments. The treatments were distributed randomly in each block. There were 2 m gaps between the blocks and 1 m alleys between the main plots to avoid lateral water movement and other interferences. The seed viability was further examined before beginning the experiment and was estimated to be 93% on average.

Soil samples were collected before sowing from 0-30 cm depth using an auger. Soil samples were air-dried and passed through a 2-mm sieve for physicochemical properties analysis. The study soil is sandy loam with 10% clay, 21% silt, and 69% sand total N, P, K and Ce was 6,12mg/kg, 4,35mg/kg, 3,12mg/kg and 91(µS/cm) respectively. The pH was 6.4.

The following treatments were applied: (1) control (C), (2) NPK (3g/plant), (3) Endo (10 mL/plant), (3) biochar (10g/plant), (4) and Bio (5g biochar + 5 mL Endo/plant). Thirty replicates were used in this study. The growth variables of interest (plant height and stem girth) were quantified. After the harvest, the production yield was evaluated by determining the weight of the ears and the weight of the grains. The determination of the nutritional value of the seeds was also evaluated.

2.4. Nutrient uptake

Uptake of N, P, and K was measured by multiplying a percentage of the specified element (nitrogen, phosphorus, and potassium) in grain dry matter to calculate total nitrogen uptake, total phosphorus uptake, and total potassium uptake. The nitrogen element was determined by the macro-Kjeldahl technique according to (A.O.A.C., 1975). Phosphorus and potassium elements were determined according to (Trough and Mager,1939;Jackson,1958),respectively.

2.5. Statistical Analysis

All statistical analyses were performed using R version 4.4.1 within the R-Studio environment. Prior to analysis, data were tested for normality and homogeneity of variances using the Shapiro-Wilk and Levene's tests, respectively. A one-way analysis of variance (ANOVA) was conducted to assess differences among treatments, followed by Duncan's post hoc test for multiple comparisons at a significance level of $p < 0.05$. Distinct letters were assigned to indicate statistically significant differences between isolates. Principal component analysis (PCA) was carried out to investigate the relationships between yield parameters and nutritional quality variables and to visualize the multivariate structure of the dataset.

3. RESULTS AND DISCUSSION

3.1. Effect of treatments on Maize growth

The results presented in Figure 2 indicate a significant ($p < 0.05$) difference in maize plant height due to the different fertilizer treatments. Maize plants under NPK treatment achieved the highest plant height (149.29 cm), compared to Bio (132.8 cm), Endo (129.6 cm), Biochar (119.78 cm),and the control (109.76cm).This higher plant height for NPK treatment could be attributed to the availability of essential nutrients such as nitrogen, phosphorus, and potassium, which

are crucial for optimizing maize growth. These results align with the observations of Talboys *et al*. (2016),who describe chemical fertilizer as an excellent source of P and N for plant nutrition, a sit is highly soluble and quickly dissolves in soil tore lease plant- available phosphate and ammonium. These results suggest that both mineral and biological nutrient inputs improved maize vegetative growth compared with the untreated control, likely through enhanced nutrient availability and uptake efficiency (Adesemoye & Kloepper, 2009). Although NPK produced the tallest plants, the performance of biofertilizer treatments was comparable, demonstrating their potential as sustainable alternatives to synthetic fertilizers (Singh *et al*., 2020).

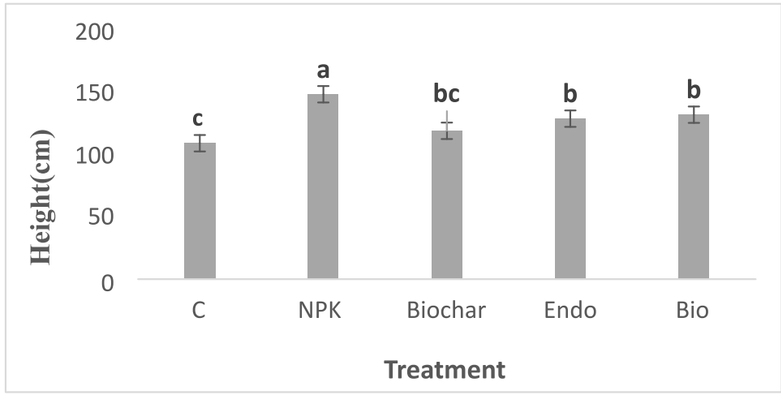

Figure 2. Effect of treatment on plant height of maize after harvesting

The results in Figure 3 show that there were no significant differences ($p < 0.05$) between the treatments, except for Biochar treatment alone on plant stem girth. Significantly wider stem girth was observed in plants treated with NPK (6.96 cm); Bio (6.93 cm) and Endo (6.81 cm) compared to C (6.6 cm) and Biochar (3.6 cm). This could be explained by the fact that the use of biochar alone may have reduced vegetative growth by immobilizing some essential nutrients during decomposition. The treatments involving Endo or Bio applications resulted in stem girth similar to those obtained with the NPK treatment. This indicates that endophytes compensate for the low availability of nutrients through various biological processes(nitrogenfixation,growth hormone production, and increased nutrient absorption) to ensure the continued proper development of the maize plant. These results are comparable to the work of Adebayo et al. (2021) and Singh et al. (2022), who showed that bio-inoculants increase the robustness of the collar diameter of corn by improving the efficient use of nutrients and growth hormone content for soils amended with biochar.

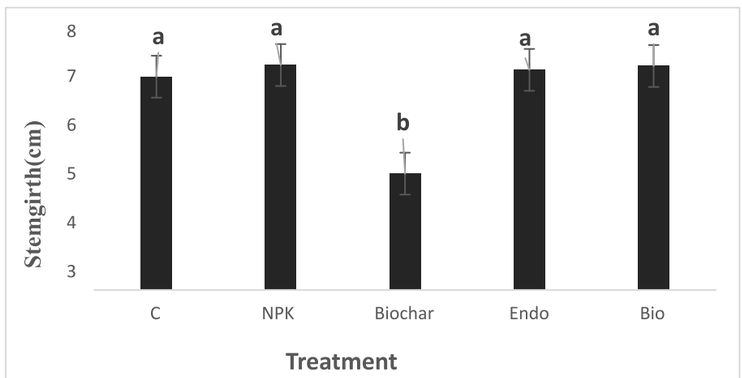

Figure 3. Effect of treatment on stem girth of maize after harvesting

3.2. Effect of treatment on Maize Yield production

Different treatments significantly($P<0.05$) influenced maize yield per hectare (Table1).This indicates that both chemical treatment and biological treatments influence production yields compared to control. The best yield production was attained by maize plants treated with NPK (9.6t/ha). Lower but still substantial yields were obtained with the biological treatments Bio (6.94 t/ha) and Endo (5.87 t/ha), compared with the control. Application of chemical fertilizers NPK resulted in 148.5 and 260.34% extra cob and grain yield of maize, respectively, over their corresponding yields in the control. This confirms the short-term effectiveness of mineral fertilizers. However, Bio and Endo demonstrated sustainable yield improvements, which is beneficial for long-term soil fertility and ecosystem resilience. Indeed, treatment Bio resulted in 99.25 and 145.4% higher cob and grain yields, respectively, and treatment Endo resulted in 49.25 and 122.41% higher cob and grain yields, respectively, over the control. These results suggest that the use of endophytes alone or in combination with biochar leads to synergistic effects that improve root development, soil microbial activity, better nutrient management, and ultimately increased production yields. Similar studies were conducted by Hasanuzzaman *et al.* (2018) and Muthusamy *et al.* (2023), who reported that biochar and microbial inoculants increase maize productivity by enhancing nutrient availability

and stress tolerance. Overall, results demonstrate the application of biochar-endophyte-based treatments instead of or in addition to mineral fertilizers can increase maize output sustainably while reducing dependency on synthetic fertilizers.

Table 2. Effects of treatment on grain and stover yield of maize

	Yield maize (t/ha)				Increase over control (%)		
	Cob	Grain	Total		Cob	Grain	Total
C	1.34^{c}	1.74^{c}	3.08^{d}		-	-	-
NPK	3.33^{a}	6.27^{a}	9.6^{a}		148.5	260.34	211.69
Biochar	1.6^{c}	2^{c}	3.6^{cd}		19.4	14.94	16.88
Endo	2^{bc}	3.87^{b}	5.87^{bc}		49.25	122.41	90.58
Bio	2.67^{ab}	4.27^{b}	6.94^{b}		99.25	145.4	125.32

For each parameter, different lowercase superscripts within the same column indicate that treatment means are significantly different at $P<0.05$ according to Duncan's Multiple Range Test for separation of means.

3.3. Effect of treatment on Nutrient Content in Maize grain

Table 3 presents the impact of different treatments on the assimilation of N, P, and K in maize seeds. N uptake varies from 1.09% under NPK to 1.98% under Bio, corresponding to a 78.38% increase compared to the control. The Bio treatment developed the highest value, while the chemical NPK treatments lightly reduced(?1.8%)nitrogenassimilation. Through enhanced soil structure, nutrient retention, and microbial activity in the rhizosphere, this improvement under Bios suggests a synergistic impact between biochar and endophytic bacteria that improves N availability and assimilation.

A similar trend was observed with phosphorus assimilation, which increased from 0.31% in the control to 0.59% for the Bio treatment, representing a 90.32% increase. The individual application of biochar (0.42%) and endophytes (0.52%) also promoted an increase of 35.48% and 67.74%, respectively. This improvement may be explained by the ability of biochar to reduce soil phosphorus fixation as well as the contribution of endophytic microorganisms, which produce phosphatases and organic acids that improve P solubility and plant availability.
The assimilation of K followed the same trend, varying from 0.19% (NPK) to 0.43% (Bio), equivalent to a 115%

increase compared to the control. Because of the cation exchange ability of biochar and the biological mobilization of K by microbial activity, the combined application of biochar and endophytes significantly increased K absorption. In general, when compared to chemical fertilization and the untreated control, the biochar and endophyte-based treatments, whether used separately or in combination, significantly improved the uptake of macro nutrients in maize grains. These results align with those of Kerametal. (2020) and Kumar *et al*. (2022), who reported comparable increases in maize production and nutrient usage efficiency after applying charcoal along with advantageous micro organisms.

Table 3. N, P and K up take in maize grain

	Nuptake (%)	%increase	Puptake (%)	%increase	K uptake (%)	%increase
C	1.11^{d}	-	0.31^{b}	-	0.2^{b}	-
NPK	1.09^{d}	-1.8	0.33^{b}	0.06	0.19^{b}	5.26
Biochar	1.3^{c}	18.18	0.42^{b}	35.48	0.34^{a}	70
Endo	1.79^{b}	61.26	0.52^{a}	67.74	0.35^{a}	75
Bio	1.98^{a}	78.38	0.59^{a}	90.32	0.43^{a}	115

For each parameter, different lowercase superscripts within the same column indicate that treatment means are significantly different at $P<0.05$ according to Duncan's Multiple Range Test for separation of means.

3.4. Principal component analysis of maize yield and nutrient uptake

PC A was conducted with the aim of evaluating the link between maize production yield and the nutrient uptake by maize seeds under various treatments. The figure above represents the correlation circle between the different variables. It emerges from this figure that these variables contribute to the formation of the axis system (D1xD2) at 92.8%. The D1 axis alone explains 50.6% of the observed variables, and the second D2 axis explains 42.2%. The production- related variables are positively and strongly correlated with the first axis(D1), suggesting that they share a common source of variation associated with plant productivity. In contrast, the second axis (D2) showed a positive correlation with the uptake of N, P, and K. The close relationship between N and P suggests synchronized uptake patterns.

The negative correlation between nutrient levels and yield parameters suggests a possible dilution effect, whereby increased biomass accumulation leads to a reduction in nutrients in plant tissues(Fan et al., 2008; Bingham et al., 2012). When productivity gains are not entirely offset by nutrient intake, this trade-off is common. These results show that the application of biofertilizer has a substantial impact on maize yield formation and nutrient uptake (Adesemoye and Kloepper, 2009; Singh et al., 2020).

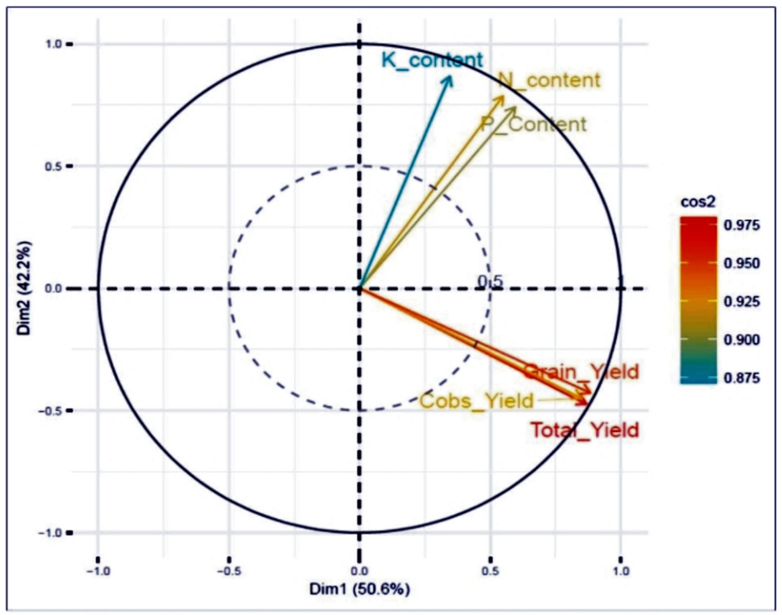

Figure 4. Principal Component Analysis of yield and nutrient relationships in maize under different treatments.

4. Conclusion

The application of microorganisms (endo), biochar, and the biochar/microorganism association has a positive effect on yield and nutrient uptake by maize. Further studies are needed to investigate their long-term effects on soil chemical and microbial properties and nutrient uptake to better understand the mechanisms behind these improvements. Additionally, research should explore the interactive effects of biofertilizers with other chemical fertilizers, as well as organic amendments, to assess their potential influence on maize yield and other crops.

RECOMMENDATION

For more environmentally friendly agriculture and for the protection of producers and consumers in Africa, the development and use of innovative biological solutions for soil fertilization is strongly encouraged.

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Implication des Femmes et des Jeunes en Agreocologie: Cas de L'association Nourrir sans Detruire (ANSD) du Burkina Faso

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Résumé

L'implication des femmes et des jeunes en agroécologie est cruciale pour la durabilité et la résilience des systèmes agricoles. Les femmes, représentant 60-70 % de la main-d'œuvre agricole, jouent un rôle important dans la production alimentaire, mais leur travail reste souvent invisible. L'ANSD s'engage à valoriser sa contribution à travers diverses actions.

La stratégie adoptée comprend le renforcement de l'accès aux ressources, le leadership féminin, l'autonomisation des femmes, l'éducation environnementale pour les jeunes et la prise en compte des ménages vulnérables. Pour sensibiliser et éduquer, des ateliers d'information sont organisés, ainsi que des programmes de formation sur des compétences pratiques comme le jardinage et l'élevage durable.

Le renforcement des capacités passe par la mise en place de formations adaptées aux besoins des femmes et des jeunes, ainsi que leur participation active à des programmes de recherche. La création de groupes d'épargne permet aux femmes d'accéder à des fonds pour investir dans des pratiques agroécologiques et d'échanger des connaissances.

L'accès à la terre et aux intrants reste un défi majeur, avec seulement 8% des terres agricoles détenues par des femmes. L'ANSD aide à surmonter ces obstacles en facilitant l'accès à la terre et aux ressources nécessaires. De plus, il est essentiel d'inclure les femmes et les jeunes dans les comités de gestion et de promouvoir des politiques favorisant l'égalité des sexes.

En somme, l'engagement des femmes et des jeunes en agroécologie est fondamental pour un développement rural inclusif et durable. Une approche holistique, combinant sensibilisation, formation, accès aux ressources et participation à la prise de décision, est nécessaire pour renforcer leur rôle et assurer un avenir résilient pour les communautés rurales.

Abstract

The involvement of women and youth in agroecology is crucial for the sustainability and resilience of agricultural systems. Women, representing 60-70% of the agricultural workforce, play a significant role in food production, yet their work often remains invisible. The ANSD (National Agency for Sustainable Development) is committed to recognizing and valuing their contribution through various initiatives. The adopted strategy includes strengthening access to resources, promoting women's leadership and empowering women, providing environmental education for young people, and addressing the needs of vulnerable households. To raise awareness and educate, information workshops are organized, along with training programs on practical skills such as gardening and sustainable livestock farming. Capacity building is achieved through the implementation of training programs tailored to the needs of women and youth, as well as their active participation in research programs. The creation of savings groups allows women to access funds to invest in agroecological practices and to share knowledge. Access to land and inputs remains a major challenge, with only 8% of agricultural land owned by women. The ANSD helps overcome these obstacles by facilitating access to land and the necessary resources. Furthermore, it is essential to include women and youth on management committees and to promote gender equality policies. In short, the engagement of women and youth in agroecology is fundamental to inclusive and sustainable rural development. A holistic approach, combining awareness-raising, training, access to resources, and participation in decision-making, is necessary to strengthen their role and ensure a resilient future for rural communities.

Introduction

femmes représentent une part importante de la main-d'œuvre agricole, souvent jusqu'à 60-70 %, et sont responsables de nombreuses tâches agricoles comme la sélection des semences, le tri des récoltes, le maraîchage, le semis, le désherbage et la récolte (FAO). Elles jouent ainsi un rôle central dans la production alimentaire locale.

En agroécologie, les femmes ne sont pas seulement productrices, elles participent aussi à la transmission des savoirs, à l'organisation collective et à la valorisation de pratiques durables qui préservent la biodiversité. Leur travail est souvent sous valorisé et l'accès aux ressources demeure un véritable défi pour elles, mais ANSD à travers son approche et ses stratégies contribue à rendre ce travail visible et à renforcer leur accès aux ressources. Ses actions visent à améliorer

l'accès des femmes et des jeunes à la terre et au bio intrants, à promouvoir le leadership féminin, et à favoriser l'éducation environnementale, tout en prenant en compte les besoins des ménages vulnérables. Cet article présente la méthodologie adoptée, les résultats obtenus, ainsi qu'une discussion sur l'impact de ces initiatives et des recommandations.

I. Méthodologie ou méthode

- Renforcement de l'accès aux femmes aux facteurs de production
- Renforcement du leadership féminin
- Implication active des femmes aux différentes activités (Représentativité à travers le système de quota) ;
- Animation de séances d'éducation environnementale au profit des plus jeunes
- Prise en compte des différentes catégories des ménages en particulier les ménages vulnérables lors des ciblages des bénéficiaires (ménages gérés par des femmes etc.)
- Diagnostic participatif et initial avant le lancement des projets permettant de prendre en compte les besoins spécifiques des femmes et couchés vulnérables.



Figure 1 : Stratégie d'implication des femmes et des jeunes

II. Résultats

1. Sensibilisation et formation des jeunes sur les pratiques agroécologiques

L'ANSD a initié un programme de formation et de sensibilisation qui vise à approfondir la compréhension des jeunes sur l'agroécologie et à encourager leur engagement dans cette démarche. Des sessions de démonstration et de partage d'expérience sont régulièrement organisées au sein des établissements d'enseignement supérieur et secondaire. Dans le cadre de ce programme, 12 jeunes ont été sélectionnés pour réaliser des vidéos sur l'agroécologie, après avoir suivi une formation sur le montage audiovisuel. Ces vidéos sont ensuite diffusées sur des plateformes numériques telles que WhatsApp et Facebook, permettant une large circulation des connaissances.

En outre, des projections vidéo sont organisées dans les écoles, accompagnées d'échanges directs avec des techniciens et des experts en agroécologie. Grâce à ces initiatives, 3850 jeunes ont été sensibilisés aux avantages de l'agroécologie à travers des ateliers d'information, soutenus par le programme Jeunes Reporters.

Pour favoriser l'adoption des pratiques agroécologiques, des jardins scolaires ont été établis dans 12 écoles, où les élèves se réunissent pour participer à des activités de production de légumes, intégrant ainsi ces produits dans la préparation de leurs repas. Cette approche pratique renforce l'engagement des jeunes tout en leur offrant des compétences concrètes en agroécologie.



Photo 1 : Des élèves produisant du compost pour leur jardin scolaire

2. Renforcement des capacités techniques et organisationnelles des femmes

Formations Techniques : Un programme de formation a été mis en place, spécifiquement conçu pour répondre aux besoins des femmes et des jeunes. Ce programme met l'accent sur des compétences pratiques, notamment la production de produits maraîchers agroécologiques à travers des jardins de case, des sites maraîchers et le maraîchage hors sol ainsi que sur l'élevage durable à travers un système de dons rotatifs d'animaux.

Pour la production maraîchère, des superficies d'au moins 1 hectare sont négociées dans les villages, aménagées et parcellées au profit des femmes. Avant le lancement des activités de production, celles-ci reçoivent une formation sur les techniques de production de biopesticides et de biofertilisants, qui seront exclusivement utilisés pour le traitement des cultures sur le site.

Concernant le système de dons rotatifs d'animaux, des chèvres sont attribuées aux femmes identifiées comme vulnérables dans les villages. Après la mise basse des chèvres, les jeunes animaux sont transférés à d'autres femmes, créant ainsi un cycle de partage et de soutien. Les bénéficiaires de ces chèvres sont également formés sur les techniques de fauche et de conservation du fourrage, afin d'optimiser la gestion de leurs animaux. Grâce à ces animaux, les femmes peuvent également valoriser les déjections pour la production de compost, contribuant ainsi à une agriculture durable et à l'amélioration de leurs pratiques agricoles.

Programmes de Formation : Les femmes sont activement impliquées dans les sessions de formation sur les techniques agroécologiques et la gestion des ressources naturelles. Elles sont également présentes dans le groupe des Paysans formateurs, favorisant ainsi l'échange de savoirs. De plus, leur engagement dans le programme de recherche permet la cocréation et le partage des connaissances, avec des femmes sélectionnées pour mener des tests sur des parcelles d'expérimentation.

Entrepreneuriat et compétence de vie :L'ANSD a créé plus de 110 groupes de femmes dédiés à la transformation des produits agricoles et forestiers non ligneux. Ces groupes bénéficient d'un soutien technique de l'ANSD, qui inclut des formations sur la transformation, la commercialisation, ainsi que l'équipement nécessaire, et facilite les mises en relation avec des consommateurs et des revendeurs. Par ailleurs, des formations spécifiques ont été mises en place pour développer des compétences en négociation, en gestion de l'environnement quotidien et en gestion financière.

Ainsi, 1800 femmes ont été accompagnées dans diverses activités génératrices de revenus (AGR), renforçant leur autonomie économique. Grâce à un programme de formation technique, 16 620 femmes ont été formées aux pratiques agroécologiques, tandis que 720 d'entre elles ont activement participé à des tests et à la réplication des formations sur le terrain. De plus, 158 femmes ont été identifiées comme leaders, ce qui a consolidé leur rôle au sein de la communauté.

Dans ce cadre, nous souhaitons partager l'histoire de SagdouPotiaga, qui réside à Kodjina, dans le village de Bilanga, à l'est du Burkina Faso. Cultivatrice depuis de nombreuses années, elle se sentait découragée face à une terre improductive. "Avant, chaque saison était une épreuve," confie-t-elle. Tout a changé lorsqu'elle a découvert la technique du zaï, enseignée par Logtori, un paysan formateur du projet IAE. Grâce à cette méthode, elle a revitalisé sa parcelle, permettant au maïs et au mil de prospérer. Aujourd'hui, Potiama parvient à nourrir sa famille convenablement, vend des produits sur le marché et a même pu acheter des moutons. Elle exprime sa profonde gratitude envers le projet IAE et Logtori pour leur précieux soutien.



Photo 2 : séance de formation des femmes sur la production de bio intrant Bokashi

3. Mise en place des groupes de solidarité et d'entraide

La création de 200 groupes d'épargne et de crédit a permis de faciliter l'accès des femmes au crédit, leur offrant ainsi des opportunités d'investir dans des pratiques agroécologiques. Ces groupes servent également de plateforme pour l'échange de connaissances sur les techniques durables.

4. Renforcement de l'accès aux ressources

- L'accès à la terre : ANSD accompagne les femmes à obtenir des terres sécurisées pour leur activités de production et de commercialisation.
- L'accès aux intrants : Aider les femmes et les jeunes à accéder à des intrants agricoles, tels que des semences, des outils, pour leur permettre de mettre en œuvre des pratiques agroécologiques.
  L'acquisition de plus de 45 hectares de terre au profit des femmes a été une avancée significative, permettant à celles-ci de sécuriser leurs activités de production et de commercialisation. Cependant, il reste un défi majeur, car seulement 8% des terres agricoles sont détenues par des femmes.

5. Participation à la prise de décision
   La participation des femmes aux prise de décision se traduit par la représentation des femmes et des jeunes dans les comités de gestion des ressources, les comités agroécologiques et les instances décisionnelles au niveau local a été renforcer à travers un système de quotas mis en place. Au total 158 femmes ont pu intégrer des organisations locales grâce à cette démarche.

Nous organisons également des cadres d'échanges avec les autorités locales et communales pour identifier les défis et les actions favorisant un accès équitable à la terre. A ce titre nous accompagnons les communes à élaborer des plans de résiliences sensibles au genre.



Photo 3 : Formation des femmes sur le leadership et le management

III. Discussion

Les résultats soulignent l'impact positif des initiatives de l'ANSD sur l'autonomisation des femmes et des jeunes dans le secteur agroécologique. L'accès accru à la terre et aux ressources a permis de renforcer la résilience des ménages, tandis que la formation et la sensibilisation ont favorisé une prise de conscience accrue des enjeux liés à l'agroécologie. La création de groupes d'épargne a également été un moteur d'autonomisation, permettant aux femmes d'investir dans leurs activités agricoles.

Cependant, des défis persistent, notamment l'accès limité aux intrants et la nécessité d'une représentation plus forte des femmes dans les instances décisionnelles. Il est essentiel de continuer à promouvoir des politiques favorisant l'égalité des sexes et d'assurer un soutien continu aux initiatives d'autonomisation.

IV. Recommandations

our garantir une pérennité des résultats obtenus et renforcer le rôle des femmes et des jeunes en agroécologie, plusieurs recommandations peuvent être formulées :

- Promouvoir des politiques permettant aux femmes d'acquérir des terres sécurisées pour leurs activités agricoles.
- Accroître le financement des programmes d'éducation et de formation spécifiques aux femmes et aux jeunes.
- Impliquer davantage les femmes dans les programmes de recherche pour la co-création de connaissances et le partage de bonnes pratiques.
- Renforcer la représentation des femmes dans les instances décisionnelles et de gestion des ressources agricoles.
- Organiser des campagnes de plaidoyer pour sensibiliser les décideurs sur l'importance de l'égalité des sexes dans le secteur agricole.

Conclusion :

En conclusion, l'engagement des femmes et des jeunes en agroécologie est un facteur déterminant pour la durabilité et la résilience des systèmes agricoles. Des efforts continus sont nécessaires pour surmonter les obstacles existants et garantir un développement rural inclusif et durable.

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Smallholder Farmers' Contribution to National Food Security in Nigeria

Smallholder Farmers' Contribution to National Food Security in Nigeria
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Abstract
Smallholder farmers in Nigeria play a crucial role in food production and make up most of the agricultural workforce. They are major contributors to Nigeria's food supply. In Nigeria, there is an increasing need for sustainable food production to meet the growing demands as the country encounters high costs of food, hunger, poverty, and malnutrition. The adoption of organic farming as a pathway to food security, environmental sustainability, improved livelihoods, and sustainable agricultural practices by smallholder farmers in Nigeria has boosted the national food security. Organic farming is a production system that sustains the health of soils, ecosystems, and people. It relies on ecological processes, biodiversity, and cycles adapted to local conditions, rather than the use of inputs with adverse effects. This practice of farming offers benefits such as higher market prices, reduced costs, and environmental sustainability. It is considered one of the promising sustainable agricultural practices that promotes a green economy. This study employed a random sampling method, selecting twenty smallholder farmers from each of the six regions in Nigeria. Structured and closed-end questionnaires were employed to gather primary data directly from farmers. The findings revealed majority of the smallholders were male (78.2 percent) with an average age of 35 years, small farm size, and primary school education. The results further show that organic farming is a viable alternative in boosting food security. This paper recommends that women and youth should be encouraged to be actively involved when providing training on organic farming. It is important to train, educate, and create awareness of organic farming among the smallholders.

Keywords: Adoption, National Food Security, Nigeria.

Résumé
Au Nigéria, les petits exploitantsagricolesjouent un rôle crucial dans la production alimentaire et constituent la majeure partie de la main-d'œuvreagricole. Ils contribuent largement à l'approvisionnement alimentaire du pays. Face à la hausse des prix alimentaires, à la faim, à la pauvreté et à la malnutrition, le Nigéria est confronté à un besoin croissant de production alimentaire durable pour répondre à la demande. L'adoption de l'agriculture biologique par les petits exploitants agricoles nigérians, comme voie vers la sécurité alimentaire, la durabilité environnementale, l'amélioration des conditions de vie et des pratiques agricoles durables, a renforcé la sécurité alimentaire nationale. L'agriculture biologique est un système de production qui préserve la santé des sols, des écosystèmes et des populations. Elle repose sur les processus écologiques, la biodiversité et les cycles adaptés aux conditions locales, plutôt que sur l'utilisation d'intrants aux effets néfastes. Cette pratique agricole offre des avantages tels que des prix de marché plus élevés, des coûts réduits et une durabilité environnementale. Elle est considérée comme l'une des pratiques agricoles durables les plus prometteuses, favorisant une économie verte. Cette étude a utilisé une méthode d'échantillonnage aléatoire, sélectionnant vingt petits exploitants agricoles dans chacune des six régions du Nigéria. Des questionnaires structurés à questions fermées ont été utilisés pour recueillir des données primaires directement auprès des agriculteurs. Les résultats ont révélé que la majorité des petits exploitants étaient des hommes (78,2 %), âgés en moyenne de 35 ans, possédant de petites exploitations et ayant un niveau d'instruction primaire. Ces résultats montrent également que l'agriculture biologique constitue une alternative viable pour renforcer la sécurité alimentaire. Cet article recommanded'encourager la participation active des femmes et des jeunes aux formations en agriculture biologique. Il est important de former, d'éduquer et de sensibiliser les petits exploitants à l'agriculture biologique.

Mots-clés: Adoption, Sécuritéalimentairenationale, Nigéria.

Introduction

Agriculture is an important sector that contributes to the economic development of Nigeria. Food security is a household's physical and economic access to sufficient food. This entails producing food that will get to every citizen both in quantity and quality (Oriola 2009). A country is food secure when most of its population has access to food. More so with increasing demand for food to achieve food security and sustainable agriculture, organic farming represents one of the various approaches to sustainable agriculture and food security. Nigeria, with a population of over 200 million people, is the most populous country in Africa. Agriculture was the economic mainstay before the discovery of oil. The country is blessed with both natural and human resources. The huge oil deposits in the Niger Delta region bring both economic benefits and adverse impacts to the environment and the nation. Available data indicate that only 11,979 ha of Nigeria's over 30 million ha of arable agricultural land are cultivated by a trifling 517 producers (USDA, 2014, p. 2) under organized organic farming. Organic farming originated in England according to the theories developed by Albert Howard in his Agricultural Testament in 1940, following the work of Rodale in the late 1930s in the United States (http://www.organic-world.net). The Agriculture and Rural Development for the European Commission (2009), defines organic farming as a form of agriculture that relies on techniques such as crop rotation, green manure, compost and biological pest control, and mechanical cultivation to maintain soil productivity and control pests, excluding the use of synthetic fertilizers and synthetic pesticides, plant growth regulators, livestock feed additives and genetically modified organisms.

The United Nations Conference on Trade and Development (UNCTAD,2015) suggests that addressing food security entails recognizing smallholder farmers for their role in achieving hunger and poverty reduction through their active participation in food production. The report also recognizes regional differences in farm sizes cultivated by smallholder farmers. For instance, in Latin America, the average farm size is 20 ha. and Brazil has 50 ha. while in Asia and sub-Saharan Africa, the farm sizes are smaller. For brevity, in Bangladesh, an average farmer has a farm size of 0.5 ha. while in China, India, and Nigeria have less than 2 ha. In the UNCTAD report, smallholder farmers are those who cultivate 2 ha. or less of land and are characterized by the type of crops grown and the labour utilization, as well as low access to financial credit and markets.

Smallholder farms are technically more efficient in terms of labour from the household to maximize production and reduce cost, while large farm sizes are labour-intensive and, if not properly supervised, lead to low food production. In addition, the ability of smallholder farmers in Nigeria to mitigate environmental peculiarities is achieved through the adoption of local methods, using native knowledge and experience passed down from generations to mitigate perceived harsh environmental conditions for farming activities. Moreover, from a biodiversity standpoint, these smallholding farmers are seen as biodiversity-friendly, as most of them cannot afford fertilizers and are into mixed farming and make use of livestock manure on their farms. This is compared to large farm holders who use intensive means, such as heavy farm machinery, fertilizers, and pesticides on their farms, which influences land degradation.

Organic farming uses fertilizers and pesticides but excludes or strictly limits the use of manufactured (synthetic) fertilizers, pesticides (which include herbicides, insecticides, and fungicides), plant growth regulators such as hormones, livestock antibiotics, food additives, and genetically modified organisms. It is the production system that sustains the health of soils, ecosystems, and people, by relying on ecological processes, biodiversity, and cycles adapted to local conditions. Organic farming is relatively new in Nigeria, but it is fast emerging as a sustainable long-term approach to food production. Its emphasis on recycling techniques, biodiversity, low external input, and high-level output strategies makes it an ideal replacement for the petroleum-intensive agricultural methods that are currently contributing to global warming (IFOAM, 2008; Swift et al, 2004). Developments in organic farming over the years have given more attention to soil fertility building and enhanced pest management methods, which guarantee organic food's authenticity through labelling (Frances, 2013). In many of the developing countries, organic farming development is done through conversion from conventional agriculture, and this practice can be imbibed into the Nigerian context. Despite the low level of activities in organic farming in Nigeria, the practice has great strengths that can be exploited to accelerate food security. The description of organic farming in this and many other studies has led to the generation of research output that enhances organic farming and makes it more sustainable and profitable. The study attempts to analyse the adoption of organic farming practices by smallholder farmers in the six regions of Nigeria, their contributions to national food security, and whether they have been able to put Nigeria on the path of self-sufficiency.

Materials and Methods

Nigeria is a multicultural country with 36 states divided into six regions, namely: Northeast, Northwest, North Central, Southeast, SouthSouth, and SouthWest (Table 1). It is estimated that about 75% of Nigeria's total land area, amounting to about 68 million hectares, has agricultural use potential, while about 33 million hectares are cultivated. In addition, of the estimated 3.14 million hectares of irrigable land, only about 220,000 ha or 7% is utilized. The average farm size for subsistence farmers in Nigeria ranges from 1 to 3 ha, with the North having more farm sizes than the South. Furthermore, agriculture employs about two-thirds of Nigeria's labour force. The rainfall pattern across the country decreases from the South to the North. The difference in the mean annual rainfall across the six geopolitical zones is as follows: North Central (269.938 mm), Northeast (300.794 mm), Northwest (225.395 mm), Southeast (442.360 mm), SouthSouth (737.836 mm), and SouthWest (323.634 mm).

The areas of study are the six regions of Nigeria, which comprises of Southwest, SouthEast, SouthSouth, Northwest, NorthEast, and North Central. The six regions were selected because of the agroecology movement in Nigeria and the need to sample more smallholder farmers employing organic farming methods in Nigeria. The high concentration of smallholder farmers in each of these regions justified the choice of the study areas. The major languages spoken in these regions are Hausa, Igbo, Yoruba, and Pidgin English. The population of the smallholder farmers was 120. They cultivate food crops such as yams, cassava, maize, and sorghum. Other crops grown by the farmers include beans, sweet potatoes, and vegetables. The cluster sampling technique was adopted, which is market-oriented. This constrains farmers to cluster around these sources of water. Therefore, cluster sampling is considered appropriate. The sampling technique involves random selection of two states in each of the six regions that make up Nigeria, which were Ogun, Ondo, Abia, Imo, Akwa Ibom, Edo, Adamawa, Bauchi, Kaduna, Sokoto, Niger, and Benue. Two local government areas were selected from each state to give a total of twenty-four local government areas used for the study. The choice of these local government areas is based on the dominance of crop producers in the different areas. The two local government areas selected in the respective states were Ogun State, Obafemi Owode, and Ogun Waterside. The two local government areas chosen in Ondo state were Idanre and Okitipupa. The two local government areas selected in Abia state were Ikwuanoand Umuhia North. In Imo state, Orlu and Owerri North local government areas were selected for sampling. Ikot Ekpene and Itu were selected as sample local governments in Akwa Ibom state. Akoko Edo and Oredo local governments were sampled in Edo state. In Adamawa state, smallholders were sampled from Hong and Michika local government areas. The two local government areas selected in Bauchi state were Bauchi and Tafawa Balewa local government areas. In Kaduna state, Zaria and Zango Kataf were selected local government areas. Gada and Sokoto South local government areas were chosen in Sokoto state. Smallholders were sampled in Bida, Mokwa, Agatu, and Oturkpo local government areas of Niger and Benue states.

Table 1. States in the six geopolitical zones of Nigeria.

S/N	North Central	North East	NorthWest	SouthEast	SouthSouth	SouthWest
1	Benue	Adamawa	Jigawa	Abia	Akwa Ibom	Ekiti
2	Kogi	Bauchi	Kaduna	Anambra	Bayelsa	Lagos
3	Kwara	Borno	Kano	Ebonyi	Cross River	Ogun
4	Nasarawa	Gombe	Katsina	Enugu	Rivers	Ondo
5	Niger	Taraba	Kebbi	Imo	Delta	Osun
6	Plateau	Yobe	Sokoto		Edo	Oyo
7	Abuja (FCT)					

the study. An interview schedule was used to get information from the respondents. The questionnaire consisted of 14 organic farming practices in each of the six regions in Nigeria, from which the respondents indicated use and non-use. These practices are crop rotation, application of compost, mulching of crops, intercropping, mixed cropping, crop residues, cover crops, animal manure, organic fertilizer, and natural insect predators. A split-half technique was used to determine the reliability coefficient, with a reliability coefficient of 0.85. The questionnaire was face validated by a panel of experts on agricultural extension, agronomist and organic agricultural researchers. The panel consisted of lecturers in agricultural extension and agronomy. The study considered the ethical considerations, which were addressed through voluntary participation. Data was analysed with the Statistical Package for Social Sciences (SPSS) 18.0 using means and standard deviation.

Results

Table 2 shows a list of organic agriculture practices from which the respondents were asked to indicate their use or otherwise using a 2-point scale of Yes (2) and No (1). The actual mean score is 1.5 due to the rating scale, and a mean of greater than 1.5 denoted a use, while a mean less than 1.5 denoted non-use. The mean scores of 10 out of 14 practices were above the actual mean score, which implies the use of these organic agriculture practices. These technologies are minimum tillage, crop rotation, sanitation, intercropping, green manure, cover crop, fire, composting, organic fertilizer, animal manure, and mulching. The results revealed the most prominent organic agriculture practices were minimum tillage (1.81, SD=0.9); crop rotation (1.80, SD=0.7), and mulching (1.79, SD=0.6). With respect to the use of minimum tillage, it is the practice that minimizes the disturbance of the soil. The soil is not tilled intensively, thereby improving the soil structure. It is a cultivation operation whereby soil is disturbed as little as possible to produce crops. Mulch residue from the previous crop is left on the surface, which aids in retarding weed growth, conserving moisture, and controlling erosion. Therefore, the practice of minimum tillage is a common operation among farmers that is usually carried out to prepare the soil before planting. Instead, organic farmers use innovative practices such as crop rotations, green manuring, and biological pest control to improve the soil structure and conserve soil organic carbon.

Crop rotation, as one of the practices, can be attributed to the use of indigenous knowledge, where farmers' belief that soil needs rest and some measures should be put in place to ensure soil maintenance and fertility. One such measure is bush fallowing, whereby farmland that has been cultivated for some number of years is left uncultivated for a few years to fallow and regain its lost nutrients. Crop rotation is another measure that is used by farmers for this purpose. In this case, the farmland is not abandoned but crops that are cultivated on the farm are planted in sequence to maintain the soil fertility. Crop rotation is a practice that is as old as farming practice itself. Subba Rao (1999) and Stockdale et al (2000) observed that crop rotations and varieties are selected to suit local conditions, having the potential to sufficiently balance the nitrogen demand of crops. Furthermore, Bending and Lincoln (1999) in their work among the US farmers noted that organic growers commonly plant rapeseed, mustard, and other brassicas as rotation crops to 'clean up' soil during the winter months. Besides, crop rotations comprising both grass-clover fields and arable crops have shown to be relatively robust in relation to most problems with weeds, pests, and diseases (Duboiset al., 1999)

Mulching ranks highly as a cost-effective means of crop residue usage against soil erosion in annual row-cropping systems on sloping lands and is at the centre of a resurgent soil conservation ethic in much of North America (Shelton et al. 1995). However, it is not commonly used among the vegetable farmers, who reported that mulching is predominantly used by yam producers. The findings of et al. (2009) showed that mulching and cover cropping were mostly regarded as not labour-intensive, highly cost-effective, compatible, and easy and cheap to adopt. The farmers had a positive impression of the effectiveness of the erosion control measures and mentioned additional Junge advantages, such as the increased soil fertility from the decomposition of organic material and the release of nutrients. However, a disadvantage of mulching was seen in the amount of grass required, the main material used as mulch in the area.

Table 2.

Organicagriculture practices	Mean	SD
Minimum tillage	1.81	0.9
Crop rotation	1.80	0.7
Farm Sanitation	1.69	0.8

Intercropping	1.66	0.2
Green manure	1.60	0.9
Cover crop	1.55	0.8
Fire	1.53	0.6
Composting	1.60	0.4
Organic fertilizer	1.68	0.9
Animal manure	1.71	0.3
Mulching	1.79	0.6
Natural pesticides	0.36	0.6
Farm scaping	0.16	0.6
Bio control	0.13	0.3

Distribution of the respondents using organic agricultural practices

Other organic agricultural practices used by farmers includeFarm sanitation (1.69, SD=0.8), intercropping (1.66, SD=0.2), green manure (1.60, SD=0.9), and cover crop (1.55, SD=0.8). Farm Sanitation is keeping the field clean, which helps in preventing the growth and multiplication of weeds, pests, and diseases. The reason may be that farmers are also aware of those things that can prevent them from having a good yield or output. Farmers go to farm every day, even after the planting period, to weed at intervals, remove any form of crop residue or decay of dead animals on their farm that can attract pests and diseases to the crop planted, and can cause pollution in the environment. Farmers are aware that if weeds are left to grow on their plot, they will compete with the crop planted for the available nutrients and will reduce their yield during harvest. Besides, some weeds affect the crop, leaving a residual effect on the crop, which can affect the taste or the appearance of the crop. Whenever this happened, the farmer would run at a loss because such a crop would not attract buyers and may have to be sold at a ridiculous price.

The results further show that the use of organic agricultural practice covered fire (1.53, SD=0.6), composting (1.60, SD=0.4), organic fertilizer (1.68, SD=0.9), and animal manure (1.71, SD=0.3). Wilson (Weeding Techniques for Organic Farm, 2007) found that flame weeding, also called flame cultivation or flaming, is a thermal physical control method that is part of the National Organic Program (NOP) under the Organic Foods Production Act of 1990. Flame weeding delays the presence of weeds in crop beds by killing the weeds present before the crop has breached the soil. This can significantly reduce hand-weeding labour costs. Farmers see the use of fire as an easy and faster method of clearing the weeds, trees, and bushes, particularly at the onset of planting season when the land is prepared. Besides, some farmers believe that when the land is prepared with fire, the ash of the weeds, trees, or residues that were burnt will make the soil fertile. Farmers see the use of fire for clearing as cost-effective compared to the use of hired labour. Anon (1999) reported that in Iowa, farmer feedback on flame weeding has been positive. However, burning as a labour-saving tool to clear land and to prevent weed infestation is now being brought into question, and many development agencies now advocate no-burning. In the communities, however, it is less a question of burning or no-burning but rather when, where, and how to reduce its negative impact (Aalangdong *et al*..1999). Some northern farmers have made a conscious decision to cease bush burning to regenerate organic material (Millar *et al* 1996). Singh (2003) noted that organic farmers in India reported the capacity of manure (compost) to fulfil the nutrient demand of crops adequately and promote the activity of beneficial macro-and micro-flora in the soil. Also, Ouédraogo *et al* (2001) showed that farmer was aware of the role of compost in sustaining yield and improving soil quality. However, lack of equipment and adequate organic material for making compost, land tenure, and the intensive labour required for making compost are major constraints for the adoption of compost technology. Olayide *et al* (2011), assessing farm-level limitations and potentials for organic agriculture in northern Nigeria, discovered that the current levels of organic fertilizer use as a share of the minimum requirements for take-off for organic agriculture in Nigeria were low despite its potentials.

Discussion

Nigeria's food security is greatly impacted by agricultural techniques, both conventional and contemporary, which influence food quality and safety (Usman, 2024). However, recently, attention has been given to formal organic farming in Nigeria. In other words, organic farming in an organized form is less than twenty years old in Nigeria (Usman, 2024). In fact, it is relatively new to the country. Many Nigerian food producers, especially the small-scale farmers who reside in rural areas and produce the larger portion of the nation's food, are not aware of the practices of organic agriculture (Abdulwahab & Umar, 2024). This is even though Nigeria is an agrarian society. Smallholder farmers are more likely than large farmers to adopt organic farming because of the similarities between traditional farming and organic agriculture (Abdulwahab etal., 2024; Adeoye, 2011). And the farmers' culture mostly influences their agricultural production methods (Simpa &Nmadu, 2019). Unlike some other African countries, Nigeria has not developed its available resources in organic farming. However, there are a few pockets of organic farming in Nigeria.

The organic farming practitioners in Nigeria are mostly a few large-scale farms and some NGOs that cultivated about 3,154 hectares and 11,979 hectares in 2007 and 2010, respectively, with little or no government involvement (Olaito, 2014). Although there is an assertion that about 70 per cent of farmers in Nigeria are of the view that they practice organic farming by default because the traditional agricultural practices in Sub-Saharan Africa are like organic agriculture (Adeoye, 2011). But true organic farming production is an approved and certified production methodology. Government policies on input supply and other incentives do not influence the optimization of organic farming productivity. A true organic farming method must fit the ecological balances and cycles in nature and be practiced carefully and responsibly to benefit the present and future generations and the environment. There is a need for intensive awareness creation on organic farming systems to achieve the potential maximization of its premium benefits (IFOAM, 2022; Olaito, 2014).

Similarly, at the 2018 National Organic Agriculture Business Summit in Lagos, stakeholders have indicated willingness to work extensively for the complete development of the value chain for organic produce in Nigeria (Taiwo, 2018). Also, there has been an advocacy for global and regional efforts towards the application of organic farming for sustainable development, particularly in the third world nations (Abdulwahab *et al*., 2024; Olaito, 2014; Markus, 2017). Therefore, there is an urgent need for research in organic farming in Nigeria for the promotion, development, and encouragement of the farmers, particularly the small-scale producers. Baldwin (2006) noted that many organic farmers typically manage weeds mechanically and, therefore, cannot focus on building soil structure in the same way as conservative tillage practitioners, who often rely on herbicides for weed control.

The smallholder farmers should be made to understand the nature, concept, techniques, benefits, principles of OA, and its role in improving food security in Nigeria and achieving sustainable agricultural production. This is because, among alternative methods of improving food access, increasing inputs is needed and organic farming can be a viable course of action. Moreover, organic farming is most likely to be a good option for enhancing the food security of smallholder farmers. It would also improve the total farm yield, income, and decrease input cost (Abdulwahab *et al*., 2024; Forfattare *et al*., 2009), due to its ability for environmental sustainability. Therefore, large-scale conversion of conventional agriculture to organic farming in Nigeria will provide Nigeria with nutritious and safe food and improve food security. However, the organic farming sector in Nigeria is not without some setbacks.

The challenges facing organic farming in Nigeria include exorbitant certification costs, restricted market access, lack of awareness, and technical expertise among the farmers (Ewere, Alao, Afanwoubo & Eze, 2024). The organic agricultural cropland in Nigeria is about 58, 028 ha and this may increase in ten years by 509% (Willer *et al*., 2024). Baldwin (2006) noted that many organic farmers typically manage weeds mechanically and, therefore, cannot focus on building soil structure in the same way as conservative tillage practitioners, who often relies on herbicides for weed control.

Conclusion

The paper has shown the nature and trend of the use of organic agricultural practices among smallholder farmers in the six regions of Nigeria by highlighting organic agricultural practices that are prominent and those that were less

prominent as well as practices that are not in use. The study showed that smallholder farmers improved food supply; however, it cannot provide the country with the much-needed production to be self-sufficient, especially in cereals crop as findings show cereal crop productions are low and not sufficient. In addition, yields are equally low and declining despite farmland expansion, which poses a food insecurity challenge for a growing population such as Nigeria. The North Central region shows a promising potential to have the capacity to produce food. However, when given adequate agricultural support, the six geopolitical zones can diversify their food productions to crops that are within the agro climatic conditions, especially cereals, and complement each other.

In addition, the study suggests private investment and collaborations with international community to improve agriculture and harness the potential of the different agro ecological conditions across the country. In the meantime, promoting dry season cultivation through irrigation to encourage dual-season harvest will assist in food production. The country has low irrigated cultivable land and most of the existing irrigation schemes have become obsolete due to high operating costs and poor maintenance culture. Therefore, a revamp and adequate funding of critical sectors in charge of water and irrigation access is a step in the right direction. This is because available literature on the use of irrigation has proven to increase crop yield. For example, China and India have the most irrigated areas among developing countries, which ultimately increase their crop yields

Other proposed measures to increase production and food sufficiency are implementing a "crop structural adjustment" program, whereby smallholder farmers in different states are supported and funded by national, state, and nongovernmental agencies to produce crops suited to their different agro climatic conditions. Overall, this study provides a useful approach for evaluating local farmer's contribution to food security and the need for targeted external support on food production, especially cereals, and the exigency to reduce post-harvest losses.

The study concluded that majority of organic farming practices in the selected local government areas in the six regions of Nigeria were always utilized by smallholder farmers. Smallholder farmers' contribution to food production in Nigeria can be improved to reduce food importation. However, apart from climate impacts on food production, smallholder farmers face low support and access to agricultural inputs for their farms. To address the challenge of low organic/inorganic fertilizer use, farmers make use of animal waste and compost to enrich the soil. The findings from the study showed that most of the organic farming practices in these regions had positive effect on food supply in the country. They were perceived to be desirable and sustainable by the smallholders. It was concluded that organic farming is gradually gaining ground and farmers are developing interest as it has to do with life and recommend that:

1 There should be more awareness on the health benefits of organic farming and risk imposed by inorganic farming to encourage smallholder farmers to make use of organic farming practices. This can be done by extension agents and NGOs

2. Extension agents can also help to educate farmers on the need to sustain their environment and harness the profits embedded in organic farming which will enhance increased income.

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République de Guinée-Bissau
Communication

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Introduction

La Charte nationale de gestion durable des terres et le Plan stratégique national de gestion et de réhabilitation des terres de la Guinée-Bissau visent à promouvoir un développement agricole durable et inclusif. Cette politique aborde des questions cruciales telles que la gestion des terres, l'accès à la terre, la commercialisation des produits agricoles et la participation des jeunes au secteur.

L'agriculture biologique en Guinée-Bissau est confrontée à des défis, mais offre également des opportunités de développement agricole durable et sûr. Le pays dispose d'un potentiel important pour l'agriculture biologique, compte tenu de sa biodiversité et de ses conditions naturelles favorables. Cependant, la mise en œuvre de pratiques biologiques se heurte à des obstacles tels que le manque de connaissances, des infrastructures limitées et un accès limité au marché.

Renforcer les avantages économiques en Afrique

La population africaine étant la plus jeune et celle qui croît le plus rapidement au monde, elle offre au continent une fenêtre d'opportunité démographique sans précédent. Donc il faut nécessite une diversification économique pour réduire la dépendance aux matières premières, l'accélération de l'intégration régionale via la Zone de libre-échange continentale africaine, le développement des infrastructures (énergie, numérique, transport), et l'industrialisation locale. Ces mesures visent à créer de la valeur ajoutée et des emplois.

Agriculture

L'agriculture en Afrique est l'activité économique qui emploie la majorité de la population.
Une stratégie globale visant à approfondir les avantages économiques en Afrique devrait se concentrer sur la diversification économique, l'intégration régionale et le développement des chaînes de valeur régionales, en plus de promouvoir l'industrialisation et l'accès aux opportunités sociales et économiques telles que l'emploi, l'éducation et la santé.

Cette vision s'appuie sur deux objectifs stratégiques jumeaux : accélérer la croissance verte inclusive et stimuler des économies prospères et résilientes.
La poursuite de ces deux objectifs que la Banque mondiale s'est fixée pour objectif d'assurer la durabilité à travers l'équilibre entre l'environnement, l'équité et l'économie.

Selon la Banque mondiale :
Illuminer et électrifier l'Afrique
Accélérer les progrès vers l'accès universel à l'électricité en Afrique grâce à une révolution des énergies propres

Nourrir l'Afrique
Renforcer la sécurité alimentaire de l'Afrique grâce à une transformation de l'agriculture africaine.
Donc il faut nécessite de transformer son agriculture en investissant massivement dans la productivité locale, les infrastructures et l'agro-industrie pour en faire un exportateur net. La stratégie repose sur l'adoption de l'agro-écologie, la modernisation des filières (semences, engrais), l'irrigation, et l'autonomisation des petits exploitants, notamment les femmes.

Industrialiser l'Afrique
D'ici 2033, l'industrialisation sera bien engagée dans toutes les régions africaines.
Étant donné que l'industrialisation est le moteur essentiel du développement en Afrique, capable de transformer les matières premières locales, de créer des emplois pour une population jeune et de réduire la pauvreté. En valorisant les

ressources sur place (agriculture, mines) et en utilisant la Zone de Libre-Échange Continentale Africaine (ZLECAf), le continent peut diversifier ses économies, booster le commerce intra-africain et diminuer sa dépendance aux chocs extérieurs

Intégrer l'Afrique

Promouvoir la libre circulation des biens, des finances et des personnes et créer des chaînes de valeur régionales comme base d'une économie africaine plus productive et pour stimuler l'industrialisation.

Améliorer la qualité de vie des populations en Afrique

Aider les Africains - en particulier les femmes et les jeunes - à réaliser leur potentiel.

Écologie

Mesure visant à équilibrer l'écologie africaine

Pour équilibrer l'écologie de l'Afrique, il est crucial d'adopter une approche holistique intégrant la préservation de l'environnement au développement durable, en promouvant la sécurité alimentaire et l'utilisation durable des ressources naturelles. Cela implique d'évaluer correctement le capital naturel, d'encourager les économies vertes et de favoriser l'entrepreneuriat durable.

Pour maintenir l'équilibre écologique

Il suffit de peu : de simples gestes du quotidien peuvent contribuer à minimiser les dommages causés à l'environnement.

D'un autre côté, plus profondément:

Économiser de l'énergie ;
Économisez du papier ;
Passez une journée végétarienne ;
Fermez le robinet ;
Réduire la consommation de plastique.

Pour rétablir l'équilibre écologique

La réutilisation des matériaux et le recyclage sont des pratiques essentielles pour minimiser l'impact environnemental. Révolutionner notre consommation de manière responsable.

Pour l'amélioration de l'écologie

Planter des arbres, recycler les déchets, stériliser les animaux de compagnie et signaler les crimes environnementaux sont quelques-unes des actions recommandées par le Water and Land Institute (IAT) pour aider à protéger les écosystèmes naturels et, ainsi, aider le monde.

Démonstration des bienfaits pour la santé

Pour démontrer les bénéfices pour la santé, des indicateurs tels que les taux de mortalité infantile et maternelle, l'espérance de vie, la prévalence des maladies infectieuses et chroniques et les indicateurs nutritionnels peuvent être analysés. De plus, un meilleur accès aux services de santé, à un assainissement de base et à l'eau potable est un facteur crucial.

Mettre en place des prestations de santé

Pour créer des avantages sociaux, vous devez d'abord définir le type d'avantages que vous souhaitez offrir (médicaux, dentaires, bien-être, etc.), puis comparer les différents régimes et fournisseurs. Il est important de tenir compte de votre budget, des besoins de vos employés et des options de couverture offertes par chaque régime. De plus, il est crucial de communiquer clairement les avantages sociaux aux employés, en leur expliquant comment y accéder et les utiliser.

Surveillance

Les objectifs des services de santé et des services liés à la santé sont de vérifier et de promouvoir le respect des normes et réglementations techniques en vigueur, d'évaluer les conditions de fonctionnement et d'identifier les risques et les dommages pour la santé des patients, des travailleurs et de l'environnement.

Démonstration des avantages sociaux

Pour démontrer les bénéfices sociaux, il est essentiel de démontrer comment les actions ou les programmes contribuent positivement au bien-être de la société et à la résolution des problèmes sociaux. Cela peut se faire au moyen de données quantitatives, de rapports qualitatifs et d'exemples concrets de l'impact positif généré.

Exercer la solidarité

L'attitude à adopter pour aider les personnes dans le besoin devrait être :

1 - Don alimentaire.
2 - Don de produits d'hygiène personnelle.
3 - Don de tissus et de vêtements qui traînent dans la maison.
4 - Action volontaire.
5 - Soutien aux causes sociales.

Démonstration des bienfaits de l'agriculture biologique

L'agriculture biologique, également connue sous le nom d'agriculture biologique, peut démontrer ses avantages grâce à des analyses qui évaluent la santé des sols, la biodiversité, la réduction des impacts environnementaux et la qualité des aliments produits de cette manière pour améliorer la croissance démographique et permettre l'engagement dans la lutte antiparasitaire grâce à la combinaison de plantes et à l'utilisation d'engrais biologiques résultant de déchets animaux, végétaux et végétaux, qui à leur tour agissent comme fixateurs d'azote.

Démonstration des bénéfices agro-écologiques

Pour démontrer les bénéfices de l'agro écologie en Afrique, il est crucial de démontrer comment elle peut accroître la production alimentaire saine, promouvoir la durabilité environnementale et renforcer l'autonomie des agriculteurs. Cela peut se faire en encourageant des pratiques agricoles durables, telles que la diversification des cultures, l'utilisation d'engrais organiques et la conservation de l'eau, ainsi qu'en développant des systèmes de production résilients et moins dépendants des intrants externes. L'agro écologie peut également améliorer la sécurité alimentaire et nutritionnelle, réduire la pauvreté et favoriser l'inclusion sociale, notamment des femmes, des jeunes et des populations autochtones, dans les activités agricoles.

L'agro écologie peut accroître la productivité agricole grâce à des techniques telles que la rotation des cultures et la diversification des cultures, qui peuvent améliorer la santé des sols et réduire la dépendance aux engrais chimiques.

* **Durabilité environnementale:**
  L'agro écologie promeut des pratiques qui réduisent l'impact environnemental de l'agriculture, telles que la réduction de l'utilisation de pesticides et d'engrais chimiques, la conservation de l'eau et la promotion de la biodiversité.

* **Résilience aux impacts du changement climatique:**
  L'agro écologie peut aider les communautés à s'adapter au changement climatique grâce à des techniques telles que la gestion de l'eau, la culture de cultures résistantes à la sécheresse et la promotion de la biodiversité.

* **Sécurité alimentaire et nutritionnelle:**
  L'agro écologie peut contribuer à la sécurité alimentaire et nutritionnelle en diversifiant les cultures, en favorisant la consommation d'aliments sains et en réduisant la dépendance aux aliments importés.

* **Renforcerl' économielocale:**
  L'agro écologie peut créer des opportunités économiques pour les populations rurales grâce à la production d'aliments sains et à la promotion des produits locaux.

* **Inclusion sociale:**
  L'agro écologie peut favoriser l'inclusion sociale en impliquant les femmes, les jeunes et les peuples autochtones dans les processus de production et en garantissant un accès équitable aux ressources et aux avantages de l'agriculture.

Engager la recherche innovante pour le développement en Afrique
Pour mobiliser la recherche innovante au service du développement en Afrique, il est crucial d'adopter une approche multidimensionnelle impliquant l'éducation, l'investissement dans la recherche et le développement, la création d'un environnement favorable aux startups et aux entrepreneurs, et la mise en place de politiques encourageant l'innovation en investissant dans l'éducation et le développement des compétences, en favorisant une culture de l'innovation et en créant un environnement propice à la recherche et à l'entrepreneuriat. Cela implique des actions telles que la promotion de la collaboration entre universités, entreprises et gouvernements, ainsi que l'accès au financement et au soutien des projets innovants.
L'innovation et l'entrepreneuriat contribuent à la création d'entreprises, à la création d'emplois, à l'augmentation de la compétitivité et de la productivité, et à l'amélioration de la qualité de vie de la population. Le rôle de l'innovation et de l'entrepreneuriat dans l'économie, que ce soit à l'échelle d'une région ou d'un pays, est véritablement crucial.

Commercialisation
L'engagement en matière de politique de commercialisation dans les communautés rurales africaines devrait se concentrer sur des solutions adaptées à leurs besoins spécifiques, favorisant l'accès aux marchés, l'amélioration de la productivité agricole et le développement durable. Cela implique la création de programmes de vulgarisation rurale qui autonomisent les agriculteurs, renforcent les coopératives et encouragent les pratiques agricoles durables.

Engagement en matière de politique de marketing dans les communautés rurales africaines :

1. Accès au marché
   * **Développement de la chaîne de valeur:**
     Investir dans les infrastructures (routes, stockage) pour faciliter le transport et la commercialisation des produits agricoles.

   * **Création de plateformes d'affaires:**
     Établir des marchés locaux et régionaux en mettant en relation les agriculteurs avec les acheteurs et en favorisant l'échange d'informations sur les prix et la demande.

   * **Marketing numérique:**
     Utiliser les technologies mobiles pour connecter les agriculteurs aux marchés, en leur fournissant des informations sur les prix, les conditions météorologiques et les meilleures pratiques agricoles.

2. Améliorer la productivité agricole:
   * **Extension rurale:**
     Donner aux agriculteurs des connaissances sur les techniques de culture, l'utilisation de semences améliorées, la gestion intégrée des ravageurs et des maladies et les pratiques de conservation des sols.

   * **Accès aux intrants:**
     Faciliter l'accès aux engrais organiques et autres outils nécessaires pour augmenter la production.

   * **Innovation technologique:**
     Promouvoir l'adoption de technologies agricoles qui augmentent l'efficacité et la productivité.

3. Développement durable:
   * **Agriculture durable:**
     Encourager les pratiques agricoles respectueuses de l'environnement, telles que la rotation des cultures, l'utilisation d'engrais organiques et la conservation de l'eau.

   * **Diversification de la production:**
     Stimuler la production de différentes cultures pour réduire la dépendance à un seul produit et accroître la sécurité alimentaire.

   * **Génération de revenus:**
     Promouvoir des activités génératrices de revenus alternatives à l'agriculture, telles que l'artisanat, le tourisme rural et l'élevage.

4. **Renforcer les communautés:**
   * **Coopératives:**
     Soutenir la formation et le renforcement des coopératives agricoles pour accroître le pouvoir de négociation des agriculteurs et faciliter l'accès au marché.

   * **Inclusion sociale:**
     Promouvoir l'égalité des sexes, l'accès à l'éducation et à la santé et la participation communautaire à la prise de décision.
   * **Éducation financière:**
     Permettre aux agriculteurs de gérer leurs finances, d'accéder au crédit et d'investir dans leurs entreprises.

Considérations supplémentaires:
   * **Culture et tradition:**
     Les politiques de commercialisation doivent prendre en compte les pratiques culturelles et traditionnelles des communautés rurales, en recherchant des solutions culturellement appropriées.

   * **Partenariats:**
     Il est essentiel d'établir des partenariats entre le gouvernement, le secteur privé, les organisations non gouvernementales et les communautés locales pour assurer le succès de ces initiatives.

   * **Suivieté valuation:**
     Il est important de surveiller et d'évaluer en permanence l'impact des politiques de marketing, en adaptant les stratégies si nécessaire pour garantir qu'elles atteignent leurs objectifs.

Éducation, formation et renforcement des capacités
Promouvoir l'éducation en Afrique est essentiel au développement socio-économique et au bien-être social du continent. L'éducation est considérée comme un outil de transformation sociale et un droit fondamental des enfants, avec pour objectif d'améliorer l'accès à un apprentissage inclusif et de qualité. Pour atteindre l'éducation primaire et secondaire universelle d'ici 2030, l'Afrique doit investir dans la formation des enseignants, garantir des conditions de travail et des salaires décents, et offrir des écoles accessibles.

Défisetopportunités :
   * **Financement:**
     De nombreux pays africains consacrent moins de 20 % de leur budget national à l'éducation, certains y consacrant même moins de 15 %.

   * **Ressources humaines:**
     La formation et la rétention d'enseignants qualifiés sont essentielles, tout en garantissant des conditions de travail et des salaires attractifs pour éviter la fuite des cerveaux.

   * **Accès etéquité:**
     Il est important de veiller à ce que les enfants, en particulier les filles des zones rurales et à faible revenu, aient accès à des écoles de qualité, en surmontant les obstacles tels que la distance, la violence et les normes culturelles.

* **Qualité de l'éducation:**
  L'apprentissage doit être pertinent et continu, s'adapter aux besoins du 21e siècle et préparer les jeunes au marché du travail.

Stratégies pour promouvoir l'éducation:

* **Construction d'écoles:**
  Construire des écoles accessibles et accueillantes est une étape fondamentale pour garantir l'accès à l'éducation.

* **Formation desenseignants:**
  Investir dans la formation et le développement professionnel des enseignants est essentiel pour garantir une éducation de qualité.

* **Politiques d'inclusion:**
  Mettre en œuvre des politiques qui favorisent l'égalité des sexes et l'inclusion des enfants vulnérables.

* **Participation communautaire:**
  Impliquer la communauté locale, y compris les parents et les dirigeants communautaires, dans la promotion de l'éducation.

* **Financement durable:**
  Rechercher un financement adéquat pour l'éducation, tant au niveau national qu'international, et veiller à ce que les ressources soient utilisées efficacement.

Entraînement
Promouvoir la formation en Afrique implique une approche multidimensionnelle visant à développer les compétences et à offrir un accès à une éducation de qualité à tous les Africains. Cela comprend l'investissement dans la formation des enseignants, le renforcement de la résilience des systèmes éducatifs et la promotion de l'innovation et de l'entrepreneuriat.

Stratégies pour promouvoir la formation en Afrique:

* **Investir dans la formation des enseignants:**
  La formation des enseignants est essentielle à la qualité de l'éducation. Les initiatives des écoles normales visent à former les enseignants à travailler en milieu rural, favorisant ainsi un accès plus équitable à l'éducation.

* **Renforcer les systèmes éducatifs:**
  L'Union africaine joue un rôle clé dans le développement du Cadre continental africain des certifications (ACQF), cherchant à aligner les systèmes d'éducation et de formation sur l'ensemble du continent.

* **Promouvoir l'innovation et l'entrepreneuriat:**
  Encourager l'innovation et l'entrepreneuriat en Afrique peut se faire en introduisant des programmes d'études axés sur l'entrepreneuriat dans les écoles et les universités.

* **Soutenir les initiatives éducatives:**
  Des initiatives telles que le programme Profuturo travaillent avec des enseignants dans plusieurs pays africains, en leur fournissant une formation, un encadrement et un soutien continu au développement professionnel.

* **Améliorer les infrastructures éducatives:**
  Investir dans la construction d'écoles, de salles de classe, de bibliothèques et garantir l'accès à des transports sûrs pour les élèves sont des mesures importantes pour améliorer l'accès à l'éducation, en particulier dans les zones rurales.

* **Utiliser les technologies d'apprentissage :**
  L'apprentissage mobile et l'enseignement à distance peuvent jouer un rôle crucial dans l'amélioration de l'accès à l'éducation, en particulier dans les zones reculées.

* **Favoriser la mobilité internationale:**
  La mobilité internationale, comme les échanges et les programmes d'études à l'étranger, peut offrir de nouvelles opportunités d'apprentissage et de développement.

* **Développer des compétences productives:**
  Les programmes de formation dans des domaines tels que la fintech et les compétences numériques peuvent préparer les jeunes Africains au marché du travail.

* **Encourager la recherche et la formation post-universitaire:**
  Soutenir les initiatives qui stimulent la recherche dans des domaines tels que les mathématiques et promouvoir les cycles de formation postuniversitaire sont importants pour le développement de compétences avancées.

* **Promouvoir la durabilité :**
  La formation au développement durable, comme la formation à l'agriculture durable, peut contribuer au développement durable en Afrique.
  En adoptant ces stratégies et en investissant dans l'éducation et la formation en Afrique, il est possible de construire des systèmes éducatifs résilients et de préparer les Africains aux défis du 21e siècle.

En Afrique, une question transversale désigne des problèmes ou des défis qui touchent de multiples dimensions de la société et du développement, transcendant les frontières géographiques et politiques. Ces questions, souvent interconnectées, nécessitent des approches intégrées pour être résolues efficacement.

Voici quelques exemples de questions transversales en Afrique:

* **Genre:**
  L'égalité des sexes est une question transversale qui touche tous les domaines du développement, de l'éducation et de la santé à la participation politique et économique.

* **Jeunesse:**
  Le continent africain compte une population jeune importante et les questions liées à l'éducation, à l'emploi et à la participation civique des jeunes sont cruciales pour l'avenir du continent.

* **Environnement et changement climatique:**
  L'Afrique est particulièrement vulnérable aux impacts du changement climatique, tels que les sécheresses, les inondations et la désertification, avec de graves conséquences sur la sécurité alimentaire, la santé et les moyens de subsistance.

* **Gestion des risques de catastrophe :**
  La prévention et la gestion des catastrophes naturelles et autres événements indésirables sont fondamentales pour protéger les populations et les infrastructures.

* **Migration:**
  La circulation des personnes à l'intérieur et à l'extérieur de l'Afrique est un phénomène complexe qui a des implications économiques, sociales et politiques.

* **Sécurité alimentaire:**
  Assurer l'accès à une alimentation adéquate et nutritive pour tous est un enjeu fondamental pour la santé et le bien-être de la population.
* **Santé:**

Les maladies transmissibles et non transmissibles, telles que le VIH/SIDA, le paludisme et les maladies cardiovasculaires, demeurent des défis importants en matière de santé publique en Afrique.

* **Paix et sécurité:**
  Les conflits armés et la violence touchent de nombreuses régions d'Afrique, avec des conséquences dévastatrices pour les populations et le développement.

* **Culture:**
  La richesse et la diversité culturelles de l'Afrique sont des éléments importants à préserver et à promouvoir, mais elles peuvent aussi être une source de conflits et de tensions.

* **Innovation et technologie:**
  L'adoption de technologies innovantes et le développement de solutions locales sont essentiels pour stimuler la croissance économique et sociale.

La résolution de ces problèmes transversaux nécessite une collaboration entre différents secteurs, notamment les gouvernements, la société civile, le secteur privé et les partenaires internationaux. Il est nécessaire d'élaborer des politiques et des programmes qui tiennent compte des interconnexions entre les différents enjeux et favorisent des solutions intégrées et durables.

En résumé : Une question transversale en Afrique est un problème qui affecte plusieurs dimensions de la société et du développement, nécessitant des approches intégrées pour sa résolution.

Développement des compétences pour une transformation productive en Afrique

Le développement des compétences de la main-d'œuvre africaine est un axe essentiel de la transformation productive du continent et de la réalisation des objectifs de l'Agenda 2063 de l'Union africaine. Ce chapitre décrit d'abord les obstacles à l'offre et à la demande de compétences sur le continent, notamment la faible qualité de l'éducation, les inégalités entre les sexes entre zones rurales et urbaines, le taux élevé d'emploi informel et le long processus de transformation structurelle de l'Afrique. Ensuite, il analyse les différences de déficits de compétences fondamentales, interpersonnelles et techniques sur le continent. Enfin, il met en évidence les nouveaux besoins en compétences résultant des transitions numériques et environnementales.

Stratégie d'intégration des agriculteurs familiaux dans l'agriculture biologique
L'intégration des agriculteurs familiaux dans l'agriculture biologique implique la mise en œuvre de stratégies combinant assistance technique, accès au marché, soutien financier et incitation à la création de coopératives ou d'associations. Il est essentiel de prendre en compte les spécificités de l'agriculture familiale et de promouvoir la diversification des cultures et l'adoption de pratiques agroécologiques.

Car l'agriculture familiale biologique est une stratégie de production durable qui favorise la souveraineté et la sécurité alimentaire et nutritionnelle des populations.

Merci

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Dillenia indica L.: A Nutritional and Medicinal Approach for Agroecology in Africa

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Abstract
This study investigates Dillenia indica L. elephant apple, a medicinal plant of significant agroecological value in Egypt, for its nutritional, phytochemical, and biological properties. The research explores the potential of this plant in enhancing the nutritional and health profiles of local farming systems, with relevance to organic and agroecological farming in Africa. This research investigates the potential of D. indica L.'s phytochemical content and biological activities to offer solutions for improving agricultural resilience and promoting human well-being.Methanolic extracts of leaves and fruits of D. indica L. were analysed for their phytochemical content. Techniques such as HPLC fingerprinting, gas chromatography, UPLC-QTOF-MS/MS, and molecular networking were employed. Tissue culture and in vitro propagation techniques were utilized to investigate the impact of growth regulators on plant quality and bioactive compound production. The plant is rich in flavonoids, phenolics, and fatty acids (notably lupeol and betulin). Key nutrients identified include potassium, vitamin A, and essential amino acids such as glycine. The fruit exhibits strong antioxidants, anti-inflammatory,anti-acetylcholinesterase, and antidiabetic properties. The tissue culture studied showed promising results for nutraceutical applications. As a conclusion, D. indica L. offers valuable nutritional and medicinal benefits, making it a promising candidate for organic and agroecological farming. Since climate conditions play a critical role in determining fruit quality, it is recommended that farming practices be optimized and that additional research be conducted on in vivo applications and bioactive mechanisms.

Résumé
Cette étude examine les propriétésnutritionnelles, phytochimiques et biologiques de *Dillenia indica* L., égalementappelée pomme d'éléphant, uneplantemédicinaled'une grande valeuragroécologiqueenÉgypte. La recherche explore le potentiel de cetteplante pour améliorer le profilnutritionnel et sanitaire des systèmesagricoleslocaux, notamment dans le contexte de l'agriculturebiologique et agroécologiqueen Afrique. Elle étudie également le potentiel des composés phytochimiques et des activités biologiques de *D. IndicaL.* pour contribuer à l'amélioration de la résilience agricole et au bien-être humain. Les extraits méthanoliques des feuilles et des fruits de *D. Indica L.* ont été analysés afin de déterminer leur composition phytochimique. Des techniques telles que l'empreinte digitale HPLC, la chromatographie en phase gazeuse, la spectrométrie de masse UPLC-QTOF-MS/MS et l'analyse de réseaux moléculaires ont été utilisées. La culture tissulaire et la propagation *in vitro* ont permis d'étudier l'impact des régulateurs de croissance sur la qualité de la plante et la production de composés bioactifs. La plante est riche en flavonoïdes, en composés phénoliques et en acides gras (notamment le lupéol et la bétuline). Parmi les nutriments clés identifiés figurent le potassium, la vitamine A et des acides aminés essentiels comme la glycine. Ce fruit présente de puissantes propriétés antioxydantes, anti-inflammatoires, anti-acétylcholinestérase et antidiabétiques. Les cultures de tissus étudiées ont montré des résultats prometteurs pour des applications nutraceutiques. En conclusion, *D. Indica L.* offre de précieux bienfaits nutritionnels et médicinaux, ce qui en fait un candidat prometteur pour l'agriculture biologique et agroécologique. Les conditions climatiques jouant un rôle déterminant dans la qualité du fruit, il est recommandé d'optimiser les pratiques agricoles et de mener des recherches complémentaires sur les applications *in vivo* et les mécanismes bioactifs.

I. Introduction

Dilleniaceae includes around 60 species, with *Dillenia indica* (Linnaeus) being the most widely favored for human consumption due to its edibility. The elephant apple (Dilleniaindica, Figure 1) is an essential medicinal plant growing in Egypt. It belongs to the Dilleniaceae family. Dilleniaindica is a highly valuable and distinctive medicinal tree cultivated in Egypt, recognized as a rich natural source of betulinic acid. The fruit is indehiscent, globular to spherical, green when immature, and turns yellow orange when fully ripe. Dillenia purified components and extracts have been shown to have therapeutic efficacy and are useful in folk medicine (Ameamsri *et al*., 2021). The properties of methanolic extracts include antibacterial, antioxidant, and anti-inflammatory qualities. Numerous active ingredients were reported by D. indica L.(Godewatte *et al*., 2021).This study evaluated the nutritional value of D. indica L. fruits, focusing on bioactive compounds alongside standard nutrients. Phytochemical profiling, metabolomics, molecular networking, biological assays, and tissue culture were employed to identify key constituents and assess growth metabolite induction.

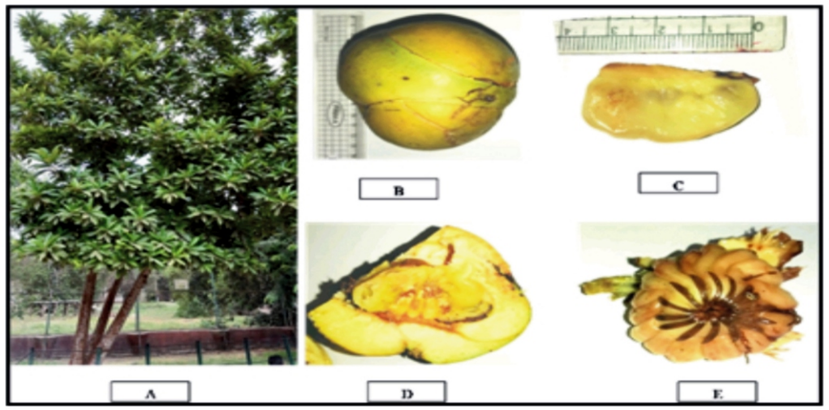

Figure : A, Aerial parts of L.(X=0.042) B, Fruit of *D.indica* L. (X=0.4) C, Seed of *D.indica* L. (X=2) D, T.S of *D.indica* L. fruit (X=0.8) E, Seeds group (X=0.8)

II. Materials and Methods

a. Plant material: Fruits of D. indica L. were gathered from the Zoo Garden. Voucher specimen was kept at the herbarium of Faculty of Pharmacy, Cairo University (28.7.23).

b. Phytochemical study: The fruits of D. indica L. were examined according to (Shaikh and Patil 2020) methods. While proximate analysis was determined according to WHO recommendations.

c. Total phenolic contents were quantified using the method of (Blainski et al., 2013). The total flavonoid concentration of the fruit extract was ascertained through the colorimetric method (Nayak et al., 2017). HPLC settings for flavonoid and phenolic content determination(Yildirim 2020).

d. GC-MS analysis: Preparation of non-saponifiable substance in accordance with modified British Pharmacopeia (Commission 1993); along with Rozema and Mitchell, fatty acids methyl ester (FAME) analysis of fruit hexane extract was carried out.

e. Fruit nutritional profile. Vitamins analysis, water soluble (vitamin C) was extracted using an altered version of the method previously reported to perform HPLC analysis. While fat-soluble vitamins were extracted and analysed using the method of (Arlai 2009). Metals determination optical emission spectrometer was used according to (Rice et al., 2017); while Amino acid detected using HPLC according to(Jaji? et al., 2013) method.

f. LC-MS/MS Analysis using Ultra-high-performance liquid chromatographic (UPLC) was performed by an Agilent LC-MS system negative and positive ion modes were tested. MS/MS Data Preprocessing: Raw data

files were converted to the mzXML format using the Ms Convert Protecto Wizard utility. Feature-Based Molecular Networking: The GNPS Feature-Based Molecular Networking (FBMN) workflow was used to construct the molecular network (Nothias et al., 2020).

g. In vitro biological activities

1. **Methods for assessment of antioxidant activities:** Antioxidant activity was evaluated using DPPH, TEAC (ABTS), FRAP, and ORAC assays with Trolox, quercetin, and ascorbic acid as standards. Results were expressed as Trolox-equivalent antioxidant values (μM), and detection was performed at 450 nm using a Bioline ELISA m reader (Alam et al., 2020).

2. **Method for determination of Acetylcholinesterase inhibition assay:** The Quanti Chrom TM Acetylcholinesterase Inhibitor Screening kit from Bioassay Systems is based on an enhanced Ellman technique(El-Hawwary *et al*., 2021) by the Bioline Elisa Reader. Donepezil was used as a reference effective AChE inhibitor.

3. **Method for evaluation of anti-inflammatory activity:** Human COX-1/ COX-2 inhibitors screening protocol (Hussain *et al*., 2022)was used.

4. **Method for antihyperglycemic activity determined according to (Kusano et al., 2011) Standard Acarbose.**

h. Tissue culture techniques: This study has been carried out in Tissue Culture and Germplasm Conservation Research. Lab., Hort. Res Institute (ARC) Egypt, during the period from 2022 to 2024.Preparation of MS medium (1 litter) according to Espinosa-Leal *et al*. (2018) method. Incubation under standard conditions of culture was followed.

III. Results:

a. Phytochemical analysis revealed the presence of carbohydrates, flavonoids, steroids, terpenoids, and tannins in alcoholic extracts of D. indica L. fruits (Table 1), which have beneficial effects on diseases and medical issues. These compounds frequently cooperate to support health (Kamboj *et al*., 2019; Ebrahim *et al*., 2024).

Table 1 Results of phytochemical screening of D. indica L. fruits

Compounds	Fruit
Alkaloids and / or Nitrogenous bases	-
Anthraquinones	-
Carbohydrate and/ or glycosides	+
Cardiac glycosides	-
Flavonoids	++
Saponins	-
Sterols and/or triterpenes	+
Tannins	++
Volatile constituents	-

b. Determination of total phenolic and flavonoid contents of D. indica L. fruits

The phenolic and flavonoid contents of D. indica L. fruits were high, at 407.91 mg GAE/L and 331.84 mg QE/L, respectively. HPLC identified seven phenolic acids (e.g., ellagic acid, the major compound) and four flavonoids

(e.g., apigenin, the major compound) as mentioned in table 2 and figure 2. These constituents possess antioxidant, anti-inflammatory, neuroprotective, and disease-preventive properties (Saikumar et al., 2023).

Table 2: Concentration of phenolics and flavonoids in fruits of D. indica L. as identified by HPLC

Characters / Item		Retention time (min)	RRT	Conc. (μg/g)
				Fruits
Phenolics	Gallic acid	3.330	0.38	961.67
	Chlorogenic acid	4.138	0.50	455.12
	Methyl gallate	5.500	0.63	24.97
	Caffeic acid	5.929	0.68	30.29
	Syringic acid	6.465	0.74	168.23
	Ellagic acid	8.642	1	1064.71
	Cinnamic acid	13.983	1.60	4.74
	Daidzein	12.212	1.41	18.27
	Querectin	12.693	1.51	311.43
	Apigenin	14.438	1.72	661.68
	Hesperetin	15.514	1.80	148.53

RRt: relative retention time relative to ellagic acid

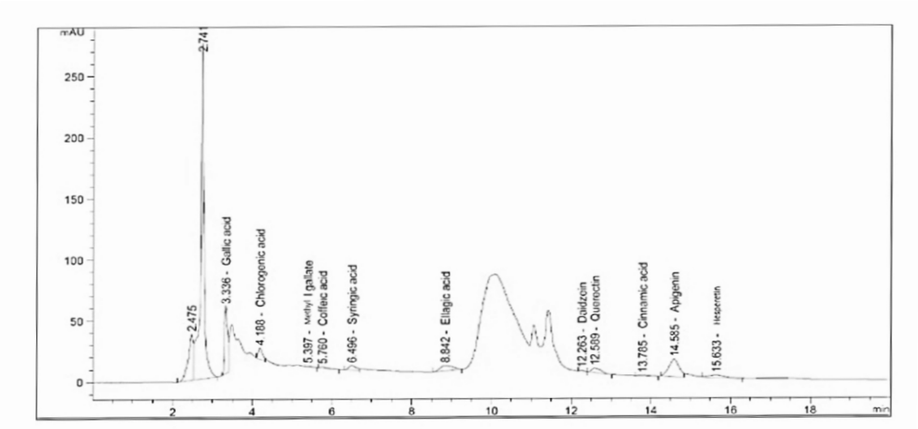

Figure 2 : HPLC chromatogram of D. indica L. fruits extract phenolics at λ= 280 nm

c. GC-MS fatty matter analysis:

GC-MS analysis of *D. indica L.* fruits revealed diverse compounds in saponi
fiable and unsaponifiable fractions, including aromatic diterpenoids, triterpenoids, and fatty acids. FAME showed 97.18% saturated fatty acids, dominated by arachidic acid (27.65%). Unsaponifiable matter comprised 22 compounds (99.07%), with hydrocarbons (52.65%; nonacosane 10.24%, octacosane 10.01%) and terpenoids (46.42%; lupeol 8.18%, betulin 7.71%) as in tables 3,4 and figures 3,4 (Abd El-Kader and Shakour 2015, Sabandaret al., 2017).

Table 3: Identified fatty acids methyl esters in the GC/MS analysis of D. indica L. fruits

Identified fatty acids methyl esters	Rt	RRt	Area%
Lauric acid	9.23	0.24	8.62
Methyl stearate	36.56	0.97	16.69
Arachidic acid	37.53	1.00	27.65
Docosanoic acid	41.75	1.11	11.61
Lignoceric acid	45.52	1.21	14.36
Palmitic acid	49.40	1.31	18.25

RRt: relative retention time relative to arachidic acid.

Table 4 :Components identified by the GC/MS analysis of the unsaponifiable matter of *D. indica* L. fruits

Identified Components	Rt	RRT	M.W	Area%
Undecane	4.43	0.11	156.31	2.10
Dodecane	8.58	0.21	170.33	4.21
Tridecane	13.86	0.35	184.36	1.09
Pentadecane, 2,6,10,14-tetramethyl	18.77	0.47	346.6	2.05
1-Nonadecene	23.18	0.59	266.5	1.11
Hexacosane	29.44	0.75	366.7	4.92
Heptacosane	34.51	0.88	380.7	2.48
Octacosane	38.78	0.99	394.8	10.01
***n*-heptacosan-7-one**	39.01	0.99	396.7	5.29
Nonacosane	39.14	1.00	408.8	10.24
Triacontane	39.30	1.004	422.8	3.09
Lupeol (3*β*-hydroxy -lup-20(29)-ene)	43.44	1.10	426.7	8.18
Betulin (3*β*-28-dihydroxy-lup-20(29)-ene)	45.98	1.16	442.7	7.71

Stigmasterol (3*β*,22E-Stigmasta-5,22-dien-3-ol)	47.51	1.21	412.6	5.32
***β* - Sitosterol (3*β*-Stigmast-5-en-3-ol)**	49.25	1.25	414.7	4.82
Cycloartenone	50.01	1.27	424.7	2.32
Betulinaldehyde (3 *β*-hydroxylup-20(29)-en-28-al)	50.55	1.29	440.7	6.48
Dillenic acid	51.05	1.30	470.7	2.30
Betulinic acid (3 *β*- hydroxy- lup-20(29)-en-28-oic acid)	62.97	1.60	456.7	3.81
Oleanolic/ ursolic acid	65.01	1.66	456.7	3.80
***n*-nonatriacontan-18-one**	68.02	0.94	563.2	3.21
Tetratetracontane	71.69	1.83	619.2	4.35

RRt: relative retention time relative to nonacosane

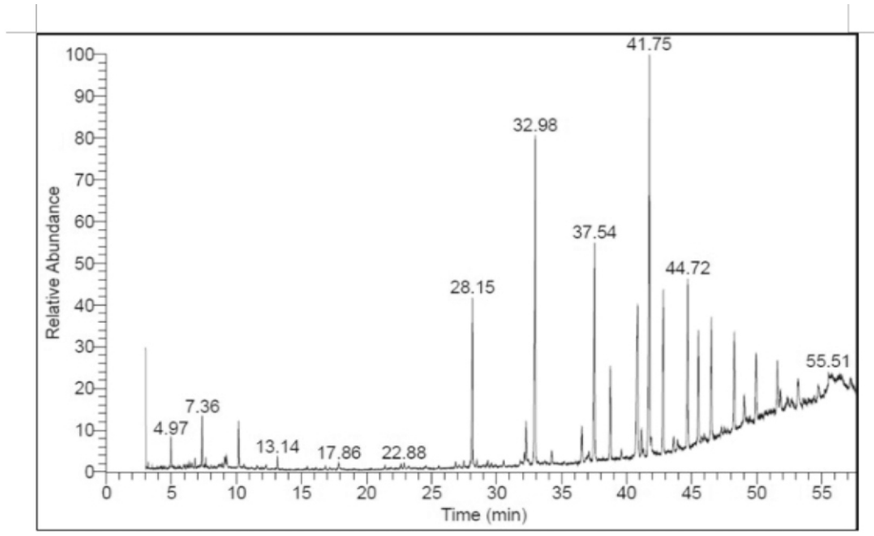

Figure 3: Total ion chromatogram for GC/MS of FAME of D. *indica* L. fruits

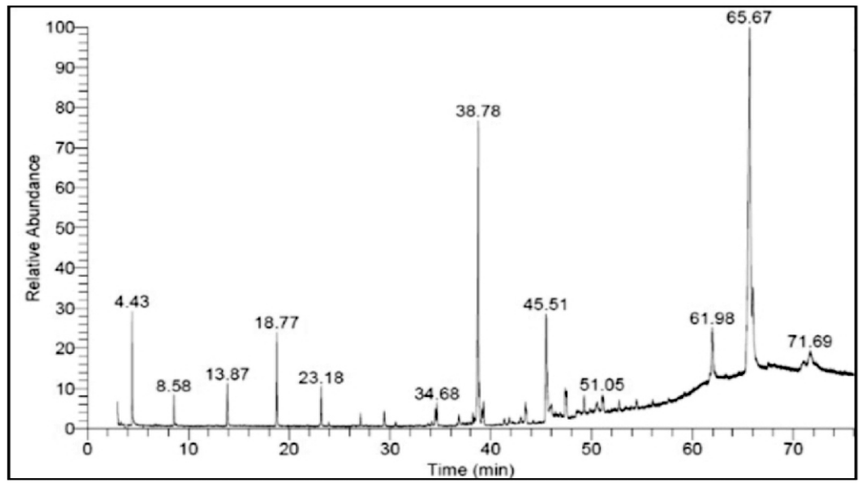

Figure 4: Total ion chromatogram for GC/MS of unsaponifiable matter of fruits

d. Fruit nutritional profile

1. **Proximate analysis** of the *D. indica L*. fruit powder analysis comprises determining the percentage of ash, protein, lipids, fiber, and moisture. Pre-analysis results showed that the extract encloses 9.01 % moisture. Ash and crude fiber contents were 3.17 and 12.83, respectively. Protein and lipid contents were 7.40 % and 0.97 %, respectively. The nutritive value is 59 k calories for each 100 g. According to these findings, fruit has a high concentration of vital nutrients.

2. **HPLC analysis of vitamin, mineral, and amino acids content:** The fruits of *D. indica* L. contain vitamins A, C, and E. Mineral analysis showed that the fruit contains many valuable and useful elements. In addition, to contains high concentrations of glycine, proline, glutamic acid, aspartic acid, and phenylalanine.
D. indica L. fruit is a nutraceutical-rich source of fiber, antioxidants, fatty acids, hydrocarbons, polysaccharides, and terpenoids, offering hepatoprotective, metabolic, antimicrobial, and pharmacological benefits**(Miocet al., 2022)**.
Global agricultural systems are noticing changes in fruit quality production due to climate change, which has significant effects on human nutrition and farmer livelihoods **(Stewart and Ahmed 2020)**. Our sample content of protein and fiber is equivalent to the fresh fruits gathered from Kushtia, Bangladesh's local market (6.81 and 1.38% respectively) **(Rahman *et al*., 2023).** The fruits collected from the Ayeyawady Region showed a higher vitamin C content compared to the Egyptian samples. Additionally, mineral analysis of fruits from other regions identified the presence of copper, sulfur, and rubidium. These differences highlight the influence of climatic variation and potential impacts of climate change on the nutritional and mineral composition of Dillenia indica fruits. Results are shown in tables 5,6, and 7

Table 5 :*D. indica* L. fruit vitamins content

Compound	RT (min)	Area	Conc. μg/mL	Conc. μg/g
Vit A/ Retinol	2.308	77.65	4.323	1.30
Vit C/ Ascorbic acid	1.620	20.0	0.62	1.24
Vit E/ alpha-tocopherol	6.329	38.91	1.531	0.46

Table 6: *D. indica* L. fruitsmineral content

Mineral	Conc in mg/kg
Potassium	11667
Sodium	267
Phosphorus	1000
Calcium	833
Manganese	< 0.05
Iron	16.3
Zinc	2.7

Table 7: Amino Acid contents of D. indica L. fruits extract

Amino acid	RT (min)	RRT	Conc. (μg/g)
Proline	1.592	0.144	2643.46
Aspartic acid	2.896	0.287	639.96
Glutamic acid	4.229	0.403	746.25
Serine	7.935	0.75	440.02
Histidine	9.372	0.89	138.99
Glycine	10.032	1	3780.77
Threonine	10.458	1.01	193.37
Arginine	11.776	1.12	392.82
Alanine	12.71	1.24	373.72
Tyrosine	14.986	1.43	138.01
Valine	18.816	1.80	282.44
Methionine	19.213	1.92	203.63
Tryptophan	20.748	2.15	310.2
Phenylalanine	21.749	2.195	545.23
Isoleucine	22.149	2.198	217.23
Leucine	23.403	2.32	408.36
Lysine	24.479	2.44	346.67

RRt: relative retention time relative to glycine

e. Metabolic profiling of the crude methanolic extracts of D. indica L. fruits

UPLC-QTOF-MS/MS Analysis: Metabolite profiling of *Dillenia indica L.* extracts using UPLC-QTOF-MS/MS, molecular networking, and database-assisted annotation (SIRIUS, NP Atlas, Reaxys) revealed at least 88 secondary metabolites, including flavonoids, anthocyanins, lipids, and terpenoids (Hamed et al., 2023) (Figure 5). The anticipated fragmentation patterns corresponding to the annotated compounds are shown. In the study, molecular ions from two extracts were visualized using a pie chart representation of nodes, reflecting their semi-relative abundance, whereas the connecting nodes mass differences were shown by the edges. Nodes were labeled with precursor m/z values and colored by sample type. Flavonoids, anthocyanins, lipids, and terpenoids were detected in molecular networking (Figure 6).

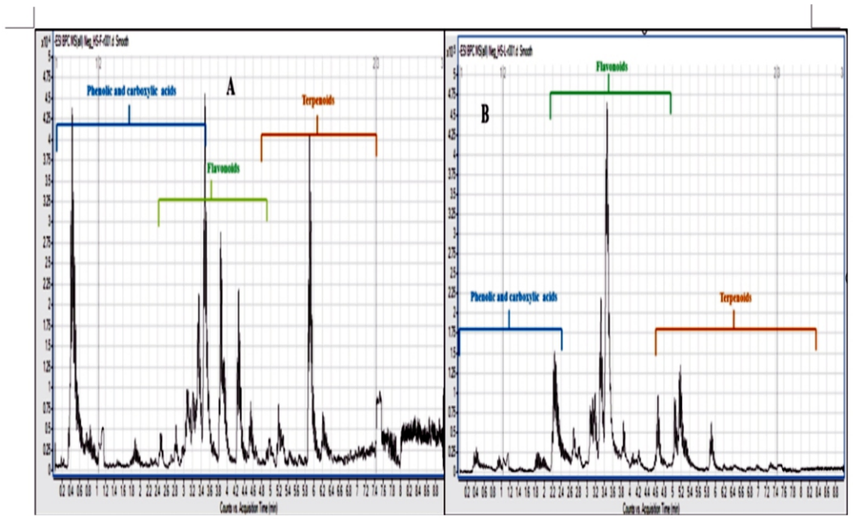

Figure 5: LC-MS base peak chromatograms of D. indica L. fruit extract in negative (A) and positive (B) ESI modes.

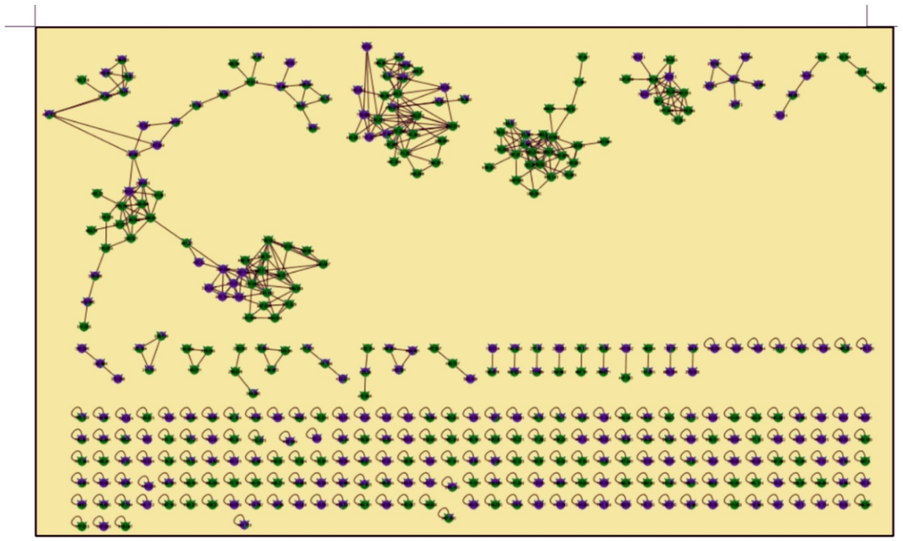

Figure 6: Molecular network constructed from LC-MS/MS study of D. indica L. fruit extracts utilizing MS/MS data in the negative and positive ESI mode. The relative abundance of the molecular ions found is depicted in the pie charts. A close-up of a few chosen nodes and clusters is shown. negative (green); positive (purple).

f. Evaluation of in vitro biological activities

* **Evaluation of in vitro antioxidant activity.** DPPH, ORAC tests, FRAP, and the ABTS radical-scavenging assay were all employed. All samples significantly scavenged DPPH and ABTS radicals. FRAP and ORAC assays were performed to determine whether D. indica L. samples can provide electrons and demonstrate in a dose-dependent way having a substantial reducing power potential (Gupta et al., 2024). The fruits showed antioxidant capacity for DPPH radical scavenging than those found in earlier investigations (Das et al., 2012; Alam et al., 2020) and revealed strong superoxide and hydroxyl radical-scavenging abilities (Mohanta et al., 2024). Phenolic substances, such as flavonoids and phenolic acids, possess strong redox properties that allow them to degrade peroxides, adsorb and neutralize free radicals, and quench singlet and triplet oxygen, thereby providing them with an enhanced antioxidant potential (Alam et al., 2017).

* **AChE inhibition activity.** Anti-Alzheimer activity of the samples was evaluated and compared with the standard donepezil. The results indicated that D. indica L. fruits methanol extracts showed significant activities. Overall, the earlier findings suggested that the chosen samples may have had a significant anti-Alzheimer effect because they are rich in beneficial metabolites like flavonoids, which are thought to be a promising lead class of compounds for the effective design and development of multi-potent AD medications (Mohanta et al., 2024).

* **COXInhibitor screening:** Samples were in vitro evaluated compared with celecoxib and indomethacin as positive controls. Migliato et al., (2011) illustrated the anti-inflammatory potential of D. indica L.fruits in anti-diarrheal, anti-edematous.

* **Alpha Amylase Inhibitor screening:** The samples were evaluated for alpha amylase inhibitor effect and compared with acarbose as an authentic. In patients with type-2 diabetes mellitus, inhibiting the carbohydrate hydrolyzing enzymes (glucosidase and amylase) is a useful method for controlling hyperglycemia(Elshibani *et al.,* 2020).

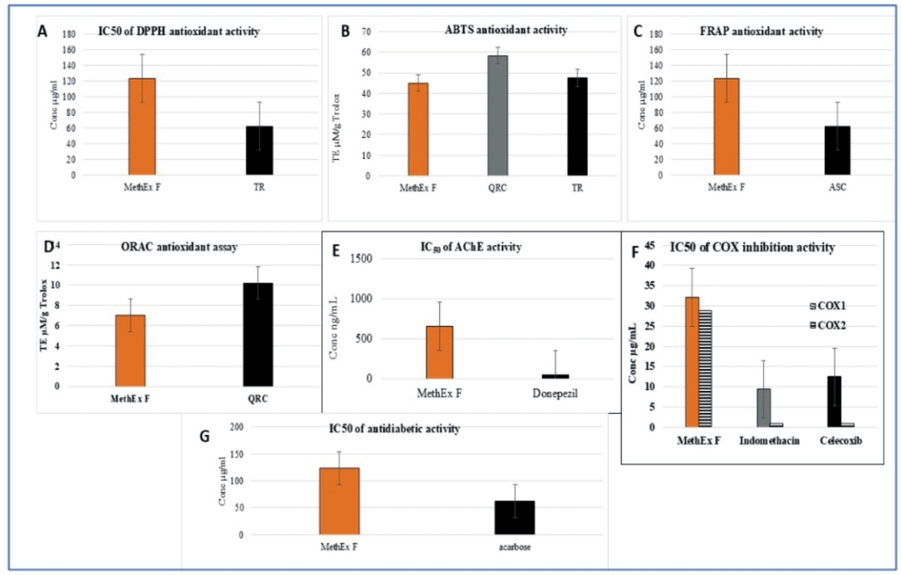

Figure 7: A)DPPH assay (expressed as IC50±SD), Trolox (TR) as standard antioxidant. B) ABTS Trolox equivalent antioxidant capacity (expressed as TE µM/g ±SD) TR and quercetin (QRC) as standard antioxidants. C) FRAP antioxidant activity (expressed as mM Ferrous Equivalents ±SD). Ascorbic acid (ASC), standard antioxidant. D) ORAC antioxidant assessment (expressed as TE µM/g Trolox ±SD). Standard quercetin. E) AChE inhibition activity comparing to standard Donepezil (expressed as IC50±SD ng/mL). F) COX inhibition, activities comparing to Indomethacin and Celecoxib as standards (expressed as IC50±SD µg/mL). G) ?-Amylase inhibition activity comparing to Acarbose as standard (expressed as IC50±SD µg/mL). MethExF ; fruit methanolic extract.

g. Tissue culture studv

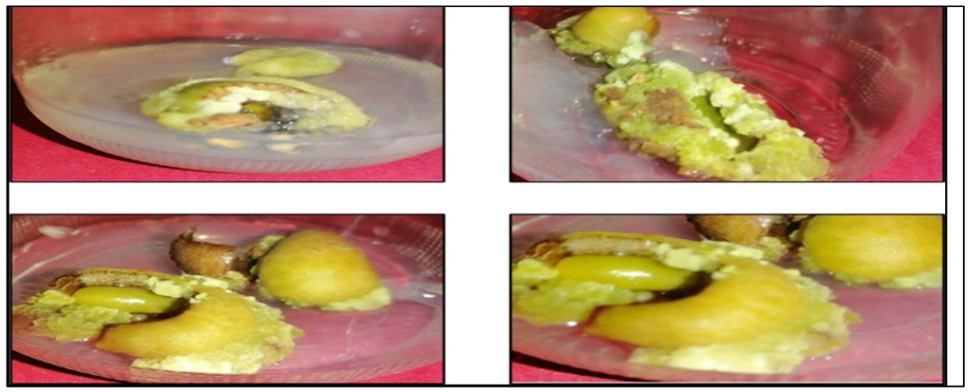

Figure 8: D. indica L. fruit callus explants cultured on MS media.

*** Investigation of plant growth regulators on callus**

Polyethylene glycol (PEG) at various concentrations was used to induce moisture stress and enhance phytoconstituents production ***(Tavakoliet al., 2020, Pradhanet al., 2021).***

In vitro propagation of *D. indica L.* demonstrated that PEG treatments enhanced phenolic, flavonoid, and terpenoid contents, enriching bioactive compounds with antioxidants, anti-inflammatory, antidiabetic, and anti-Alzheimer potential ***(Ebrahimet al., 2025).***

IV. Discussions

Assessment of *Dillenia indica L.* fruit identifies it as a rich source of nutraceutical and nutraceutical-relevant compounds, consistent with extensive prior research recognizing fruits as major suppliers of micronutrients, including vitamins, minerals, dietary fibres, and antioxidants. The high fibre content and the mucilaginous seed material likely contribute to the elevated carbohydrate levels (Dasanayaka *et al*., 2022). Fruit extracts contain diverse terpenoids, known as anti-inflammatory, anti-hyperglycemic, anti-dyslipidemic, antioxidant, and anti-mutagenic activities (Mioc *et al*., 2022), and represent the first reported HPLC quantification of D. indica fruit amino acids, revealing measurable concentrations. UPLC-QTOF-MS/MS analysis coupled with GNPS molecular networking enabled the identification of key phytoconstituents, while their biological activities are supported by published literature. The fruit is rich in flavonoids, particularly apigenin and quercetin, which exhibit strong antioxidants, antidiabetic, and neurotropic properties (Gao et al., 2023), as well as hydrocarbons and polysaccharides that further enhance antioxidant capacity (Balachandran et al., 2023), including in vitro acetylcholinesterase (AChE) inhibition associated with anti-Alzheimer potential (Kamel et al., 2023). COX enzyme inhibition suggests notable anti-inflammatory potential, possibly linked to betulinic acid and betulinic acid-related constituents such as betulinic acid (Mioc *et al*., 2022), while antidiabetic activity has been validated through ?-amylase inhibition (Mechchate *et al.*, 2021), supporting the potential use of the fruit in dietary supplements aimed at hyperglycemia management. In vitro propagation studies on D. indica L. and D. suffruticosa confirm their medicinal importance (Fernandes et al., 2019), with tissue culture offering advantages over

conventional propagation methods, and PEG treatment significantly increasing the accumulation of pharmaceutically relevant bioactive metabolites beneficial to the pharmaceutical sector (Ahmad et al., 2020). PEG acts as an osmotic agent and growth retardant (Abd El-Kader et al., 2019), and although our findings differ from reports of increased leaf pigment levels under high-PEG osmotic stress (Zholobova et al., 2024), they align with evidence that PEG enhances shoot proliferation and microshoot development (Manokari et al., 2022). The integration of advanced metabolite profiling and in vitro optimization strategies can accelerate natural product-based drug discovery by improving the selection of bioactive candidates within complex plant extracts.

V. Conclusion and Recommendations

Dillenia indica L. plants (family *Dilleniaceae*) are traditional medicinal herbs with reported neuroprotective potential. Phytochemicals from these plants are considered safe and non-toxic, suggesting potential applications in Alzheimer's therapy, though clinical studies are still required. Nutritional and phytochemical profiling of D. indica L. fruits revealed vitamins (C, E, A), essential minerals (Mg, Ca, P), amino acids, proteins, fibres, and bioactive constituents such as flavonoids, phenolics, terpenoids, fatty acids, and mucilage, conferring antioxidants, anti-inflammatory, and neuroprotective benefits. UPLC-QTOF-MS/MS and GC/MS analyses identified diverse secondary metabolites, including betulin and betulinic acid, while tissue culture studies enhanced phenolic and terpenoid levels through growth regulators and elicitors. Overall, Dillenia holds promise for nutraceutical and pharmaceutical development, but further biological studies, pharmacokinetic evaluations, and clinical trials are needed to isolate active compounds, validate safety, and establish efficacy in managing neurodegenerative and metabolic disorders.

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Rooting climate resilience with agroecological urbanism

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Abstract
As African cities rapidly urbanize, urban food systems face compounded challenges of climate change, environmental degradation, youth unemployment, and food insecurity. This study explores how urban agroecology, specifically through the lens of "agroecological urbanism," can contribute to climate resilience and sustainable urban transformation. Using a qualitative case study approach, the research investigates two urban agroecology hubs in Uganda's Kampala Metropolitan Area: JERO Farm and the Agency for Integrated Rural Development (AFIRD). These hubs demonstrate distinct yet complementary models. Data was collected through focus group discussions, in-depth interviews, small group interviews, field observations, and visual analysis. The findings are structured around three core themes: climate-resilient innovations, community engagement, and systemic barriers. Both hubs apply agroecology principles to adapt to urban constraints while contributing to climate adaptation and mitigation. Community participation is central to both models, strengthening social resilience and local food systems. However, issues such as insecure land tenure, high operational costs, and limited policy support continue to constrain broader adoption and institutional integration. The study calls for inclusive urban planning, creation of urban "agroecology villages", and supportive markets to enable systemic transformation.

Keywords: Urban Agroecology; Climate Resilience; Permaculture.

Résumé
Face à l'urbanisation rapide des villes africaines, les systèmes alimentaires urbains sont confrontés à des défis complexes liés au changement climatique, à la dégradation de l'environnement, au chômage des jeunes et à l'insécurité alimentaire. Cette étude explore comment l'agroécologie urbaine, et plus particulièrement le concept d'" urbanisme agroécologique ", peut contribuer à la résilience climatique et à une transformation urbaine durable. À travers une étude de cas qualitative, la recherche examine deux pôles d'agroécologie urbaine dans la zone métropolitaine de Kampala, en Ouganda : la ferme JERO et l'Agence pour le développement rural intégré (AFIRD). Ces pôles présentent des modèles distincts mais complémentaires. Les données ont été recueillies par le biais de discussions de groupe, d'entretiens approfondis, d'entretiens en petits groupes, d'observations de terrain et d'analyses visuelles. Les résultats s'articulent autour de trois thèmes principaux : les innovations résilientes au climat, l'engagement communautaire et les obstacles systémiques. Les deux pôles appliquent les principes agroécologiques pour s'adapter aux contraintes urbaines tout en contribuant à l'adaptation au changement climatique et à son atténuation. La participation communautaire est essentielle aux deux modèles, renforçant la résilience sociale et les systèmes alimentaires locaux. Cependant, des problèmes tels que la précarité foncière, les coûts opérationnels élevés et le soutien politique limité continuent de freiner une adoption plus large et une intégration institutionnelle. L'étude conclut en appelant à une planification urbaine inclusive, à la création de villages agroécologiques urbains et à des marchés de soutien pour permettre une transformation systémique.

Mots-clés : Agroécologie Urbaine ; Résilience Climatique ; Permaculture.

Introduction
As urbanization accelerates across Africa, cities face mounting pressures of food insecurity, environmental degradation, and unemployment, particularly among youth and women. "Agroecological urbanism", thereafter referred to as urban agroecology, has emerged as a promising response, advancing sustainable food systems, community health, and

ecological restoration within constrained spaces (Rudolph & Muchesa, 2024; Peano *et al*., 2020).Despite this potential, the practice remains under-recognised in scholarship, weakly supported in policy, and unevenly implemented. Conceptual inconsistencies and the absence of standardized evaluation frameworks limit recognition of the benefits of urban agroecology and hinder identification of successful implementation drivers (Dumont *et al*., 2021).

Much of the current literature foregrounds "urban agriculture" rather than "urban agroecology." For example, research shows that urban agriculture could contribute 15-20% of global food supply yet structural, social, and political barriers constrain its scaling up, deep and out (Altieri *et al*., 2025). Institutional gaps, weak educational outreach, and the lack of structured learning platforms further undermine the transformative potential for urban agroecology (Kay *et al*., 2022). Addressing these barriers requires intentional scholarship to model environments and multi-stakeholder frameworks that can strengthen community-driven approaches and embed sustainability into urban agroecology (Bisaga *et al*., 2019).

However, existing scholarship has focused on rural agroecology, framed in ways that lack ecological and social justice dimensions suitable for the urban context (Siegner et al., 2020; Villarino *et al*., 2021). For instance, a study biased to rural agroecology mapped 12 experiences in San Luis Potosí, noting the limited attention given to urban contexts despite rising urban pressures (Anzaldo Montoya & Munguía Moreno, 2025). This neglect limits recognition of urban agroecology as a transformative pathway and constrains policy innovation (Cheng *et al*., 2022; López-García & Carrascosa-García, 2024; Rudolph, Muchesa & Kroll, 2020). Given the limited knowledge of urban agroecology, it remains difficult to address systemic challenges and foster participatory, community-based climate resilience in African cities.

This study addresses these gaps by examining two Kampala-based urban agroecology hubs: JERO Farm and the Agency for Integrated Rural Development (AFIRD), members of Participatory Ecological Land Use Management (PELUM) Uganda, a charter under the 14-country PELUM Association. The study explores how the hubs integrate agroecology principles in constrained urban settings, engage diverse communities, and navigate systemic barriers. In doing so, the study contributes empirical evidence from sub-Saharan Africa and offers insights into scaling urban agroecology through enabling policies, municipal planning, and grassroots innovation.

Theoretical Framing
This study is guided by an integrated theoretical framework that combines the High Level Panel of Experts on Food Security and Nutrition (HLPE) 13 agroecology principles (Wezel *et al*., 2020), Social-Ecological Urbanism (SEU), resilience theory, and the concept of "agroecological urbanism" to analyse sustainable urban farming initiatives as dynamic and context-specific systems. The HLPE principles provide a normative and analytical lens to assess ecological practices, social relations, and governance arrangements, particularly the principles of recycling, input reduction, biodiversity, synergies, co-creation of knowledge, fairness, and resource governance. SEU provides the overarching lens by conceptualising cities as interconnected social and ecological systems in which urban form, institutions, and discourse shape ecological processes and social outcomes (Berghauser Pont *et al*., 2022). Within this framing, urban agroecology is understood as a socio-ecological intervention that actively redesigns urban spaces and institutions to enhance sustainability, resilience, and social equity. Resilience theory informs the analysis by focusing on adaptive capacity, diversity, redundancy, and transformability in the face of climate and urban pressures (Folke *et al*., 2010), while agroecological urbanism situates these processes within the spatial, infrastructural, and political realities of dense cities. Together, these perspectives enable a holistic examination of how urban agroecology contributes to climate resilience, food security, and social transformation under conditions of constraint and uncertainty. Linking agroecology innovations (adaptive practices), climate resilience (system robustness), community engagement (social resilience), and navigating challenges (system vulnerabilities), the Resilience Theory informs the following research questions.

Research Questions
1. How do urban agroecology innovations build climate resilience?
2. How do institutions engage communities in the urban agroecology innovations?
3. How can existing challenges in urban agroecology be addressed?

Methodology
This study employed a qualitative comparative case study design to explore practices, innovations, and challenges of urban agroecology in the Kampala metropolitan area of Uganda. The Kampala Metropolitan Area refers to the functional urban region comprising Kampala City and the surrounding districts of Wakiso, Mukono, and Mpigi, which are interconnected through commuting, infrastructure, markets, and shared ecological systems (Uganda Bureau of Statistics

and Kampala Capital City Authority, 2019).Two agroecology hubs were purposively selected: JERO Farm in Entebbe, a demonstration site applying agroecology principles through demonstration and farm-based learning, and the AFIRD in Nkoowe, a development organization supporting peri-urban and urban agroecology through farmer mobilisation, women and youth training, and value addition (AFIRD Uganda, 2022; JERO Farm, 2025).

JERO Farm, located in Kitala Village, Wakiso District, central Uganda, is a pioneering urban agroecology hub that showcases how small spaces can be transformed into productive, sustainable food systems. Serving as a one-stop center for agroecological training and demonstration, the farm empowers households to reconnect with food sources through hands-on practices. With over 120 extension farms, 80 women's groups, 50 farm outlets, and influence in 20 agroecology expos nationwide, JERO Farm is catalysing a shift from food consumption to food citizenship in Uganda's rapidly urbanizing landscape (JERO Farm, 2025).

AFIRD is based in Nkoowe, Wakiso district,along Kampala-Hoima Road in Uganda and has been a key driver of ecological and inclusive rural development since its founding in 1997. Officially registered as an NGO in 1998, AFIRD operates nationally, with active programs in Wakiso, Mpigi, and Mukono districts. With over 25 years of experience, it has supported 5,000+ households, trained 170+ farmer groups, and integrated ecological farming into 36+ schools. Guided by a strategic plan, AFIRD's work focuses on farmer-led development, youth empowerment, advocacy and lobbying, and institutional development, promoting sustainable livelihoods and agroecological transformation at the grassroots level (AFIRD Uganda, 2022).

The two selected hubsare members of the PELUM network and engaged in urban agroecology. PELUM Uganda Secretariat staff guided the selection of the two hubs to participate in the study.With Secretariat guidance, we purposively selected JERO Farm and AFIRD for their contrasting institutional models:farm-based versus NGO-led. We employed a qualitative approach, an appropriate approach for capturing lived experiences and contextual dynamics in the two urban agroecology hubs (Yardley *et al*., 2019).

Data collection drew on multiple methods to ensure triangulation and credibility (Haywood & Lawlor, 2018; Rouse & Harrison, 2015). These included two focus group discussions (FGDs), three in-depth interviews (IDIs), one small group interview (SGI), field observations, photographic documentation, and informal WhatsApp exchanges. Two FGDs were conducted: one with AFIRD staff and another with JERO staff and farmers. An IDI with JERO's team leader (Richard Mugisha) focused on leadership, innovation, climate resilience, and youth engagement, complemented by two IDIs with AFIRD staff (Faizo, Youth Empowerment Program Manager, and Justine, Advocacy and Lobbying Program Manager). These interviews explored innovations, market linkages, bio-input production, and community strategies. An SGI with representatives from both hubs, JERO Farm and AFIRD (Richard, Faizo, Justine),further clarified challenges (Table 1). Observational visits to the two hubs enabled direct assessment of farming agroecological techniques, while photographs (e.g., Fig 1) provided additional empirical evidence. All FGDs, SGIs and IDIs were conducted on Zoom, audio-recorded, transcribed, and verified by an independent review team for quality control. The lead author sought clarifications from the participants through WhatsApp exchanges.

Table 1: Study participants

Method	JERO	AFIRD
3IDIs	1 (male)	2 (1 male, 1 female)
2 FGDs	1 FGD (4 male, 1 female)	1 FGD (3 male, 2 male)
1 SGI, merged	1 (male)	2 (1 male, 1 female)

Data analysis followed a comparative case study analysis approach. Using a pre-determined coding framework derived from the research questions and Resilience Theory (Folke et al., 2010), transcripts and field notes were deductively coded into three categories: climate resilience, community engagement, and navigating challenges. Each case was analysed independently (within-case analysis) to produce detailed institutional narratives, then compared across cases (cross-case analysis) through a comparative matrix (Table 2). This revealed both shared patternsand distinct emphases. Manual qualitative data analysis integrated illustrative quotations to preserve participants' voices and contextual depth.

Table 2: comparative matrix

Parameter	AFIRD	JERO Farm
Institutional focus	Formal NGO with national partnerships and structured programming.	Small, family - owned micro -farm with community roots.
Coverage	Works across multiple districts with formal programs in schools, prisons, and communities.	Operates on ~0.5 acre but influences via 120+ extension farms, 80+ women's groups, and 50+ outlets.
Institutional engagement	Engages directly with district -level governance (e.g., Mpigi district demo garden)	Focused more on household and community advocacy

Visual analysis of three photos further enriched the findings. Following Shaari (2013), images were examined through pre-iconographic description, contextual analysis, iconographic interpretation, and iconological reading. Cross-image comparison tested typicality and refined interpretations, situating visual evidence within broader narratives of innovation, participation, and resilience.
Written and verbal consent was obtained from study participants (Richard, Justine and Faizo), participation was voluntary, and confidentiality was maintained. Triangulation across methods enhanced credibility, while peer debriefing, Zoom team discussions, and member checking with key study participants (Justine, Faizo, Richard) ensured trustworthiness.

Interpretation of key findings

JERO Farm and AFIRD both champion urban agroecology in Uganda, but through distinct approaches. JERO emphasizes creativity, low-cost practices, and grassroots engagement, while AFIRD pursues structured, technically advanced systems with stronger policy and institutional links. Both foster resilience, innovation, and community empowerment, yet their contrasting methods highlight the adaptability of urban agroecology across diverse urban and peri-urban contexts. This study presents valuable insights into how urban agroecology can be tailored and mainstreamed in rapidly urbanizing Uganda. After analysing the data from the JERO farm and AFIRD study participants, the research team identified the following three themes (Table 3).

Table 3: Themes

Theme	Core focus	Key findings
Theme 1: Urban agroecology innovations for climate resilience	Ecological and technological innovations in space constrained urban settings	JERO Farm demonstrates small-space diversification, drip irrigation, hydroponics, composting, waste reuse, and closed- loop systems that stabilise production under climate variability. AFIRD integrates agroforestry, bio-input production, composting, and seed multiplication to support both adaptation and mitigation.
Theme 2: Community engagement in agroecological urbanism	Participation, learning, and social empowerment	JERO Farm uses free training, follow-up mentoring, school programmes, and women's groups to embed agroecology in daily life. AFIRD applies decentralised training, farmer-led learning centres, youth and women enterprises, digital platforms, and institutional engagement to scale learning across communities
Theme 3: Addressing urban agroecology challenges	Structural, institutional, and market barriers	Key constraints include land scarcity and insecure tenure, costly and limited water access, weak policy recognition, low consumer awareness, high input costs, and fragmented markets. These barriers limit long term investment, scaling, and institutionalization of agroecology.

Theme 1: Urban agroecology innovations for climate resilience

Urban agroecology in the Kampala metropolitan area illustrates how small-scale, resource-constrained food systems respond to climate variability through adaptive and ecologically grounded practices. JERO Farm and the AFIRD Centre emerge as adaptive systems that integrate climate adaptation and mitigation within everyday urban food production. Their innovations demonstrate how resilience is built through diversity, recycling, reduced external inputs, and strengthened ecological feedback in dense urban environments.

At JERO Farm, water conservation and efficient resource use form the foundation of climate adaptation. The adoption of drip irrigation linked to hydroponic systems represents a response to increasingly unreliable rainfall and extended dry periods. As the team leader, Richard explained, "JERO [Farm] is actively making use of drip irrigation systems already." In urban and peri urban areas where piped water infrastructure is poorly developed, irrigation becomes unavoidable, yet water availability remains limited. Hydroponic systems that recycle water and nutrients, therefore, play a critical role in reducing vulnerability to water scarcity while maintaining production stability. Unlike rural systems characterised by seasonal production cycles, urban markets require a continuous daily supply of fresh vegetables and fruits. The stable irrigation infrastructure at JERO Farm, illustrated by the hydroponic system in Fig. 2, functions as a key climate adaptation strategy that buffers production against rainfall variability while sustaining urban food availability.

JERO Farm further demonstrates how diversification and circular resource use enhance both climate adaptation and mitigation within severe spatial constraints. Operating on approximately half an acre of sloping terrain, the farm supports nearly 40 plant types through intercropping, terracing, sack gardens, and vertical production systems (Fig. 1). As Richard noted, "We are innovating mobile gardens… people pay more for a water bottle turned into a garden." The integration of fruit trees (Fig. 1) such as mango, passion fruit, and banana with vegetables including kale, marigolds, tomatoes, nakati (or African eggplant or Solanum aethiopicum), and onions strengthens functional biodiversity, which improves tolerance to heat stress, pests, and rainfall extremes. Organic waste streams are tightly managed, with food scraps converted into black soldier fly larvae for poultry and fish feed, while livestock manure is used to produce biogas. The resulting slurry is returned to the soil as organic fertilizer, reducing reliance on synthetic inputs and associated emissions. These closed-loop practices contribute to climate mitigation by lowering emissions from waste and fertiliser use, while also enhancing soil organic matter and moisture retention, thereby strengthening adaptive capacity. The reuse of urban waste materials, visible across the farm landscape in Fig 1, further supports climate adaptation by reducing plastic blockage in drainage channels and lowering flood risk during heavy rainfall events. Fig. 1 is strong visual evidence of JERO Farm's approach to urban agroecology, combining diversified planting with recycled materials, terracing, and careful pathing to manage water and space.



Fig 1. Urban agroecology technologies at JERO Farm



Fig 2. Hydroponic system at JERO Farm

At the AFIRD Centre, climate resilience is framed explicitly as the integration of adaptation and mitigation strategies within urban agroecological systems. Composting, household waste recycling, and the use of local seeds were described as accessible practices that reduce dependence on expensive external inputs while lowering emissions associated with fertiliser production and transport. As one participant explained, "People use home kitchen waste to make compost, manure… and don't depend on the expensive fertilisers." Agroforestry plays a central role in AFIRD's approach to climate adaptation by moderating microclimates and reducing urban heat stress. Justine, an AFIRD staff member, explained,
"We don't use ACs [Air Conditioners]. Instead, we rely on natural cooling systems, which are made possible by the agroforestry practices established on the ground… when you move from a hot environment outside and enter through AFIRD's gate, you immediately start to feel the coolness."
She further noted that "a single mature tree can provide a cooling effect equivalent to several air conditioners," highlighting how small-scale tree planting contributes simultaneously to climate adaptation through temperature regulation and to climate mitigation through carbon sequestration. These agroforestry-based innovations are illustrated in Fig 3, which shows integrated agro-technologies at the AFIRD Centre.



Fig 3: Agro technologies at the AFIRD Centre, Nkoowe, Wakiso district.

AFIRD also links waste management innovations directly to climate action through biofertilizer production and seedling multiplication. As Faizo, an AFIRD staff member, explained, "…our tech looks at two aspects - mitigation… we are not only reducing emissions from waste but also building carbon sinks with the humus that farmers use. We are increasing adaptation through increasing access to low cost organic and biofertilizers. We multiply seedlings to promote tree planting." These practices strengthen mitigation by reducing methane emissions from unmanaged organic waste and increasing carbon storage in soils and biomass, while also enhancing adaptation by improving farmer access to affordable inputs that stabilise yields under climate stress.

While the two hubs differ in scale and institutional orientation, with JERO emphasising household level and micro scale innovations and AFIRD focusing on training oriented and technical interventions, both demonstrate how agroecological principles translate into concrete climate outcomes. Each reduces vulnerability to water scarcity, lowers dependence on external synthetic inputs, and creates ecological buffers against urban heat, flooding, and rainfall variability. Their integration of traditional practices with accessible technologies exemplifies agroecological urbanism, embedding food production, climate adaptation, and mitigation within the urban fabric.

Despite their institutional differences, with JERO operating as a family run micro farm and AFIRD functioning as an NGO led training centre, both serve as learning hubs within Kampala's urban socio ecological system. They provide demonstration spaces and training opportunities that strengthen adaptive capacity, support mitigation efforts, and create livelihood opportunities for youth and women. Together, these cases highlight how urban agroecology can contribute meaningfully to climate resilient food systems while advancing mitigation goals, even under conditions of spatial constraint and increasing climatic uncertainty.

Theme 2: Community engagement in agroecological urbanism
Community engagement is central to agroecological transformation in urban Uganda, and both JERO Farm and AFIRD demonstrate how participatory approaches strengthen social capital, empower marginalised groups, and build climate resilient urban communities. Community engagement emerges not as an add-on activity but as a core mechanism through which agroecological knowledge is co-created, adapted, and sustained over time. In both cases, learning, experimentation, and collective action link ecological practices with social organisation, thereby reinforcing adaptive capacity in rapidly urbanising contexts.

At JERO Farm, community engagement begins with accessible and practice-based learning. The farm offers free training sessions that focus on hands on skills and immediate application at household level. As Richard explained, "We allowed coming and learning free of charge… We help them establish kitchen gardens." These training activities are reinforced through follow-up visits, which create feedback loops between trainers and participants. As one farmer supported by JERO Farm noted, "Farmers ought to implement what they're taught and trigger JERO Farm to make follow up visits." This iterative process strengthens learning, accountability, and adaptation, ensuring that agroecological practices are embedded within everyday household food systems and adjusted to local constraints.

Youth engagement is a deliberate and strategic focus at JERO Farm, reflecting the HLPE principles of co-creation of knowledge and human and social values. Through partnerships with organisations such as Rural Community in Development, JERO delivers agroecology education in schools. Richard, the JERO farm leader, explained, "We are hired by an organization to cover about nine schools… telling them about how they can grow without these chemicals." He emphasised the urgency of targeting younger generations, stating, "The biggest gospel should now go to the young generation… encourage them, embrace them, and give them awareness that this is how things are done." These interventions respond to widening disconnections between urban youth and food production. Reflecting on one encounter, he recalled, "I went to one of the biggest schools… a student thought food came from the store market." Practical demonstrations and school gardens therefore, function as adaptive learning spaces that reconnect youth to food systems while building long term resilience through knowledge transmission.

Women's engagement at JERO Farm further illustrates how agroecological urbanism integrates social inclusion with climate resilience. Through groups such as Women of Hope, women are supported to adopt agroecological practices that improve household nutrition and income. As Richard noted, "Led by the co-manager of JERO, the 33 participants of 'Women of Hope'… collaborate with JERO[Farm] in implementing agricultural techniques to improve their family's nutrition and income." JEROFarm positions itself not only as a training site but also as a socially embedded enterprise. Richard described the farm as "an organic demonstration farm that seeks to address issues of malnutrition… and evidence of how proper farming techniques can support families and communities and become profitable." This integration of livelihood generation with ecological practices strengthens social resilience and enhances households' capacity to cope with climate and economic shocks.

At AFIRD, community engagement operates at a broader and more decentralised scale, reflecting a systems-oriented approach to agroecological transformation. Engagement extends beyond individual farmers to include schools, prisons, markets, and organised youth groups. As Faizo explained, "Our community is quite broad. We work with schools, prisons, and farmers… We organize Open Days for people to come and see the urban farming technologies we are doing." These open learning spaces align with the HLPE principle of knowledge co-creation and reinforce resilience by enabling cross-sector learning and experimentation within urban socio-ecological systems.

AFIRD further strengthens participation through collaborative innovation processes. Farmers engage directly in the development, testing, and refinement of biofertilizers and biopesticides, contributing to local knowledge co-creation. Digital tools also support engagement and knowledge exchange. Through the iKnowFarm App, AFIRD markets products and disseminates agroecological information. As Faizo explained, "We enrich the app with information on markets and agroecology practices… and get support from the community in terms of content development and feedback." These mechanisms enhance adaptive capacity by linking local practice with wider networks of information, markets, and learning.

Youth and women empowerment are central to AFIRD's engagement strategy and closely linked to resiliencebuilding through livelihood diversification. Faizo observed, "Some of the youths are now making their pesticides… using garlic and onions, and they are selling them too." Women are similarly supported to develop value-added enterprises based on agroecological production. One staff member explained, "Women groups we train… do herbal soap, body lotions, organic pesticides and teas, using herbs they grow in sack gardens." These activities connect ecological knowledge with income generation, reducing vulnerability to climate and economic stress while addressing broader challenges related to unemployment, nutrition, and health.

Replication and decentralisation are defining features of AFIRD's model and reflect resilience theory principles related to redundancy, modularity, and scaling out. Justine described how "a network of facilitators learns innovations and transform their landscapes by establishing their agroecology learning model centres." Some participants have transformed their own homes into learning hubs. She recounted the example of "an old lady called Katabaire Joy… she has now created a 'Joy Centre,' and she is currently building accommodations for participants." Through this approach, agroecological knowledge is embedded within communities rather than concentrated in a single site. AFIRD's work has contributed to the establishment of up to 30 school and community green spaces, integrating agroecology into daily urban life and strengthening collective resilience.

AFIRD also engages strategically with government institutions to influence governance and policy environments. A permaculture demonstration garden established at the Mpigi District local government headquarters serves both as a learning space and an advocacy platform. Justine emphasised its role, stating, "Through exposures… government officials, farmers, and visitors learn innovations on the ground and then replicate them." By situating agroecology within formal institutional spaces, AFIRD enhances visibility, legitimacy, and the potential for wider adoption, aligning with HLPE principles related to responsible governance and supportive enabling environments.

Taken together, JERO Farm and AFIRD illustrate complementary pathways of community engagement within agroecological urbanism. JERO emphasises farm-based training, mentorship, and school partnerships, with a strong focus on youth and women as future custodians of agroecology. AFIRD adopts a more formalised, network-based approach that connects farmers, women, and youth to enterprise development, digital platforms, and decentralised learning centres. Both cases demonstrate that urban agroecology functions not only as a set of farming practices but as a participatory process of education, empowerment, and resilience building within Uganda's rapidly urbanising socio-ecological systems.

Theme 3: Addressing urban agroecology challenges
While urban agroecology offers important pathways for sustainable food production, environmental regeneration, and climate adaptation, practitioners in Kampala metropolitan encounter persistent structural, institutional, and social barriers that constrain its wider adoption. These challenges reflect misalignments among ecological innovation, urban governance, infrastructure, and market systems. Experiences from JERO Farm and AFIRD illustrate how such constraints shape everyday practice and limit the scaling of agroecological urbanism in peri urban environments.

Land scarcity and tenure insecurity emerged as a central challenge undermining long-term resilience. As one AFIRD participant observed, "In Uganda and especially Kampala, people are using containers, vertical farming, rooftop farming, balcony farming, because there is no land." Justine echoed this concern, stating simply, "Land is a problem… land is inadequate." Insecure tenure increases farmers' exposure to sudden displacement and discourages long term investments in soil health, agroforestry trees, and water infrastructure that are central to agroecological resilience. Faizo described the situation starkly: "Urban farmers are losing land at a very high rate. There is a lot to be done on land rights." This instability weakens feedback between ecological stewardship and social benefit. Participants therefore argued for stronger integration of agroecology into urban planning through designated agricultural zones. Justine criticised existing greening initiatives for prioritising aesthetics over function, stating, "KCCA [Kampala Capital City Authority] is creating green spaces… but when you look at what is planted, they are not even beneficial. We need to be intentional, not just after green colour, but plants that serve other purposes, medicinal, indigenous, useful trees."

Access to water represents another major constraint with direct implications for climate adaptation. Many urban farmers rely on purchased water, which significantly increases production costs and limits crop choices. As Justine explained, "Someone tells you I now spend like 1000 UGX to buy [a 20-litter jerrican of] water… they start to think they need to buy water for other plants they don't value." This situation reduces adaptive flexibility, particularly during dry periods when water demand increases. Collective solutions were proposed to strengthen resilience at the community level. Justine suggested shared infrastructure such as rainwater harvesting and communal water access, stating, "If possible, we have

some common water points… it can give opportunities for people to always get some water to take care of their gardens." Such approaches align with resilience theory by emphasising shared resources and collective action to buffer climate stress.

Market-related challenges further limit the viability of urban agroecology. Price instability driven by political and market dynamics undermines income security. As Justine noted, "Prices often rise due to political factors and market dynamics." At the same time, low consumer awareness constrains demand for agroecological products. Faizo observed, "Many people are not aware of agroecology products, mainly the consumers." Justine added, "People don't know the value of these [agroecological] products… they just see [them as] vegetables." Without differentiation from conventional produce, agroecological products are undervalued. As Justine lamented, "They are put in the same markets [with conventional products] … people don't see the difference." Faizo further explained how this affects livelihoods, stating, "You produce your small quantities, and you want to sell it at a higher price… but someone will tell you, I can get it cheaper in the market." These dynamics weaken producers' economic resilience and discourage the wider adoption of urban agroecology. Both practitioners emphasised the need for organised, farmer-led markets and designated stalls that recognise the added ecological and social value of agroecological produce.

High input costs and limited access to agroecological inputs compound these challenges. Justine noted that "Some of these inputs are expensive… and not easy to get [in urban establishments]." Faizo elaborated, stating, "Limited access to most agroecology inputs… fertilizers, seed, pesticides… keeps the production small." Even where local input production exists, scale remains a constraint. As he explained, "Even we who are engaged in processing them, the production is still small, probably because the levels of technologies we use are still low." These limitations restrict productivity, consistency, and the ability of farmers to respond to climatic variability. Proposed solutions included expanding composting facilities, scaling up bio input production, and strengthening farmers' capacity in seed saving and local input manufacture, all of which align with HLPE principles of recycling, input reduction, and autonomy.

Additional barriers relate to urban infrastructure and cost structures. High transportation costs and expensive market stalls reduce profitability and access to consumers. As Justine explained, "The cost of hiring stalls and transporting produce is too high." Without supportive infrastructure and coordinated market systems, agroecological markets remain fragmented, increasing vulnerability for small scale producers.

Urban agroecology in Kampala is constrained by land insecurity, limited and costly access to water, weak consumer awareness, high input costs, and unregulated market competition. Practitioners from JERO Farm and AFIRD consistently argued for stronger municipal collaboration, the integration of agroecology into urban planning frameworks, improved market structures, and targeted support measures such as designated agricultural zones, subsidies, and demonstration sites. Despite these challenges, both initiatives continue to function as nodes of resilience within the urban socio-ecological system. However, scaling their impact requires systemic interventions that move urban agroecology beyond isolated projects and position it as a recognised and supported pillar of sustainable and climate-resilient city development.

Discussion of key findings

This study underscores the growing significance of urban agroecology as a locally adaptable, socially embedded, and ecologically grounded pathway for strengthening sustainable food systems in Uganda. Drawing on the case studies of JERO Farm and AFIRD, the findings demonstrate how urban agroecological practices function as integrated socio-ecological systems that simultaneously address food security, climate adaptation, and community resilience. Innovations such as resource recycling, diversified production, reduced use of external inputs, and participatory learning align closely with the HLPE agroecology principles and with resilience theory, which emphasises diversity, feedback, and adaptive capacity in the face of disturbance. Within the framework of agroecological urbanism, these initiatives show how food production, waste management, and social organisation are re-integrated into urban spaces, contributing to both climate adaptation and mitigation while advancing food sovereignty and ecological justice (Peano et al., 2020; Rudolph and Muchesa, 2024).

The findings illustrate how urban agroecology strengthens resilience. At JERO Farm, practices such as mobile gardens, composting, drip irrigation, and diversified cropping reflect key resilience attributes including diversity, modularity, and efficient resource use, which enhance the system's capacity to absorb climatic shocks while maintaining core functions. At AFIRD, broader systemic interventions such as vermicomposting, agroforestry, bio input production, and seed multiplication demonstrate redundancy and functional diversity, both of which are central to resilient systems (Folke et al., 2010). These practices also align with multiple HLPE agroecology principles (Wezel et al., 2020), including

recycling, input reduction, diversity, synergies, and resilience, illustrating how ecological processes are deliberately harnessed to stabilise production under conditions of environmental uncertainty.

Across both cases, learning and adaptation emerge as dynamic processes rather than static outcomes. By linking ecological innovation with continuous community training, experimentation, and feedback, JERO Farm and AFIRD exemplify core socio-ecological processes of adaptive learning and self-organisation. These processes resonate with the HLPE principles of co-creation and sharing of knowledge, human and social values, and culture and food traditions (Wezel et al., 2020). In resilience theory terms, such feedback loops enable systems to adjust practices in response to disturbance, reducing vulnerability while expanding the range of possible responses to climate variability. This capacity for learning is particularly important in urban contexts, where environmental, social, and economic conditions are rapidly changing.

Community engagement plays a central role in strengthening social resilience and expanding adaptive capacity. JERO Farm's engagement with schools and women's groups embeds agroecological knowledge within households and everyday routines, reinforcing intergenerational learning and local stewardship. This approach reflects HLPE principles related to equity, social inclusion, and responsible governance, by prioritising access to knowledge for youth and women who are often marginalised in urban food systems. AFIRD's decentralised model of farmer-led learning centres and youth-led enterprises further exemplifies the principle of co-creation of knowledge and supports resilience through distributed leadership and redundancy. As argued by Rudolph and Muchesa (2024), embedding agroecology within education systems and participatory governance arrangements can catalyse broader systemic change, a finding reinforced by empirical evidence from both cases.

The adaptive reuse of urban waste materials for food production, particularly evident in JERO Farm's bottle and tyre gardens, illustrates resilience through transformability. Transformability, a core concept in resilience theory, refers to the capacity to create fundamentally new system configurations when existing conditions become untenable. By repurposing waste materials and underutilised urban spaces into productive agroecological landscapes, urban farmers actively reconfigure urban metabolisms toward circularity and sustainability. These practices strongly align with the HLPE principles of recycling, circular and solidarity economy, and efficiency in resource use, while echoing global examples of creative urban reuse documented by Suau (2015).

Despite these strengths, the findings also reveal structural constraints that limit the scaling and institutionalisation of urban agroecology. Insecure land tenure, limited access to affordable water, weak policy frameworks, and fragmented markets constrain farmers' ability to invest in long term ecological functions such as soil restoration, agroforestry, and water harvesting. From a resilience perspective, these constraints reduce both adaptive capacity and transformability by locking agroecological initiatives into precarious niches. Similar barriers have been observed elsewhere. In Brazil, James et al. (2023) highlight the importance of enabling environments, including public programmes and supportive institutions, for scaling agroecology. Likewise, Sokolowski et al. (2024) and Monkes and Easdale (2023) show how fragmented implementation and state neglect undermine agroecological coherence in Latin America. These parallels situate Uganda's challenges within broader global patterns of uneven institutional support and political marginalisation of agroecology.

The concept of agroecological urbanism (Tornaghi and Dehaene, 2021) provides a useful lens for interpreting these findings,especially for Kampala, where urban planning continues to prioritise commercial greening over multifunctional food-producing landscapes. Several HLPE principles, including responsible governance, circular economy, and connectivity between producers and consumers, remain weakly institutionalised in Kampala's urban policy. As Nicol (2020) argues through the framework of scaling out, scaling up, and scaling deep, urban agroecology must move beyond isolated grassroots experiments to reshape governance norms, planning frameworks, and cultural values. AFIRD's permaculture garden at the Mpigi District headquarters illustrates a strategic effort to influence governance by embedding agroecology within institutional spaces, thereby strengthening legitimacy and creating opportunities for policy learning.

JERO Farm and AFIRD demonstrate adaptability through ecological diversity, learning, and social organisation, and transformability through their efforts to contest urban systems that marginalise food production and informal livelihoods. However, without coordinated governance, supportive infrastructure, and enabling policies (Anderson et al., 2019),their transformative potential remains spatially limited and socially uneven. As Robbins et al. (2019) remind us, these constraints are not merely technical but deeply political, reflecting broader struggles over land, resources, and power in urban environments. Strengthening urban agroecology, therefore, requires not only technical innovation but

also institutional reform that aligns urban governance with the full spectrum of HLPE agroecology principles and the long-term objectives of climate resilience.

Conclusions and Recommendations

Urban agroecology in Uganda emerges from this study as both an expression of everyday resilience and a practical pathway toward more just and sustainable urban futures. The experiences of JERO Farm and AFIRD demonstrate how community-led agroecological practices integrate ecological stewardship, social empowerment, and economic innovation within dense urban environments. Through small-space farming, bio-input production, and grassroots education, these initiatives simultaneously address food insecurity, climate risk, and youth unemployment, illustrating the capacity of urban agroecology to respond to multiple, interconnected challenges.

The identified constraints reduce adaptive capacity and limit the ability of agroecological initiatives to move from isolated sites of innovation to stable and transformative components of urban food systems.The study highlights that realising the transformative promise of urban agroecology requires coordinated action across research, theory, practice, and policy. Strengthening the evidence base, advancing urban focused agroecological theory, supporting community-based hubs of learning and innovation, and embedding agroecology within urban planning and governance frameworks are all essential. Without such systemic alignment, urban agroecology risks remaining marginal despite its demonstrated contributions to climate resilience, livelihoods, and social justice.

Urban policy frameworks should formally recognise agroecology as a multifunctional land use that contributes to food security, climate adaptation, and ecosystem services. Municipal authorities should integrate agroecology into urban and peri urban planning through designated agricultural zones, secure land tenure arrangements, and long-term access agreements that enable farmers to invest in soil, water, and tree-based systems. Water governance should prioritise shared infrastructure such as rainwater harvesting, communal water points, and incentives for water efficient technologies. Market policies should support differentiated agroecological produce through designated market spaces, reduced stall fees, and public procurement schemes that recognise ecological and social value.

Practitioners should continue to prioritise diversified, low-input, and circular production systems that enhance ecological functions and reduce dependency on external inputs. Scaling should emphasise replication and decentralisation rather than standardisation, supporting household, school, and community-based agroecology hubs as learning spaces. Training programmes should foreground participatory methods, farmer led experimentation, and locally adapted technologies, particularly those that improve water efficiency and waste reuse. Strengthening local capacity for seed saving, composting, and bio input production will enhance autonomy and resilience at farm and community levels.

Social movements, farmer organisations, and civil society groups have a critical role in advancing urban agroecology as a political and cultural project. Advocacy efforts should focus on land rights, food sovereignty, and the recognition of agroecology within urban governance agendas. Building alliances among farmers, youth, women's groups, environmental organisations, and consumers can strengthen collective power and visibility. Education and awareness campaigns should highlight the multiple benefits of agroecological food, linking nutrition, climate action, and social justice. By situating agroecology within broader struggles for equitable and sustainable cities, social movements can help transform urban food systems from the margins to the mainstream.

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Renforcement Des Capacités Pour l'agriculture Biologique et Agroécologique à Tous Les Niveaux (RCABAEN)

Renforcement des capacités pour l'agriculture biologique et agroécologique à tous les niveaux (RCABAEN)
Abdoul SY Nouakchott Mauritanie
Movement for the Equalization of Conditions
Field : Education / Entrepreneurship
Promoting the Local Dimension in
Resource Management
Un argument de taille au passif des politiques de recherche-développement

Les exploitations agricoles familiales constituent 90 % environ des 608 millions d'exploitations mondiale,84 % d'entre elles, ont une superficie de deux hectares maximums donc 12 %du total des terres agricoles, avec une contribution de 35 % à l'approvisionnement alimentaire mondiale.

Leur pratique de gestion des terres a un impact direct sur les écosystèmes. Malheureusement, dans de nombreux pays les petits producteurs souffrent de manque de formation, d'apprentissage et de renforcement des capacités.

Pourtant ce sont les états qui élaborent les politiques de recherche-développement. Sont-ils préoccupés des prévisions qu'aucun d'agenda n'atteindrait les objectifs fixés sans une implication de toutes les parties prenantes ?
Alors la résolution n'est-elle pas l'ascendance verticalo-horizontale du sommet des états sur l'ensemble de ses démembrements et jusqu'aux petits producteurs pour promouvoir le RCABAEN comme une volonté politique résolue afin que le :

- RCABAENcontribue aux objectifs mondiaux pour laconservation durable de la biodiversité avec les communautés et établit de manière durable un vase communicant entre conservation et développement.
- RCABAENprésentela biodiversité comme un atout pour un développement local inclusif, équitable et durable au bénéfice des communautés aux plans économique, social, de l'atténuation et de l'adaptation au changement climatique et de la santé des communautés.
- RCABAENcrée une pondération entre les types d'innovations et des synergies entre les différents niveaux pour " placer la protection de l'environnement au cœur des préoccupations des communautés et de l'ensemble des acteurs au développement ".
- RCABAENpromeut les nouvelles technologies et les connaissances scientifiques et traditionnelles pour permettre la restauration écologique des écosystèmes dégradés et la bioéconomie.

Le nexus (sensibilisation-information-communication) est le premier outildu RCABAEN car de nombreux acteurs potentiels du changement ne profitentpas toujours des avancées techniques dans les systèmes de production. Un bon système de partage permettra de maximiser les effets de synergie et gérer les échanges avec les différents secteurs connexes.

De ce fait une amorce de déconstruire le conventionnellement s'établit et à travers ce qui suit libérer le choix des comportements agricoles durables.

- **La durabilité écologique**

  L'amélioration de la structure et de la fertilité des sols
  La prévention de l'érosion et du compactage des sols
  La promotion de la diversité biologique
  La réalisation de rotations de cultures,
  Le recyclage des nutriments
  L'utilisation des énergies renouvelables,

- **La durabilité sociale**

L'agriculture biologique est une option pour la promotion de la durabilité écologique, économique et sociale. Pendant que leRapport de Synthèse 2021de la FAO attire notre attention de manière synoptique sur l'état des ressources en terres, en sols et en eau dans le monde " des systèmes au bord de la rupture ".

- **La durabilité économique**

L'agriculture biologique (AB) génère 30% d'emplois supplémentaires dans les zones rurales en plus des rendements biologiques élevés et avec une utilisation efficiente des ressources locales.

Les coûts d'exploitation en AB (semences, main-d'œuvre loyers etc…) sont nettement moins élevés en production conventionnelle :

* 50-60% pour les céréales et les légumineuses,
* 20-25% pour les vaches laitières et
* 10-20% pour les produits de l'horticulture.

L'agriculture biologique facilite l'accès aux marchés pour les petits exploitants et favorise donc la génération de revenus parce que la certification en Agriculture Biologique (AB) offre des opportunités aux fermes et entreprises. Les consommateurs souhaitent voir sur le marché des produits bio, sans aucun résidu de synthèse. Ce respect des normes AB permet également d'élargir et de diversifier le réseau de partenaires commerciaux.
Cependant la conversion a la AB correspond à un certain nombre d'exigences comme le facteur temps pour la transition vers une production plus naturelle et durable à la prédisposition des communautés et aux conditions locales et les connaissances et les pratiques des communautés de l'AB. Plus spécifiquement le cas par cas s'imposeen règle de succès pour l'application de l'AB.

De ce point de vuelenexussensibilisation-information-communication de RCABAEN de départdoit aligner un complément plus diversifié d'éléments pourun transfert de savoir et de compétences pour l'adoption de système de production et l'appropriation une série d'éléments des techniques comme

- la gestion durable des terres (GDT). Si on sait que les causes de perte de la biodiversité sont dues aux usages anthropiques de dégradation et de fragmentation des écosystèmes naturels ;
- la gestion durable des sols (GDS). Si on également que les corridors écologiques et les espaces protégées contribuent à la mobilité des espèces et leur offrent la possibilité de s'adapter aux différentes des conditions climatiques et ;
- la gestion intégrée des ressources en eau (GIRE) peut exalter le niveau d'amélioration de l'efficience d'une utilisation durable des ressources, augmenter la productivité et réaliser les progrès attendus des ODD.

On pourrait donc voir le verre à moitié plein et placer l'espoir sur les agriculteurs familiaux pour l'intérêt qu'ils peuvent porter aux approches et pratiques durables. A l'exemple de l'agri-accélérateurs 2.0 avec l'approche IRA CSA en Mauritanie.
C'est inquiétant !
Le marché des produits biologiques et agro-écologique est très peu développé et assez contraignant à côtéde l'existence de divers autres produits de :

- l'agriculture traditionnelle ;
- l'agriculture conventionnelle ;
- l'agriculture durable ;
- de systèmes de production intégrée …

Etant entendu que la lutte contre la dénutrition et de la pauvreté compte parmi les défis les plus pressants denotre époque, ces différents systèmes agricoles et plus globalement le système alimentaire, l'environnement alimentaire, la chaine d'approvisionnement et en constituent la clé de voûte.

Et 98 % des aliments produits proviennent de la terre.

Hélas l'intensification comme modèle d'agriculture dominante soumet de fortes pressionsaux écosystèmes terrestres et aquatiques productifs qui atteignent des niveauxde stressinquiétants.

Au point qu'on en oublied'une part que la sécurité alimentaire pour les générations futures du monde dépend de la protection durable des ressources en terres, en sols et en eau ; et d'autre part on en tort les principes de santé, d'équité et de précaution pour la durabilité.

Malgré tout le temps court, les séances se rapprochent ! 2030 c'est dans moins de 5 ans et 2060 semble trop proche pour passer à la conversion pour réaliser les changements souhaités et les objectifs fixés.

Ironie du sort les approches durables de l'AB ne bénéficient pas d'applicationpratiquedu fait d'une volonté politique mitigée pour leur réalisation générale et collective. Pendant ce temps les effets du changement climatique se manifestent de différentes manières selon la position géographique.

L'état des ressources pédologique et hydrologique sont à leurs extrêmes du fait de leur surexploitation, des mauvaises pratiques, de la dégradation des terres, de la pollution etc…qui remettent en cause l'interdépendance et l'intégrité des écosystèmes. La pratique de l'agriculture non durable produit aussi des externalités sur les autres ressources (terres, sols et eau).

L'Agriculture représente la première cause de déforestation et de dégradation des terres donc elle est intimement liée aux enjeux forestiers. Cette relation entre les deux secteurs permet d'étayer les estimations alarmantes projetées par laFAO:
Qu'à l'horizon 2050 l'agriculture va devoir accroître de près de 50 % le niveau de production d'aliments, de 2012 pour satisfaire la concrétisation de l'objectif Faim zéro en 2030.

Le mouvement de reflux de personnes sous-alimentées est passé de 604 millions de personnes sous-alimentées en 2014 à 768 millions en 2020 ;
Il faudrait selon les mêmes estimations investir encore 265 milliards de dollars supplémentaires par an pour atteindre les deux premiers ODD (dont 140 milliards seraient consacrés à l'agriculture et au développement rural).

La population mondiale devrait atteindre 9,7 milliards de personnes en 2050 et 11,2 milliards en 2100 ;
En 2021, les régions tropicales ont perdu 11,1 millions d'hectares de couverture arborée, dont environ un tiers dans les forêts tropicales ;

Dans la suite de ces estimations les retombées et agressions sur les compartiments environnementaux sont factuelles et des dommages techniquement difficiles à surmonter :

La biodiversité qui est l'un des axes fondamentaux biologique (CDB) des Nations unies concernant les objectifs de conservation à l'horizon 2030.

L'interaction étroite entre changement climatique et érosion de la biodiversité produisent des causes communes et simultanément dans l'ordre des urgences et doivent traiter égalementde manière concomitante et vu sous cet angle, la loi de l'ordre de préséance semble obsolète.

Aucune patience aux usages anthropiques (surexploitation des ressources naturelles, à la pollution et autres …) qui sont à l'origine du changement climatique et malheureusement c'est la biodiversité qui subit cette pression croissante du changement climatique.

Les forêts et les terres constituent un important réservoir de biodiversité terrestre et de régulation du climat un renforcement de capacités des acteurs permettra :

- D'accroitre les rendements agricoles, la production alimentaire, et la disponibilité de nourriture dans le Monde
- D'augmenter l'accès des populations à des cultures plus nutritives,
- De créer des opportunités d'emplois, de revenus, un meilleur accès économique et àla santé.

Le processus est enclenché en Mauritanie, depuis 2023 (PBF, OIT, FAO et TECHKHIL) à travers l'agri-accélérateur 2.0.
L'engagement du CSA mais encore plus de volonté politique !

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The Relevance of Agricultural Extension Services in the Adoption of Organic Agriculturein IjebuNorthLocal Governmentareaof Ogunstate, Nigeria

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Abstract

The global push for sustainable agriculture has brought organic farming to the forefront as an environmentally sound alternative to conventional practices. However, the adoption of organic agriculture remained limited, especially in developing countries, due to a lack of awareness, technical knowledge, and institutional support. This paper examined the critical role of agricultural extension services in facilitating the transition to organic farming. Drawing on theoretical frameworks such as Rogers' Diffusion of Innovation and supported by recent empirical studies, the paper explored how extension services contributed to farmer awareness, skill development, behavioral change, and market integration. Key findings highlighted that well-designed extension approaches, such as participatory learning, field demonstrations, and ICT-based outreach, significantly influenced the adoption of organic practices. However, challenges such as underfunded extension systems, lack of specialized training, and weak policy support hindered effectiveness. The article concluded with strategic recommendations for strengthening extension systems, including capacity building, policy reform, and enhanced farmer engagement, to accelerate the adoption of organic agriculture and promote sustainable rural development.

Keywords: Sustainable Agriculture, Diffusion of innovation, extension systems

Résumé

La dynamique mondiale en faveur d'une agriculture durable a placé l'agriculture biologique au premier plan, comme alternative respectueuse de l'environnement aux pratiques conventionnelles. Cependant, son adoption demeure limitée, notamment dans les pays en développement, faute de sensibilisation, de connaissances techniques et de soutien institutionnel. Cet article examine le rôle crucial des services de vulgarisation agricole dans la transition vers l'agriculture biologique. S'appuyant sur des cadres théoriques tels que la théorie de la diffusion de l'innovation de Rogers et étayé par des études empiriques récentes, il explore comment ces services contribuent à la sensibilisation des agriculteurs, au développement de leurs compétences, à l'évolution de leurs comportements et à leur intégration au marché. Les principaux résultats soulignent l'influence significative de méthodes de vulgarisation bien conçues, comme l'apprentissage participatif, les démonstrations sur le terrain et la communication numérique, sur l'adoption des pratiques biologiques. Toutefois, des obstacles tels que le sous-financement des systèmes de vulgarisation, le manque de formation spécialisée et un soutien politique insuffisant en limitent l'efficacité. L'article conclut par des recommandations stratégiques visant à renforcer les systèmes de vulgarisation, notamment par le renforcement des capacités, la réforme des politiques et une implication accrue des agriculteurs, afin d'accélérer l'adoption de l'agriculture biologique et de promouvoir un développement rural durable.

Mots-clés: Agriculture Durable, Diffusion De L'innovation, Systèmes De Vulgarisation Agricole

Introduction

In response to growing concerns over environmental degradation, soil depletion, pesticide overuse, and climate change, organic agriculture has emerged as a sustainable alternative to conventional farming (FAO, 2020). Organic agriculture promotes biodiversity, enhances soil fertility, and minimizes the use of synthetic chemicals, aligning with global goals for food security and environmental protection (Gliessman, 2015). Despite its benefits, the adoption rate of organic farming remains relatively low, particularly in developing countries (Parrott & Marsden, 2021). One of the most significant barriers to adoption is the lack of awareness, technical know-how, and institutional support among farmers (Alarima, Adamu, & Masunaga, 2020). Transitioning from conventional to organic farming is not merely a change in inputs but a holistic transformation in farming philosophy, management practices, and market orientation (Altieri & Nicholls, 2017). This transformation requires adequate guidance, training, and encouragement functions that fall under the domain of agricultural extension services.

Agricultural extension services serve as the bridge between scientific research and farmers' day-to-day practices (Rogers, 2003). They play a critical role in disseminating information, building skills, encouraging behavioral change, and linking farmers to institutional resources. This paper explores how extension services influence the adoption of organic agriculture and what can be done to improve their impact.

Numerous studies have emphasized the importance of extension services in enhancing agricultural productivity and sustainability (Parrott & Marsden, 2021). According to Rogers' Diffusion of Innovation Theory (2003), adoption of new agricultural practices is a social process influenced by communication channels, time, and the nature of the innovation. In the context of organic farming, where knowledge-intensive and principle-based systems are involved, the role of information and support becomes even more crucial (Altieri & Nicholls, 2017). Research by Alarima et al. (2020) found that farmers who received regular extension support were more likely to adopt organic soil and pest management techniques. Similarly, Altieri and Nicholls (2017) highlighted that training programs and farmer field schools enhanced the capacity of smallholder farmers to embrace agroecological approaches. However, extension systems in many developing countries are underfunded, poorly staffed, and often oriented toward conventional, high-input farming systems (Parrott & Marsden, 2021). The effectiveness of extension services depends not only on content but also on delivery methods, such as participatory learning, ICT tools, peer networks, and demonstration plots (Rogers, 2003). Moreover, the presence of supportive policies and access to certification and markets significantly affect the outcomes of extension-driven adoption of organic farming (FAO, 2020).

GENERAL OBJECTIVE

The general objective was to examine the relevance of agricultural extension services in the adoption of organic agriculture among farmers.

SPECIFIC OBJECTIVES

1. To assess the level of awareness and knowledge of organic agriculture among farmers exposed to extension services.
2. To identify the key extension approaches and methods used to promote organic farming.
3. To evaluate the influence of extension services on farmers' attitudes and decisions to adopt organic methods.
4. To explore the challenges faced by extension agents and farmers in promoting and adopting organic agriculture.
5. To propose strategies to strengthen the effectiveness of extension services in scaling up organic agriculture.

Discussion

EXTENSION SERVICES AS DRIVERS OF ORGANIC AWARENESS

Extension services provide farmers with critical knowledge on organic practices such as composting, green manuring, crop rotation, and biological pest control (Gliessman, 2015). In areas where formal education is limited, extension agents play a central role in transferring research-based knowledge to farmers in simple, applicable ways (Alarima et al., 2020).

BEHAVIORAL INFLUENCE AND TECHNOLOGY ADOPTION

Organic farming adoption depends on more than just awareness; it requires trust, confidence, and behavioral change (Rogers, 2003). Extension agents influence these through continuous engagement, practical demonstrations, and exposure to successful organic farms (Altieri & Nicholls, 2017). Farmers who participate in farmer field schools or peer learning groups often show greater commitment to organic practices (Parrott & Marsden, 2021).

INSTITUTIONAL SUPPORT AND MARKET ACCESS

Extension services also link farmers to organic markets and certification bodies (FAO, 2020). These connections are vital for creating incentives, such as premium prices and export opportunities. In regions with institutional support and well-trained extension staff, farmers are more likely to view organic farming as economically viable (Parrott & Marsden, 2021).

CHALLENGES LIMITING EXTENSION EFFECTIVENESS

Several challenges hinder extension services from effectively promoting organic agriculture:

* Lack of specialized training among extension personnel in organic systems (Alarima et al., 2020)
* Limited financial and logistical support for field-based work (Parrott & Marsden, 2021)
* Farmer skepticism about organic yields and market availability (Altieri & Nicholls, 2017)
* Weak policy frameworks that still prioritize input-intensive agriculture (FAO, 2020)

RECOMMENDATIONS

1. Capacity building: Train extension officers specifically in organic and agroecological practices (Altieri & Nicholls, 2017).
2. Participatory approaches: Encourage farmer-led experimentation and peer learning networks (Rogers, 2003).
3. Policy reform: Align national agricultural policies with sustainability goals, including funding for organic extension (FAO, 2020).
4. Technology integration: Use ICT tools (e.g., SMS alerts, mobile apps, radio programs) to scale organic education (Parrott & Marsden, 2021).
5. Market and certification access: Facilitate group certification and connect farmers with organic markets (FAO, 2020).

CONCLUSION

Agricultural extension services are vital in enabling the adoption of organic agriculture. Their role extends beyond information dissemination they shape farmer attitudes, build technical skills, and connect stakeholders in the agricultural value chain (Rogers, 2003). However, their potential is limited by inadequate training, weak institutional support, and insufficient funding (Parrott & Marsden, 2021).

To ensure a sustainable future for agriculture, investment in robust, farmer-centered, and sustainability-oriented extension systems is critical. Enhancing the capacity and reach of these services can significantly accelerate the transition toward organic farming, especially among smallholder farmers in the Global South (Altieri & Nicholls, 2017; FAO, 2020).

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Restoring resilience using holistic land and livestock management in semi-arid communal farming lands: Case study of Dembe Stream catchment in Zimbabwe

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Abstract

Degraded rangelands and croplands, declining soil fertility, and reduced biodiversity are common challenges in Zimbabwe's semi-arid communal farming areas. These are primarily driven by unsustainable land and livestock management practices. Holistic land and livestock management (HLLM) is an agroecological approach that reverses ecosystemdegradation andbuild community resilience to climate change. However, little empirical research has been conducted to evaluate the contribution of HLLM towards community resilience. This study, therefore. assesses the impact of HLLM on ecological restoration in Ward 10 of Chinyika communal lands in Gutu District of Masvingo Province, Zimbabwe. Since 2019, communities were mobilised by a non-governmental organisation, Participatory Ecological Land Use Management (PELUM),to implement HLLM practices, including the use of mobile night bomas or moving kraals. The aim of adopting HLLM was to improve soil fertility, restore biodiversity, and enhance water retention and availability, particularly in the Dembe Stream catchment and surrounding villages. Using a mixed methods approach, data were gathered through interviews with community members, direct field observations, and participatory assessments of soil fertility, biodiversity, and hydrological changes. Information from community elders highlighted that the Dembe Stream stopped flowing during dry seasons from 1996 to August 2023. However, records from the Meteorological Services Department of Zimbabwe show no significant increase in precipitation in the area. Resultsindicate that following the adoption of HLLM in 2019 and its implementation in December 2020, dry season flows resumed in September 2023, thus restoring the stream's perennial status. HLLM significantly improved soil health, livelihoods, streamflow, social capital, resurgence of biodiversity, ecosystem services, and resilience. The

study concludes that HLLM can effectively restore degraded ecosystems, enhance catchment water availability, support land productivity, and empower communities to sustainably manage their natural resources. This study contributes to the body of knowledge on the importance of using group or ultra-high density grazing towards environmental protection and improving livelihoods andecosystem functionsand services in dry communal farming regions.

Keywords: agroecology, bomas, climate change, holistic planned grazing,Chinyika communal lands.

Résumé

La dégradation des pâturages et des terres cultivées, la baisse de la fertilité des sols et la réduction de la biodiversité constituent des défis communs aux zones agricoles communautaires semi-arides du Zimbabwe. Ces problèmes sont principalement dus à des pratiques de gestion des terres et du bétail non durables. La gestion holistique des terres et du bétail (GHTB) est une approche agroécologique conçue pour inverser la dégradation des écosystèmes et renforcer la résilience des communautés face aux changements climatiques. Cependant, peu de recherches empiriques ont été menées pour évaluer la contribution de la GHTB à la résilience communautaire. Cette étude évalue donc l'impact de la GHTB sur la restauration écologique dans le quartier 10 des terres communautaires de Chinyika, dans le district de Gutu, province de Masvingo, au Zimbabwe. Depuis 2019, les communautés ont été mobilisées par une organisation non gouvernementale, Participatory Ecological Land Use Management (PELUM), pour mettre en œuvre des pratiques de GHTB, notamment l'utilisation de bomas mobiles nocturnes ou d'enclos mobiles. L'objectif de l'adoption de la GHTB était d'améliorer la fertilité des sols, de restaurer la biodiversité et d'améliorer la rétention et la disponibilité de l'eau, en particulier dans le bassin versant du ruisseau Dembe et les villages environnants. Les données ont été recueillies par le biais d'entretiens avec les membres de la communauté, d'observations directes sur le terrain et d'évaluations participatives de la fertilité des sols, de la biodiversité et des changements hydrologiques. Les anciens de la communauté ont indiqué que le ruisseau Dembe s'était asséché pendant la saison sèche de 1996 à août 2023. Or, les relevés du Département des services météorologiques du Zimbabwe ne montrent aucune augmentation significative des précipitations dans la région. Les résultats indiquent qu'après l'adoption du modèle de gestion durable des pâturages (HLLM) en 2019 et sa mise en œuvre en décembre 2020, le débit de la saison sèche a repris en septembre 2023, restaurant ainsi le caractère permanent du ruisseau. Le HLLM a considérablement amélioré la santé des sols, les moyens de subsistance, le débit du ruisseau, le capital social, la biodiversité, les services écosystémiques et la résilience. L'étude conclut que le HLLM peut restaurer efficacement les écosystèmes dégradés, accroître la disponibilité en eau des bassins versants, soutenir la productivité des terres et permettre aux communautés de gérer durablement leurs ressources naturelles. Cette étude contribue à la connaissance de l'importance du pâturage en groupe ou à très haute densité pour la protection de l'environnement, l'amélioration des moyens de subsistance et le maintien des fonctions et services écosystémiques dans les régions agricoles communautaires arides.

Mots-clés: agroécologie, bomas, changementclimatique, pâturageholistiqueplanifié, terrescommunautaires de Chinyika.

Introduction

Almost half of the world's habitable land is used for agriculture, and about a third of the population's livelihoods rely directly on it (Li et al., 2025). Agricultural systems are constantly being improved to adapt to changing food tastes, environmental conditions, ensure food security, and support the livelihoods of growing populations. Resilient farming communities have the capacity to withstand and recover from shocks and stresses, such as global climate change, market fluctuations, local disruptions in livelihoods, ecosystem health, culture, supply of food, deteriorating soil quality, pests, and diseases. While Africa's collective contribution to greenhouse gas (GHG) emissions is less than 5 %,its economic, social, political, and environmental sectors are disproportionately affected by climate change (Fonjong *et al*., 2024). The continent is highly dependent on climate-sensitive sectors like rainfed agriculture, experiences lots of conflicts, has weak socio-economic development, and low adaptive capacity to frequent natural disasters.

Farming systems serve as sources and sinks of greenhouse gases (GHGs). They are critical in climate change mitigation, adaptation, and resilience. Agriculture serves as the second-highest GHG-emitting sector after energy, accounting for 11.7% of global emissions (Sokal and Kachel, 2025). In Zimbabwe, agriculture is also the second largest contributor to GHG emissions after the energy sector. The two sectors produce 45.9% and 37.1% of total GHG emissions in the country, respectively (Sithole *et al*., 2023). Major emitters in this sector include livestock farming and agricultural soils, for example, the emission of methane from manure. Agriculture also contributes to GHG emissions through activities such asland-use change, energy use, deforestation, livestock production, nitrogen fertilizer use, and irrigation.

The toolbox of solutions for addressing agricultural risks involves innovations to improve production, social and economic capacities, strengthen resource management, and build resilience. Some approaches are in the early stages of piloting or are applied at local scales because expertise is maintained by traditional and indigenous knowledge systems (Sokal and Kachel, 2025). Whereas other strategies have been tried and tested, upscaled, and replicated. Climate-smart agriculture (CSA) practices, encompassing both nature and technology-based actions, offer promising solutions to improve productivity and mitigate GHG emissions (Sithole *et al*., 2023).

1.2 Holistic land and livestock management

Holistic land and livestock management (HLLM) is an innovative framework restoring degraded land by employing mobile overnight kraaling and planned grazing (ACHM, 1992; Messner et al., 2025). The use of mobile night kraals or bomas involves keeping cattle overnight in temporary movable kraals placed directly in crop fields. The purpose of night bomas is to deposit livestock excreta, concentrating nutrients and organic matter to naturally fertilise fields,hence improve soil fertility for crops (Nordborg, 2016). This reduces the need for manual labour to transport manure and increases crop yields, resource management, rangeland health, and sustainable livelihoods.

Holistic planned grazing is a key rangeland management practice for land restoration and preventing overgrazing in paddocks. It harnesses the power of its hooves to break down hard ground so that air and water can penetrate. Livestock are kept at the right place, at the right time, with the right behaviour (Nordborg, 2016; Messner et al., 2025). As livestock graze, defecate, stomp, and salivate, they build soil and deepen plant roots.Animal dung and urine help fertilize the soil loosened by hooves (ACHM, 1992; Huruba *et al*., 2022).Farmers develop grazing plans for animals spend specific periods in a paddock before they are moved to another one. Scheduled or timed grazing in

paddocks allows adequate time for plants to recover, regenerate, keeps perennial grasses healthy, minimises the need to burn and expose soil. Short-duration overnight cattle kraaling in natural rangelands creates nutrient hotspots attractive to large mammalian herbivores (Huruba *et al*., 2022). Nevertheless, very few studies have been conducted to determine the importance of holistic land and livestock management as an approach to building resilience in agriculture. This study explores the importance of HLLM in enhancing climate-resilient and sustainable food production in communal areas. Findings help to equip farming communities with practical strategies to strengthen climate-resilient agriculture and learn from real-world success stories. Chinyika communal lands in Zimbabwe were taken as a case study.

2. Materials and methods

2.1 Location and description of study area

Chinyika communal lands lie in a semi-arid region in the southeastern part of Zimbabwe. The main livelihood activity is subsistence crop and livestock production. Farmers grow maize as a staple crop, as well as sorghum, groundnuts, and millet. They also keep cattle, goats, donkeys, sheep, and poultry (Chirinda, 2024). Figure 1 shows the location of Dhembe Stream in ward 10 of Chinyika communal lands.

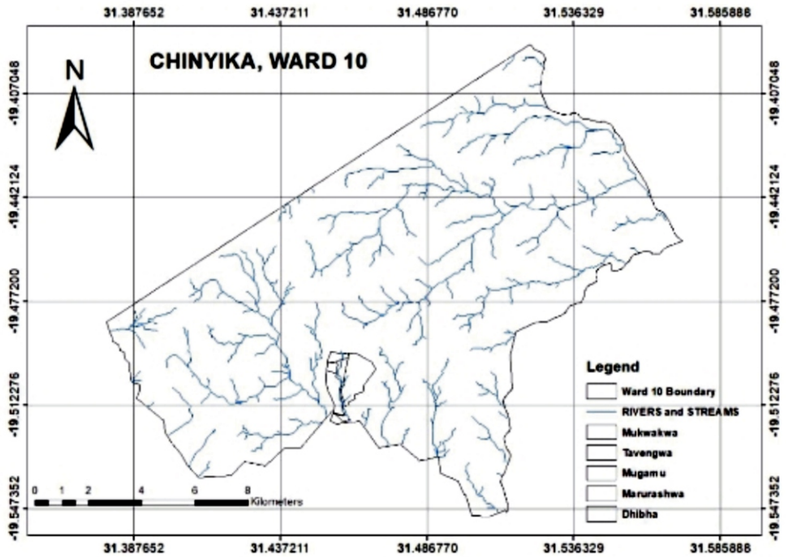

Figure 1. Layout of Dhembe Stream catchment and the 5 paddocks

The mean annual rainfall is 370.76 mm. The wettest month was 1990 while the driest month was 2008. The annual rainfall data series show a slight increasing trend from 1990 to 2023 (Figure 2

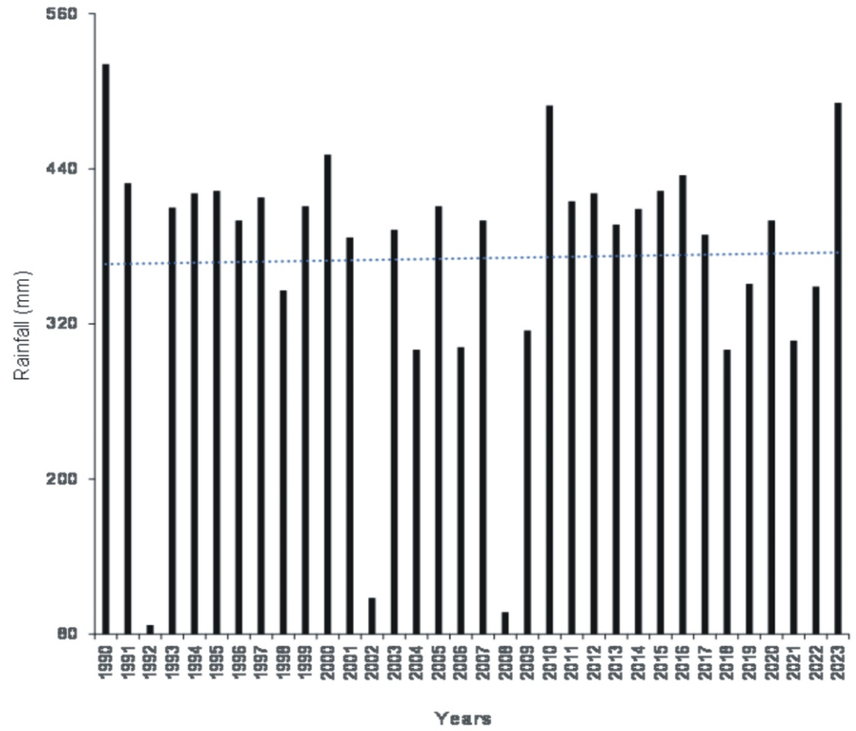

Figure 2: Variation of annual rainfall from 1990 to 2023

2.2 Social mobilisation process

Successful implementation of holistic management of land and livestock in Dembe Stream catchment evolved out of trust relationships and a long history of capacity building and strategic support (Table 1).

Table 1. Timeline of social mobilisation towards the agroecology movement

Timeline	Activity
1990s	Chinyika villagers experienced poor yields due to persistent droughts, hence they relied heavily on food aid and remittances.
1990's-2018	Lack of resilience to droughts or poor rains experienced in the 1990's was attributed to growing small grains, particularly finger millet,andmaize.Revitalisation of small grains movement using the guiding principle: 'Food and economic self-sufficiency'encouraged each family to hold enough finger millet in storage to cater for 3 years.

2018	A small-grains field day was held. A HLLM expert was invite d to attend the event, and relationships were initiated.
2019	The first gathering of the PELUM landscapes regeneration joint learning programme was initiated at the Seed and Food Festival in Harare. A 5-day workshop was held focusing on community mobilization, HLLM, including holistic planned grazing and principles of learning.
2020	First implementation of overnight mobile boma in crop fields during the dry season. First wet season when collective action herding was implemented.
2022	More than 80 cattle from 10 owners were used for night kraaling.The boma was moved to different croplands. Implementation of herding during the day continued in the dry season for 2 consecutive years from 2022.
September 2023	The Dembe Stream started flowing again during the dry season.
July & September 2024	Increase in implementation ofthe wet season grazing plan.
2025	Collapse of implementation of planned grazing during the dry season due to a lack of adequate enforcement to protect boundaries of paddocks.

Source: Survey results

2.3 Collection and analysis of soil samples

Soil samples were collected from a 0-15 cm depth of the soil profile. At this depth, there is the highest concentration of nutrients essential for plant growth. The sampleswere transported in sealed plastic bags and delivered to a laboratory at Fambidzanai Permaculture Centre in Harare for analysis. Soil samples were analysed for pH, organic matter content, and macronutrients including nitrogen (N), phosphorus (P), and potassium (K). Soil pH is an important determinant of nutrient availability, whereas organic matter is vital for soil structure and fertility. The analyses provided baseline data on soil fertility, which is essential for agricultural planning and sustainable land management. The soil data were further subjected to principal componentanalysis (PCA). Percentage differences in soil properties were determined in holistic planned rangelands andcrop fields, and their respective control or unimpacted lands.

2.3 Vegetation assessment

We employed rapid and participatory methods of data collection, utilising the step point method to collect plant species across the rangelands(Evans & Love, 1957; Mentis, 1981). This is a quickmethod to determinefieldconditions. It shows significant merit for long-termvegetation monitoring (Oudtshoorn, 2014). However, the method has been criticised for a lack of accuracy (Biko'o et al., 2025). Nevertheless, for participatory community-based monitoring, the method remains worthwhile. In this case, the method entails walking for 200 steps across an environmental gradient in the rangeland with a walking stick. After every two steps, the species or surface on which the tip of the walking stick landed is recorded. The ecological status of each identified plant species is also described, and relative frequencies are calculated to decipher species composition along the transect.

3. Results

3.1 Variation of grass species in areas under holistic planned grazing and open grazing

In areas under open grazing, five grass species were identified: *Hyparrheniahirta*, *Eragrostiscurvula*, *Eragrostisviscosa*, *Digitaria ciliaris*, and *Cynodon dactylon*. All these are classified as increasers, consistent with their tendency to dominate in overgrazed rangelands. Non-native species accounted for 6.5% of the recorded flora, including *Mimosa pudica, Chamaecristanictitans*, *Digitaria ciliaris*, and *Asperula odorata*, collectively covering 36% of the transect. Although present, these species have not been declared invasive in Zimbabwe. Overall ground cover was classified as 28% grasses, 23% bare ground, and the remainder a mix of woody species, herbs, and forbs with limited grazing value.

In contrast, transects under holistic planned grazing supported eight grass species: *Hyparrheniahirta*, *Eragrostiscurvula*, *Melinisminutiflora*, *Melinis repens*, *Eragrostisviscosa*, *Eragrostiscapillaris*, *Digitaria ciliaris*, *Heteropogoncontortus*, and *Cynodon dactylon*. Grasses covered 39.6% of the transect, with all species classified as increasers except *Heteropogon contortus*, which is palatable when young. Bare ground accounted for only 7.5% of the transect. Non-native species, *Chamaecristanictitans* and *Digitaria ciliaris*, contributed 17% cover. Notably, woody encroachers such as *Terminalia sericea* and *Dichrostachys cinerea* were also present along these transects.

3.2 Influence of holistic land and livestock management on soil fertility

HLLM had a positive effect on soil quality. Crop fields and rangelands under this system exhibit improved soil properties compared to unimpacted sites. In crop fields, pH values were 28% higher under holistic management. NPK, soil organic matter, and soil carbon were elevated by between 106% and 417.7% relative to controls. A similar trend was observed in rangelands: Soils under holistic management showed increases of 22% in pH, 58% in organic matter, 59% in soil organic carbon, 179% in phosphorus, 97% in nitrogen, and 121% in potassium compared to open grazing areas (Figure 3).

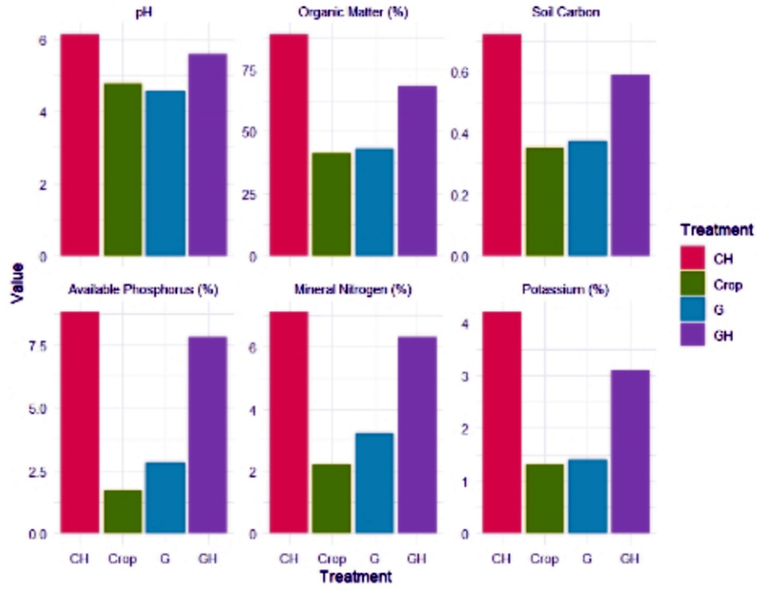

Figure 3. Comparison of selected soil variables on crop fields under holistic management (CH), crop fields with no holistic land management (Crop), and rangelands under holistic planned grazing (GH) and rangelands under open grazing (G)

The first PCA component explained 98.2% of the variation. All soil variables had relatively low loadings of about around 15%. The second PCA component explained 1.5% of variation. N (33%) and P (28%) loaded highly on this component. The PCA biplot (Figure 4) clearly separated treatments, with the left side of the plot comprising open grazing and unimpacted crop fields having relatively lower values of soil variables. The,right-hand side had relatively higher concentrations ofsoil parameters. Grazing under holistic management was largely associated with high N and P, while impacted crop fields were associated with high pH, K, soil carbon, and organic matter.

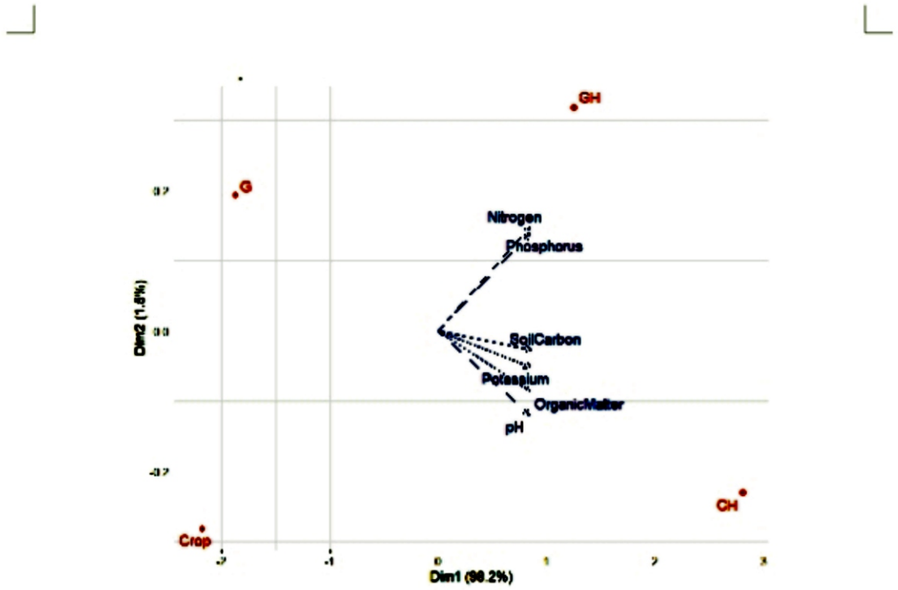

Figure 4: Impact of holistic land management on soil nutrients

3.3 Changes in Dembe streamflows

Key informants indicated that prior to 1996 Dembe Stream flowed perennially into Chinyika River. There were abundant grass and enough water for watering animals and domestic use by riparian households. They also highlighted that during the 1996/1997dry season; the stream was dry.

Community members observed that in September 2023, Dembe Stream started flowing for 500 m into the Chinyika River during the dry season. . This occurred 2 years after implementating the grazing plan. Further upstream, there was a small puddle that remained with water until the end of April 2022. In 2020,the puddle was dry by end of March. In 2025, Dembe Stream continued flowing above ground all year. Since then, it is flooded during wet seasons.

4. Discussion

By implementing HLLM, farmers in Chinyika communal lands increased crop production and improved animal management. They realised environmental benefits, including reduced land degradation in the paddocks. Soil nutrients also improved (Figure 4).Similar findings were reported by Huruba *et al*. (2022), where the community had experienced water problems, degraded land had developed hard surfaces, inadequate grass for livestock, declining crop yields. Livestock herders had to move 15 km to get water. They also camped at water sources for most of the dry season. However, HLLM rejuvenated dry streams, improved water availability, water infiltration, seed germination, animal health, and soil aeration. Most rivers in the area that had ceased to flow started flowing.

ACHM (1992) also observed that planned grazing and the use of bomas improved soil aeration and fertility, crop yields, rangeland management, and sustainable livelihoods. Land degradation was reduced, and pastures were improved in the dry semi-arid regions to the northwest of Zimbabwe.

5. Conclusion

This paper has shown that HLLM employs two approaches, namely, holistic planned grazing and mobile kraaling. The use of livestock regenerates the land, improves ecosystem function and health, and builds plant and wildlife biodiversity. The study highlighted that an increase in the plant density or grass cover enhanced plant diversity, eradication and suppression of invasive species. Timed grazing restored grassland soils to their pristine state, inhibiting conditions that favour native species. This current work contributes to an emerging method of sustainable grazing by addressing some distinct knowledge gaps that link ecological and socio-economic systems.

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Authors' contributions

All co-authors contributed to the writing of this article.

Competing interests

The authors declare that he has no financial or personal relationships that may have inappropriately influenced them in writing this article.

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Effect of Tithonia Compost on Soil Chemical Properties, Growth and Yield of Radish (Raphanus Sativus L.)

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Abstract

The use of compost cannot be overemphasised because of its usefulness in the improvement of physical and biological conditions of soil, which leads to improved crop yield. A pot experiment was conducted in a screen houseat Kwara State University, Malete, Ilorin, Nigeria, to investigate the impact of Tithonia compost on the soil chemical properties, growth, and yield of radish (Raphanus sativus L.).The six treatments comprised a control (zero addition), Tithonia compost at rates of 70, 80, 90, and 100 kg N/ha, and NPK 15-15-15 applied at a rate of 100kg N/ha. The treatments were laid out in a completely randomized design (CRD) with three replicates.The biometric data collected were plant height, number of leaves, stem girth, root weight, and leaf weight. Radish plants grew significantly better (P<0.05) with the application of NPK at 100 kgN/ha, followed by Tithonia compost at 100 kg N/ha. However, Tithonia compost at 100 kgN/ha significantly (P<0.05) improved the yield of Radish by 13% and 59% compared with NPK fertilizer and control, respectively. Tithonia compost at 100 kgN/ha had a significant and additive effect on soil nutrients after harvesting of radish when compared with NPK.
Tithonia compost at 100 kgN/ha could serve as an alternative to mineral fertilizer for the production of radish, with the additional advantage of enhancing post-planting soil nutrient status.

Keywords: Growth, NPK, radish, Tithonia compost, yield

Résumé
L'importance du compost ne saurait être surestimée en raison de son utilité pour l'amélioration des conditions physiques et biologiques du sol, ce qui conduit à une augmentation des rendements agricoles. Une expérience en pots a été menée sous serre à l'Université d'État de Kwara, à Malete, Ilorin, au Nigéria, afin d'étudier l'effet du compost de Tithonia sur les propriétés chimiques du sol, la croissance et le rendement du radis (Raphanus sativus L.). Six traitements ont été appliqués : un témoin (sans apport), du compost de Tithonia à des doses de 70, 80, 90 et 100 kg N/ha, et un engrais NPK 15-15-15 appliqué à la dose de 100 kg N/ha. Les traitements ont été disposés selon un dispositif complètement randomisé (DCR) avec trois répétitions. Les données biométriques recueillies étaient la hauteur des plants, le nombre de feuilles, la circonférence de la tige, le poids des racines et le poids des feuilles. La croissance des radis était significativement meilleure (P<0,05) avec l'application d'engrais NPK à 100 kg N/ha, suivie par celle du compost de Tithonia à 100 kg N/ha. Cependant, le compost de Tithonia à 100 kg N/ha a significativement (P<0,05) amélioré le rendement des radis de 13 % et 59 % par rapport à l'engrais NPK et au témoin, respectivement. Le compost de Tithonia à 100 kg N/ha a eu un effet significatif et additif sur la teneur en éléments nutritifs du sol après la récolte des radis, comparativement à l'engrais NPK.Le compost de Tithonia à 100 kg N/ha pourrait constituer une alternative aux engrais minéraux pour la production de radis, avec l'avantage supplémentaire d'améliorer la teneur en éléments nutritifs du sol après la plantation.

Mots-clés : Croissance, NPK, radis, compost de Tithonia, rendement

Introduction

Radish *(Raphanus sativus L.)* is a root vegetable of the Cruciferae family grown primarily for its tender roots, which are consumed raw in salads or in pickles. Radish boosts hunger, avoids constipation, and has a cooling impact. Patients with jaundice, liver problems, and piles are advised to take it. Fresh leaf juice has laxative and diuretic properties. (Kushwah *et al*., 2019.) With 15-40 mg of vitamin C (ascorbic acid) per 100 g of edible material, radishes are a significant source of nutrients. Aluminum, Barium, Lithium, Manganese, Silicon, Titanium, Fluorine and Iodine are among the trace elements found in radish (up to 18 u g/10 g) (Olowoake *et al*., 2025). It contains mustard oils, which give it pungency (Ahmed *et al*., 2023). The growth and yield of radish depend on soil nutrient conditions, which could be enhanced by fertilization. Fertilization is the process of providing nutrients to plants to enhance growth and development (Lemma and Abewoy, 2021). Organic fertilizers are composed of living and/or organic matter and are natural soil enhancers compared to artificial and synthetic enhancers (Irfan *et al*., 2023). One type of organic fertilizer is compost. Compost is technically obtained by composting, a biological process mediated by different microorganisms, which transform complex compounds from the biomass to simpler molecules through a process of oxidative or enzymatic hydrolysis, characterized by different temperature-determined stages called mesophilic, thermophilic, cooling, and maturation phases, where the entire composting process occurs. (Aguilar-Paredes *et al*., 2023). The final product is a humus-like, stable, dark, and highly nutritious substrate, whose specific composition depends on the origin of the composted waste (Piccolo, and Drosos, 2025)Compost has been shown to increase the availability of essential nutrients in the soil, such as nitrogen, phosphorus, and potassium, and to improve soil structure and water-holding capacity (Hakimi *et al*., 2024). Mexican sunflower biomass is commonly used as green manure, mulch, or compost to improve soil fertility and biology. The potential of *T. diversifolia* as green manure has been confirmed by a few researchers. Kolawole *et al*. (2014) found *T. diversifolia* to be an important source of organic fertilizer in improving crop yield. It is a high-quality organic source of nutrient release and is able to supply nutrients to the plant (Aboyeji *et al*., 2019). The leaves of Mexican sunflower *(Tithonia diversifolia)* are a potential organic material for composting (Aboyeji, 2022). Biomass of this plant contains both macro nutrients and micro nutrients, such as nitrogen, phosphorus, potassium, calcium, magnesium, zinc, iron, manganese, copper, and boron that are beneficial for plant growth and development (Sparta *et al*., 2025). However, there is a dearth of information on the application rate of Tithonia compost to soil that would improve growth performance and root yield of radish in the Southern Guinea Savannah zone of Nigeria. Therefore, the objective of this study is to investigate the effect of different rates of Tithonia compost on soil chemical properties, growth and yield of radish.

Materials and Methods

The experiment was carried out in the screen house of the Faculty of Agriculture, Kwara State University, in the Southern Guinean Savannah of Nigeria. Pit composting method was used to compost the Tithonia (plant biomass was chopped into pieces, layered, and mixed with poultry manure). The compost used for this study was prepared by the pit method (Olowoake and Adeoye, 2012). The chemical constituents of the organic materials used for the compost are shown in Table 1.

Table 1. Chemical composition of Tithonia and Poultry manure used for Compost Production

Treatment	Nutrient		
	Nitrogen (%)	Phosphorus (%)	Potassium(%)
Tithonia plant	0.22	0.17	0.28
Poultry manure	1.14	0.41	2.09

Soil samples were randomly taken from selected field areasat 0 to 15 cm depth using soil auger before the study. The samples were bulked to form a composite sample from which a representative sample was collected, air-dried, and crushed. The soil samples were sieved through 2 mm and 0.5 mm wire mesh. The soil particle size, pH (H2O), Organic carbon, total N, available phosphorus (P), Potassium (K), Magnesium (Mg), Calcium (Ca), Iron (Fe), and Zinc (Zn) were determined by the method as described by (Okaleboet al.,1993).Eighteen pots were each filled with 4.5kg of soil. The treatments used were control, Tithonia compost at 70, 80, 90, 100 kgN/ha, and NPK at 100 kg N/ha. The treatments were arranged in a completely randomized design (CRD) with three replicates. Radish seeds were sown in the pot at 4 seeds per pot and later thinned to 2 plants/stand. Watering and weeding were carried out throughout the experimental period. Post-planting soil analysis of the experimental soil used in the screen house was also carried out after harvest to determine the residual nutrient status of the soil. At 8weeks after planting, data were collected on growth and yield parameters, which include plant height, number of leaves/plants, stem girth, radish yield/pot, and leaves fresh weight. Data collected were subjected to Analysis of variance (ANOVA) using Statistical Analysis System (SAS) at 5 % level of significance. The means were separated using Duncan's Multiple Range Test (DMRT).

Results and Discussion

Physical and chemical properties of soil

Table 2 shows the physical and chemical properties of the soil used for the screenhouse study. The textural class of the soil is loamy sand; the soil had a pH (H2O) of 5.4, which could be described as moderately acidic, low in total Nitrogen (N) and Organic Carbon (OC), although it was observed to be rich in available Phosphorus (P).Hence, the soil requires fertilizers to adequately support plant growth and development.

The available phosphorus of 17.64 mg/kg was higher than the critical level of 10-16mg/kg (Adeoye and Agboola, 1985; Olowoake et al., 2024). The total nitrogen was 1.12g/kg, indicating that it was lower than the critical level, which ranges from 0.01 to 1.20 g/kg (Bremmer, 1982). The K status of the soil, which was 0.13 cmol/kg, was lower than the critical level of 0.2 cmol /kg (Adeoye, 1986). Exchangeable magnesium values of 0.86 cmol/kg were higher than the critical level of 0.20 - 0.40 cmol/kg-1 (Adeoye and Agboola, 1985). Calcium value of 2.25 cmol/kg was below the critical level of 2.6 cmol/kg (Agboola and Corey 1972, Olowoake et al., 2024). These findings indicate that the soil could be poor in nutrient supply except for P. Furthermore, this points out that the application of soil amendments may enhance the growth and yield parameters of radish.

Table 2: Physical and Chemical properties of Experimental soils

Parameters	Value
pH (H_2O)	5.4
O.C. (g/kg)	0.16
N (g/kg)	1.1
Av.P (mg/kg)	18
Exchangeable bases(cmol/kg)	
K	0.1
Na	0.2
Ca	2.3
Mg	0.9

Extractable micronutrients(mg/kg)	
Fe	106
Cu	1
Zn	2
Mn	85
Particle size (g/kg)	
Sand	790.0
Silt	120.0
Clay	90.0
Textural class	Loamy sand

Effect of different rates of Tithonia compost and NPK fertilizers on the growth and yield parameters of radish

Table 3 shows the effect of fertilizer types on growth and yield parameters of radish. The application of NPK at 100 kg N/ha produced the highest growth parameters the high values of radish height, number of leaves, and stem girth in the pot treated with NPK over Tithonia compost might be as a result of its quicker release of N, P, and K, which are the major nutrients required by crop for vegetative growth, seed and root development. This observation is in line with the findings of Olowoake (2014) that mineral fertilizers release nutrients to the soil faster than compost. Similar findings were reported by Zahir *et al*. (2006),who observed that the application of NPK for the cultivation of radish had the maximum increase in vegetative growth. Also, Lalrindiki *et al*. (2022) reported that inorganic N fertilizers are associated with moisture accumulation and luxuriant growth of plants, as generally observed from vegetative parameters.

The values of radish plant height, stem girth, and number of leaves were observed to be low in the pot without any fertilizer treatment when compared to tithonia compost and NPK fertilizer treatments, respectively. This might be as a result of low nutrient status of the soil, especially N (Olowoake, 2017). The tithonia compost at 100 kgN/ha enhanced radish root yield compared to NPK. This is in line with the report of Jeptoo *et al*. (2013)that tithonia compost increased the root yield of carrot. Similarly,, tithonia compost at 100 kgN/ha produced the highest weight leaves when compared to NPK this is in line with the work of Aboyeji *et al*., (2019) who reported that higher fresh weight of Tithonia leaves could be attributed to taller plants and more number of leaves produced making the plants to trap more sunlight for the process of photosynthesis and transporting the assimilates to the roots. Alvarez *et al*. (2023) reported that organic fertilizers have been shown to impact higher biomass accumulation (dry weight) in plants, improving quality.

Treatment	Rate kgN/ha	Plant height (cm)	Number of leaves/plant	Stem girth (mm)	Root yield weight (g/pot)	Leaf weight (g/pot)

Control	0	11.8d	7.2e	5.25c	56.3d	18.0e
TC	70	12.9d	8.7d	6.28b	71.8c	25.0d
TC	80	14.9d	10.1c	6.28b	82.3c	30.7c
TC	90	25.9c	10.5c	6. 31b	83.6c	41.3c
TC	100	34.0b	13.1b	6.71b	138.8a	72.6 a
NPK	100	35.7a	14.2a	7.85a	120.6b	60.5b

Table 3: Effect of fertilizer types on the growth and yield parameters of Radish

Means having the same letter along the columns indicate no significant difference using

Duncan Multiple Range Test at 5% probability level. Legend: TC- Tithonia compost

Table 4 shows the results of fertilizer application on some soil chemical and physical properties after harvest. The increase in the soil pH level of the pots after harvest from radish cropping is an indication of the buffering capacity of the treatment applied (Olowoake, 2022). This enhanced the availability of the applied nutrients released from compost, resulting in increased crop growth and yield. The available nutrient contents (N, P, and K) in Tithonia compost after harvest increased more than those of NPK fertilizer or control pots. This finding corroborates the work of Olowoake and Adeoye (2013), who found that compost increases soil pH and Org C, N, P, and K. Akinyele *et al*. (2012) opined that organic fertilizers show greater capacity than inorganic fertilizers in retaining nutrients in forms that can easily be taken by plants over a longer period. Adequate residual N was not observed in the pot fertilized with NPK, because much of the nitrogen from the inorganic fertilizer could have been lost in addition to plant uptake by other pathways (e.g., denitrification, ammonia volatilization, and leaching (Govindasamy *et al*., 2023).

The amount of Organic Carbon reduced in the control and NPK-treated plots, which is in agreement with Olowoake (2023), who reported that the use of inorganic fertilizers has not been helpful under intensive agriculture because it is often associated with soil degradation brought about by loss of nutrients due to its unsustainable utilization by crops and leaching. Compost, apart from releasing nutrient elements to the soil, has also been shown to improve other soil chemical and physical properties, which enhance crop growth and development (Olowoake and Adeoye, 2012).

Table 4. Effects of fertilizer types on some soil chemical and physical properties post- harvest

Treatment	Rate (kgN/ha	pH (H_2O)	Organic carbon (g/kg)	Total N (g/kg)	Available P (mg/kg)	K (cmol/kg)	Sand	Silt	Clay
							_____(g/kg)_____		
Control	0	5.5b	0.72c	0.08b	18.7d	0.23c	80b	9b	11a
TC	70	6.4a	0.82c	0.10b	19.7cd	0.28bc	79b	12a	9b
TC	80	6.1a	0.99c	0.10b	20.1c	0.32b	79b	10b	11a
TC	90	6.3a	1.22b	0.14a	20.8c	0.34b	80b	10b	10a
TC	100	6.7a	1.80a	0.17a	40.4a	0.49a	80b	11a	9b
NPK	100	5.6b	1.19b	0.15a	22.3b	0.37b	82a	11a	7b

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level. Legend: TC- Tithonia compost

Conclusion and Recommendation: This study showed that NPK fertilizer at 100 kg N/ha gave the best vegetative growth of radish. However, the Tithonia compost at 100 kg N/ha performed better on yield parameters than NPK. This shows that Tithonia compost could be a very attractive alternative fertilizer to mineral fertilizer because it has the potential to supply nutrients to plants by enhancing the soil's physical and chemical qualities compared to mineral fertilizer.

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Impact of Agricultural Technologies in Strenghtening Organic Farming among Youth Farmers in Southwestern Nigeria

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Abstract

This study examined the impact of agricultural technologies in strengthening organic farming among youth farmers in southwestern Nigeria. The study employed a descriptive survey design. A multi-stage sampling technique was employed to select 1,440 youth farmers who leveraged agricultural technologies from Ogun, Oyo, Ondo, and Ekiti States were purposively selected based on their predominance in organic food production. Data was analysed using descriptive statistics, t-test, and Probit regression. The results showed that most of the youth farmers were male (75.8%), married (83.5%), had an education (70.6%), had access to extension services (62.4%), technology usage (67.9%), and cooperative membership (85.4%). The t-test result showed a significant difference in the income of the youth farmers before and after the usage of agricultural technologies. Probit regression results revealed that technology usage ($\beta = 0.891$, $p < 0.01$), access to training ($\beta = 0.989$, $p < 0.01$), and farm size ($\beta = 1.724$, $p < 0.01$) significantly impacted organic food production in the study area. Conversely, the high cost of technology ($\beta = -1.621$, $p < 0.01$) and poor access to credit ($\beta = -1.392$, $p < 0.01$) remained barriers to adoption and usage of agricultural technologies. It is concluded that youth farmers with education, training, and credit facilities experienced higher income in the study area. The study, therefore, recommended that the usage of tractor-coupled implements, solar pumping machines, and access to credit facilities with supportive government policies may encourage massive youth participation in organic farming in southwestern Nigeria.

Keywords: agricultural technologies, organic farming, youth farmers

Résumé

Cette étude a examiné l'impact des technologies agricoles sur le renforcement de l'agriculture biologique chez les jeunes agriculteurs du sud-ouest du Nigéria. L'étude a utilisé une enquête descriptive. Un échantillonnage à plusieurs degrés a permis de sélectionner 1 440 jeunes agriculteurs des États d'Ogun, d'Oyo, d'Ondo et d'Ekiti, sélectionnés de manière ciblée en raison de leur prédominance dans la production d'aliments biologiques. Les données ont été analysées à l'aide de statistiques descriptives, du test t et d'une régression Probit. Les résultats ont montré que la plupart des jeunes agriculteurs étaient des hommes (75,8 %), mariés (83,5 %), instruits (70,6 %), avaient accès aux services de vulgarisation agricole (62,4 %), utilisaient des technologies (67,9 %) et étaient membres d'une coopérative (85,4 %). Le test t a révélé une différence significative dans les revenus des jeunes agriculteurs avant et après l'utilisation des technologies agricoles. Les résultats de la régression probit ont révélé que l'utilisation des technologies ($\beta = 0,891$, $p < 0,01$), l'accès à la formation ($\beta = 0,989$, $p < 0,01$) et la taille de l'exploitation ($\beta = 1,724$, $p < 0,01$) ont un impact significatif sur la production d'aliments biologiques dans la zone d'étude. À l'inverse, le coût élevé des technologies ($\beta = -1,621$, $p < 0,01$) et le faible accès au crédit ($\beta = -1,392$, $p < 0,01$) demeurent des freins à l'adoption et à l'utilisation des technologies agricoles. Il en ressort que les jeunes agriculteurs bénéficiant d'une éducation, d'une formation et d'un accès au crédit ont perçu des revenus plus élevés dans la zone d'étude. L'étude recommande donc que l'utilisation d'outils

agricoles attelés aux tracteurs, de pompes solaires et l'accès au crédit, associés à des politiques gouvernementales favorables, puissent encourager une participation massive des jeunes à l'agriculture biologique dans le sud-ouest du Nigéria.

Mots-clés : Technologies Agricoles, Agriculture Biologique, Jeunes Agriculteurs

Introduction

Agricultural technology, also known as agtech or agritech, refers to the application of scientific and engineering principles to improve agricultural practices. It encompasses a broad range of tools, techniques, and innovations designed to enhance crop and livestock production, increase efficiency, and promote sustainability in farming (Afolabi & Osei, 2024). It includes the use of modern machinery such as tractors, combines, harvesters, and other equipment designed for efficient planting, harvesting, and processing of crops. It can also be a combination of precision farming technologies such as drones, GPS systems, sensors, and data analytics to optimize resource use (water, fertilizer, pesticides) and improve crop yields (Ogboru, 2025). It can be the use of information and communication technology (ICT) such as mobile devices, software, and cloud-based platforms for farm management, market access, and information sharing as well as renewable energy technologies like implementing solar, wind, and other renewable energy sources to power farms and reduce reliance on fossil fuels to meet the growing global demand for food by optimizing yields and efficiency and minimizing water usage, reducing fertilizer and pesticide application, and promoting soil health as well as reducing costs, increasing productivity, and improving market access for farmers (Adeolu *et al*., 2025). Digital technologies in agricultural production refer to the use of electronic devices, software, and networks to optimize farming practices, increase efficiency, and improve crop yield (Ghazi *et al*., 2021). This includes tools such as drones, sensors, and smart farming applications that collect and analyse data to inform decision-making processes.

The agricultural sector remains a central pillar of Nigeria's economy, employing nearly 70 % of the population and contributing 22.35 % to the country's Gross Domestic Product (GDP) in 2021 (Adeoti *et al*., 2021). Agricultural technologies and digital tools, including mobile applications, precision agriculture, and blockchain technology, have been recognized for their potential to transform agricultural practices, leading to improved yields, resource management, and market access to farmers all over the world, including in Southwestern Nigeria (Ogboru, 2025). These technologies can significantly reduce labour costs and improve efficiency. The integration of digital technologies in agriculture, as buttressed by Oluwasemilore and Oluwasola (2021) facilitates information dissemination, empowering farmers with timely data on weather conditions, pest management, and market prices. Furthermore, mobile apps have been developed to connect farmers to agronomists and experts, fostering knowledge exchange and improving farming techniques (Ihenacho *et al*., 2021).

Despite the sector's importance for economic growth, poverty reduction, and national food supply, food insecurity remains widespread and persistent (Ogunniyi *et al*., 2022). The vulnerability of smallholders is compounded by their dependence on rain-fed agriculture, poor access to inputs and credit, and weak post-harvest infrastructure (Eze *et al*., 2021). Moreover, the lack of effective agricultural technologies and digital devices leads to lower food production and high post-harvest losses, reducing both farmer income and food availability (Adeolu *et al*., 2025). The Ogun State, with its fertile soil and favourable climate, has immense potential for agricultural growth, but farmers in the region face numerous challenges, including limited access to information, inadequate financial services, poor market linkages, climate change, and low agricultural productivity, among others (Ogunniyi *et al*., 2022). The low agricultural production in the region could be due to the current practice among farmers in the region. Most farmers rely heavily on traditional farming systems, which have impacted negatively on their farm output. This situation calls for targeted interventions that address the barriers to digital technology adoption and embrace comprehensive approaches to enhance the effective utilisation of digital technologies by farmers in the region (Adeoti *et al*., 2021). Understanding these imbalances between organic food production and rapid population growth will provide insights into how agricultural technologies can be leveraged to strengthen organic farming among youth farmers in southwestern Nigeria.

Methodology

The study was carried out in the southwestern geopolitical zone of Nigeria. The Southwestern zone lies between latitudes 50N and 90N, with an area of 114,271 square kilometres representing 12% of the country's total land mass. The zone has four distinct sub-ecologies, namely: swamp, mangrove forest, moist and dry lowland forest, and derived savannah. The zone comprises Oyo, Ogun, Osun, Ondo, Ekiti, and Lagos states (Adeoye & Ademolu, 2022; Ogun State Diary, 2025). A descriptive research design of survey type was adopted for this study in the form of a well-structured

questionnaire, and oral interviews were used to elicit information from the respondents. The reliability of the instrument was determined using the Cronbach alpha reliability test, which yielded a reliability coefficient of 0.87%. A multi-stage sampling technique was used to select 1,440 youth farmers in organic farming. Data were analysed using descriptive statistics such as frequency counts; percentages, mean, and standard deviation were used to describe the socio-economic characteristics of respondents. A t-test was used to determine the differences in the organic output and income of the youth farmers before and after the usage of agricultural technologies. Probit Regression was used to determine the socio-economic parameters of the respondents. Model Specification: Probit regression equation: Socio-economic parameters

$$P(Y=1/\chi) = Q(\chi\beta)$$

Y = Binary outcome; β = Vector of coefficient ; Q = Cumulative distribution function

For this study $Y_1 = f(\chi_i)$

$Y_1 = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}$ and $X_{16})$

The model's specification is as follows:

$$\beta 0, \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 \; _5X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{16} X_{16}$$

Where Y = (yes = 1; no = 0)

X_1 = Years of Age, X_2 = Sex (where Female = 0 and Male = 1),

X_3 = Education (if educated = 1, Otherwise = 0), X_4= Farm size (The number of hectares)

X_5 = Household size (The number of household members)

X_6 = Farming experience (The number of years spent farming)

X_7 = Seasonal income (Total amount of income per household after technology usage)

X_8 = Membership of cooperative (if yes = 1, no = 0), X_9 = Access to extension services (if yes = 1, no = 0)

X_{10} = Seasonal output (Total kilograms of harvest per household after technology usage)

X_{11} = Access to free training (if yes = 1, no = 0)

X_{12} = Number of technologies used (The number of technologies used)

X_{13} = Types of technology used (The type of technologies used)

X_{14} = Cost of technology (if expensive = 1, Otherwise = 0)

X_{15} = Access to credit (if yes = 1, no = 0)

X_{16} = Type of organic farming (The type of organic farming)

β_0 is the intercept

$\beta_1 - \beta_{16}$ Are the coefficients to be estimated

Note: If Y is the dependent variable, it means all the socio-economic parameters ($X_1 - X_{16}$) are the independent variables.

Results and Discussion

Socio-economic characteristics of the arable youth farmers in the study area

Table 1: Socio-economic characteristics of the youth farmers

Variables	Frequency	Percentage	Mean	SD
Age (years)			35.5	6.9
20 - 29	72	5.0		
30 - 39	528	36.7		
40	840	58.3		
Sex				
Male	1092	75.8		
Female	348	24.2		
Marital Status				
Single	198	13.8		
Married	1203	83.5		
Divorced	39	2.7		
Education				
No Formal	424	29.4		
Formal	1016	70.6		
Household size (persons)			5	2
1 - 3	198	13.8		
4 - 6	615	42.7		
> 6	627	43.5		
Farming experience (years)			8	4
0 - 5	99	6.9		
6 - 10	750	52.1		
> 10	591	41.0		
Types of organic farming				
Arable Crops	775	53.8		
Fruits/Vegetables	312	21.7		
Spices	353	24.5		
Farm size (hectares)				
<1 hectare	186	12.9		
1-2 hectares	310	21.5		
3 - 4 hectares	678	47.1		
>4 hectares	266	18.5		
Sources of capital				
Personal savings	9	0.6		
Loan from Cooperative	1197	83.1		
Government grant	6	0.4		
Bank loan	3	0.2		
Group contribution (Esusu)	162	11.3		
Salary	63	4.4		
Seasonal output (Kg) Before			5,986	1,231
1,000 – 5,000	613	42.6		
5,001 – 10,000	559	38.8		
10,001 – 15,000	208	14.4		
15,001 & above	60	4.2		
Seasonal output (Kg) After			14,331	4,010
1,000 – 5,000	102	7.1		
5,001 – 10,000	300	20.8		
Seasonal income (N) Before			N 956,921.00	N255,236.01
0 - 1,000,000	945	65.7		
1,000,000 - 1,500,000	303	21.0		
1,500,000 - 2,000,000	190	13.2		
>2,000,001	2	0.1		
Seasonal income (N) After			N1,911,340.22	N594,710.22
0 - 1,000,000	103	7.2		
1,000,000 - 1,500,000	318	22.1		
1,500,000 - 2,000,000	667	46.3		
>2,000,001	352	24.4		
Membership of a cooperative				
Yes	1230	85.4		
No	210	14.6		
Access to extension services				
Yes	899	62.4		
No	541	37.6		
Access to free training				
Yes	1023	71.0		
No	417	29.0		

Number of technologies used			5	2
1 - 3 technologies	159	11.0		
4 - 6 technologies	603	41.9		
>6 technologies	678	47.1		

Source: Field Survey, 2025

Table 1 shows that the majority (75.8%) of the arable youth farmers were male, while 24.2% were female. This implies that both male and female youth farmers leveraged agricultural technologies to grow organic food in the study area. The majority (83.5%) were married, 70.6% had formal education, 53.8% were into arable farming, 83.1% sourced capital through loans from the cooperative, 85.4% were members of the cooperative, 62.4% had access to extension services, and 71.0% had access to free training, while 47.1% used more than 6 agricultural technologies on their farms. This aligns with the findings of Hashmiu *et al*. (2022), who found that married individuals often demonstrate increased responsibility towards adopting sustainable agricultural practices to secure family livelihoods. Cooperative membership and credit access play a pivotal role in promoting innovation adoption due to access to resources, training, and knowledge sharing in food production (Afolabi & Osei, 2024). The mean and standard deviations of respondents' age were 37.5±9.9 years, households size 5±2 people, farming experience 8±4 years, seasonal output before the use of agricultural technologies 5,986±1,231kg and 14,331±4,010kg after the use of agricultural technologies, seasonal income before the use of agricultural technologies N956,921.00±N255,236.01, seasonal income after the use of agricultural technologies N1,911,340.22±N594,710.22 and number of technology used were 5±2 technologies respectively. Similar findings were reported by Akinrotimi *et al*. (2022), who emphasized that educational attainment, household size, and income significantly facilitate the uptake of innovative technologies by enhancing understanding, awareness, and practical implementation capacity. Previous studies, including those by Adeolu *et al*. (2025), highlight that farm size and access to credits can significantly impact the adoption of resource-intensive technologies due to scalability issues. This supports the findings of Akinrotimi *et al*. (2022), who reported that the adoption of digital devices in agricultural services significantly influences the marketability of perishable farm produce through sales platforms, online markets, and online orders.

Types of Agricultural Technologies used in organic farming

Table 2: Distribution of respondents on the types of agricultural technologies used

Technologies	Frequency	Percentage
Hardware Technologies		
Tractor-mounted implements	57	4.0
Disc plough and harrow	56	3.9
Nursery trays	227	15.8
Drip irrigation kits	160	11.1
Solar water pumping machines	103	7.2
Solar CCTV Cameras/bulbs	38	2.6
Digital weighing scale	250	17.4
Manure kits/trays	138	9.6
Greenhouses	100	6.9
Software Technologies		
e-Agroshops/marketing	30	2.1
e-Extension services/innovations	41	2.8
e-Updates on organic farming	43	3.0
e-Weather forecast updates	51	3.5
e-Banking apps	146	10.1

Source: Field survey, 2025 Note: Yes (1), No (0)

Table 2 clearly identifies the types of agricultural technologies adopted and used by youth farmers in organic farming in the study area were digital weighing scale (17.4%), nursery trays (15.8%), drip irrigation kits (11.1%), e-Banking apps (10.1%), manure kits/trays (9.6%), solar water pumping machines (7.2%), greenhouses (6.9%), tractor-coupled implements (4.0%), disc plough and harrow (3.9%), e-Weather forecast (3.5%), e-Updates on organic farming (3.0%), e-Extension services/innovations (2.8%) and solar cctv cameras/bulbs (2.6%) while e-Agroshops/marketing (2.1%). This implies the respondents used one or two types of agricultural technologies for organic food production. These results support the findings of Adeyongo *et al*. (2022) on the adoption of agricultural innovations among farmers in the Federal Capital Territory, Nigeria. Adopting different types of agricultural technologies by farmers, like digital extension services, can provide farmers with instant access to agricultural advice, prices, and weather forecasts, which will ultimately enhance their agricultural production (Afolabi and Osei, 2024).

Impact of Agricultural Technologies on Organic Farming

Table 3: Mean rating of the responses of respondents on the impact of agricultural technologies on organic farming among youth farmers in the study area

Items	Mean	SD
Technologies help to increase organic efficiency, productivity, and	4.0	1.1
sustainability	3.9	1.0
Digital devices help in data-driven decision-making in organic farming	3.8	1.0
Blockchain technologies enhance the organic food supply and higher yields	3.6	0.9
Technologies increase farmers' income and improve their livelihood	3.4	0.9
Technologies create employment opportunities for youths in organic farming	3.0	0.9
Technologies create market opportunities for organic produce and products	2.8	0.8
They improve access to innovative market information through platforms	2.8	0.7
Mobile extension and advisory services are provided to farmers in rural areas	2.7	0.7
They connect buyers and sellers to reduce post- harvest losses of organic	2.6	0.7
produce	2.6	0.7
They enable organic farmers to adopt climate-smart agricultural practices	2.6	0.7
Enhancing food supply chain transparency and traceability through blockchain	2.5	0.7
Leveraging AI and machine learning to predict pest outbreaks and controls	2.5	0.5
Offering virtual training programmes for farmers on the best organic practices	2.5	0.5
Creating online platforms for farmers to share knowledge and experiences	2.5	0.5
Using online markets to connect farmers with consumers and reduce	4.5	0.8
middlemen		
Digital soil mapping technologies to analyse soil health for better crop yield		
Grand mean		

Source: Field survey, 2025. Note: Strongly Agree (4), Agree (3), Disagree (2) and Strongly Disagree (1). Mean cut-off point = 2.5

Table 3 showed that the sixteen (16) items had means ($\bar{x}$) that ranged from 2.15 to 3.99, which is above the cut-off point of 2.5, with youth farmers obtaining a grand mean of 4.45 and a standard deviation of 0.78. This implies that all the respondents were not far from the mean and from one another in their responses. These results agree with the findings of Eze *et al*. (2021), who emphasized the role of blockchain technology in enhancing agricultural supply chains in Nigeria. These results corroborate the findings of Oyediran & Tijani (2021) on the role of digital technologies in promoting food and nutrition security in Nigeria. It is also in tune with the findings of Gupta & Rajput (2021) on mobile applications for farmers to access weather and market updates.

Challenges Limiting the Adoption and Usage of Agricultural Technologies in Organic Farming

Table 4: Mean Ranking of the responses of respondents on the challenges limiting the usage of agricultural technologies for strengthening organic farming in the study area

Challenges	Mean	SD	Rank
High cost of agricultural technologies	2.9	0.7	1st
Poor access to credit facilities	2.9	0.7	2nd
Resistant to change/adoption	2.9	0.6	3rd
High cost of digital devices	2.8	0.6	4th
Limited access to the internet for information	2.7	0.5	5th
Limited access to free trainings	2.6	0.5	6th
Lack of technical know-how	2.5	0.5	7th
Lack of equity for loans	1.9	0.5	8th
Lack of awareness	1.8	0.4	9th
Inadequate research support	1.7	0.4	10th
Limited market access	1.6	0.4	11th
Poor extension services	1.6	0.4	12th
High cost of organic produce/products	1.6	0.4	13th
Unstable electricity	1.6	0.3	14th

Source: Field survey, 2025. Note: Severe (2), Mild (1), and not a challenge (0) Mean = 1.5

Table 4 identifies substantial challenges limiting the adoption and usage of agricultural technologies for strengthening organic farming among youth farmers in the study area. High cost of technologies (1st), poor access to credit facilities (2nd), resistance to change/adoption (3rd), and high cost of digital devices (4th) were ranked as they emerged as major impediments. These findings agree with earlier studies of Johnson & Williams (2022), which emphasized that the financial burden of digital technologies in smallholder agriculture significantly hinders technology adoption and usage. Furthermore, limited access to the internet for information (5th), limited access to training (6th), and lack of technical know-how (7th) are also notable challenges. These factors negatively impact the practical feasibility of adopting and using advanced agricultural technologies and leveraging digital solutions among arable youth farmers, as supported by recent findings from Ogboru (2025).

Testing of Hypotheses

Hypothesis One

There is no significant difference in the seasonal output of the youth farmers before and after the use of agricultural technologies in the study area.

Table 5: T-test Analysis on the seasonal output of the youth farmers before and after the usage of agricultural technologies in the study area

Variables	t value	p value	Decision
Organic output before Organic output after	9.10	0.01	Significant

Source: Field Survey, 2025 Significant at $p<0.05$

Results in Table 5 revealed that there is a significant difference in the seasonal output of the youth farmers before and after the usage of agricultural technologies in the study area ($t = 9.10$; $p<0.05$). This finding supports the findings of Eze & Okeke (2023) that the combination of agricultural technologies, indigenous knowledge, and community participation in the sustainable management of organic farming produce and products in southwestern Nigeria significantly contributed to their farm harvest.

Hypothesis Two

There is no significant difference in the seasonal income of the youth farmers before and after the usage of agricultural technologies in the study area.

Table 6: T-test Analysis on the seasonal income of the youth farmers before and after the usage of agricultural technologies in the study area

Variables	t value	p value	Decision
Seasonal income before Seasonal income after	11.24	0.03	Significant
Source: Field Survey, 2025	Significant at $p<0.05$		

Results in Table 6 showed that there is a significant difference in the seasonal income of the youth farmers before and after the usage of agricultural technologies in the study area ($t = 11.24$; $p<0.05$). This finding agrees with the findings of Adebayo et al. (2024), who found that the adoption of agricultural technologies increases farmers' output and income in arable food production.

Table 7: Probit regression analysis on the impact of agricultural technologies for strengthening organic farming among youth farmers in the study area

Variables	Coefficient (β)	Std Error	Z Statistics	P-value
Age	0.514**	0.712	1.29	0.050
Sex	0.593**	0.363	1.60	0.050
Education	1.410***	0.954	1.41	0.001
Farm size (hectares)	1.724	0.621	2.78	0.012
Household size	1.216	0.978	1.05	0.020
Farming experience (years)	0.341	0.792	1.24	0.000
Seasonal income (after)	0.710***	0.694	1.02	0.001
Membership of a cooperative	1.121	0.651	1.72	0.010
Access to extension services	0.744	0.366	2.03	0.000
Seasonal output (after)	1.190***	0.389	3.06	0.001
Access to free training	0.989***	0.361	2.74	0.001
Number of technologies used	0.834***	0.227	3.67	0.001
Types of technologies used	0.891***	0.329	2.71	0.001
Cost of technology	-1.621***	0.167	-3.72	0.001
Access to credit	-1.392***	0.191	-2.37	0.001
Types of organic farming	1.620***	0.538	3.01	0.001
Constant	-2.994	0.839	-3.57	0.001
Log-likelihood	-49.93			

LR chi^2 (16)	60.96
Prob > chi^2	0.0000
Number of observations	1440
Pseudo R^2	0.640
Correctly Predicted Cases (%)	90.7%

Source: Field Survey, 2025 **Significant at ***1%, **5%**

The probit regression results (Table 7) clearly established that technology usage ((β = 0.891, p < 0.01), education ((β = 1.410, p < 0.01), farm size ((β = 1.724, p < 0.01), access to free training ((β = 0.989, p < 0.01), number of technologies used ((β = 0. 834, p < 0.01), types of technologies used ((β = 0.891, p < 0.01) and income ((β = 0.710, p < 0.01) positively impacted the likelihood of agricultural technologies for strengthening organic farming among youth farmers in the study area. This finding corroborates the findings of Ogboru (2025), who discovered that farmers' socio-economic characteristics and extension agents can use digital technologies to enhance agricultural production in southwestern Nigeria. This finding also supports the findings of Hashmiu *et al*. (2022), who concluded that cash crops and food security can be encouraged by massive arable production, which is achievable by promoting digital solutions and green agriculture in Ogun State. Afolabi & Osei (2024) found that predictive tools and smart farming technologies boost cassava production in Nigeria. The negative correlation between high cost of technology ((β = 0.621, p < 0.01), poor access to credit ((β = -1.392, p < 0.01) indicates barriers to usage of agricultural technologies, a phenomenon similarly reported by Ogunniyi *et al*. (2022). Conversely, age ((β = 0.921, p < 0.05) and sex ((β = 0.582, p < 0.05) significantly bolster adoption and usage of agricultural technologies, reinforcing the critical role age and gender play in supporting technological advancements, as found by Peterson & James (2021). This aligns with observations by Eze *et al.* (2021), who highlight younger farmers' propensity towards innovation and technology adoption in organic food production. R2 was 0.64, which means that 64% level of the variation in the impact of agricultural technologies for strengthening organic farming among youth farmers in southwestern Nigeria.

Conclusion

This study concludes that leveraging agricultural technologies has positively impacted and strengthened organic farming among youth farmers in southwestern Nigeria. Youth farmers with education, access to free training, credit facilities, manageable household size, and access to agricultural technologies had increasing income and improved crop yields, while the high cost of technologies, poor access to credit, resistance to adoption/change, limited access to the internet, and lack of technical know-how remained major challenges.

Recommendations

Based on the findings, the study recommended the following:

1. Farmers leveraging on agricultural technologies like tractor-coupled implements, solar pumping machines, nursery trays, drip irrigation kits, manure kits/trays, and access to credit facilities with supportive government policies should be put in place to encourage massive youth participation in organic farming.

2. Farmers should explore alternative funding options such as cooperative savings schemes, partnerships with private investors, and reinvesting profits into technology upgrades instead of relying solely on government credit facilities.

3. There is a need for extension services to be strengthened to support the youth farmers with the necessary training on technology usage.

4. There is a need to strengthen organic farming among youth farmers in southwestern Nigeria; free training programmes on new agricultural technologies and take-off grants should be regularly organized for youth farmers to arouse their interest in organic farming and bolster organic food production across Nigeria.

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Assessing knowledge, Attitudes, and practices of poultry producers and consumers for designing an agroecological certification system in Benin

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Abstract
The agroecological transition involves the adoption of sustainable and resilient practices that break with conventional methods, requiring a shift in values towards environmentally friendly agriculture that promotes biodiversity. This study aims to define organic certification criteria that meet the needs of poultry breeders and consumers in southern Benin, in a context where certification systems remain insufficiently developed to support this transition. Key barriers include institutional challenges such as the absence of locally adapted certification standards reflecting smallholder farming realities, weak regulatory frameworks, high certification costs, inadequate farmer training programs , a shortage of qualified local inspectors and certification bodies, and low awareness among producers and consumers about the benefits and requirements of agroecological certification. The study was conducted among 78 breeders selected through purposive sampling, and 100 consumers chosenusing stratified and simple random method in six communes of Benin: Glazoué, Agbangnizou, Abomey, Abomey-Calavi, Ouidah, and Tori Bossito. Data collected via questionnaire on Kobo Toolbox were analyzed using descriptive statistics, chi-square tests, and analysis of variance. Knowledge, Attitude, Practice (KAP) analysis reveals complex dynamics. Producers exhibitbasic certification knowledge (score 3.11) and a positive attitude (2.05), yet implementation remains a zero practice score(score 0), mainlydue to economic and technical constraints. Although consumer interest in certified products is increasing a persistent gap between purchase intention and actual behavior, driven by high prices, limited availability, and information deficits. These findings highlight that the effectiveness of an agroecological certification system depends on adapting standards to local realities, strenghtening producers training in agroecological practices, and implementing supportive public policies to overcome economic and technical barriers.

Keywords: Agroecological Certification, Poultry Farming, Sustainable Transition.?

Résumé
La transition agroécologique implique l'adoption de pratiques durables et résilientes qui rompent avec les méthodes conventionnelles, nécessitant une évolution des valeurs vers une agriculture respectueuse de l'environnement et favorisant la biodiversité. Cette étude vise à définir les critères de certification biologique répondant aux besoins des éleveurs et des consommateurs de produits avicoles du sud du Bénin, dans un contexte où les systèmes de certification restent insuffisamment développés pour accompagner cette transition. Parmi les principaux obstacles figurent des défis institutionnels tels que l'absence de normes de certification adaptées localement et reflétant les réalités des petites exploitations, des cadres réglementaires insuffisants, des coûts de certification élevés, des programmes de formation inadéquats pour les agriculteurs, une pénurie d'inspecteurs et d'organismes de certification locaux qualifiés, ainsi qu'une faible sensibilisation des producteurs et des consommateurs aux avantages et aux exigences de la certification agroécologique. L'étude a été menée auprès de 78 éleveurs sélectionnés par échantillonnage raisonné et de 100 consommateurs sélectionnés par échantillonnage aléatoire stratifié et simple dans six communes du Bénin : Glazoué, Agbangnizou, Abomey, Abomey-Calavi, Ouidah et Tori Bossito. Les données recueillies par questionnaire sur KoboToolbox ont été analysées à l'aide de statistiques descriptives, du test du $?^2$ et de l'analyse de variance. L'analyse des connaissances, attitudes et pratiques (CAP) révèle une dynamique complexe. Les producteurs possèdent des connaissances de base en matière de certification (score de 3,11) et une attitude positive (2,05), mais la mise en œuvre reste nulle (score de 0), principalement en raison de contraintes économiques et techniques. Certes, l'intérêt des consommateurs pour les produits certifiés est croissant; cependant, un écart persiste entre l'intention d'achat et le comportement réel, attribué aux prix élevés, à la disponibilité limitée et au manque d'information. Ces résultats soulignent que l'efficacité d'un système de certification agroécologique nécessite l'adaptation des normes aux réalités locales, la formation des producteurs aux pratiques agroécologiques et la mise en œuvre de politiques publiques incitatives pour lever les obstacles économiques et techniques.

Mots-clés: Certification Agroécologique, Élevage De Volailles, Transition Durable.

Introduction

The livestock sector plays a central role in Benin's economy, contributing 13.7% to the national Gross Domestic Product (GDP) in 2022 (DSA, 2023). Beyond its considerable economic weight, this sector is essential for ensuring food security and constitutes a fundamental pillar of rural development. Specifically, livestock farming provides animal protein to a growing population while simultaneously generating income for millions of rural and peri-urban households.
However, the significant environmental impacts of livestock farming-whether practiced extensively or intensively-have made a transition towards more sustainable production systems strategically necessary for Benin. Over recent decades, livestock systems in the country have undergone profound structural changes, marked by progressive intensification aimed at meeting rising demand for animal products. Although this intensification has contributed to higher production and improved meat availability, it has unfortunately exacerbated environmental degradation. Consequently, accelerated deforestation in livestock zones, alarming erosion of local biodiversity (Djaouga *et al*., 2021), and contamination of water and soil resources by livestock effluents and veterinary residues (Djagba *et al*., 2019) have become increasingly evident. This growing tension between production imperatives and ecological preservation underscores the urgent need to reassess currently dominant agricultural models and explore more sustainable alternatives.

In this context, agroecology emerges as a promising pathway to reconcile production with sustainability. Defined as a holistic approach that improves agricultural systems by harnessing natural processes while minimizing synthetic inputs (Wezel *et al*., 2020; Tittonell, 2020), agroecology provides both a conceptual and practical framework for economically viable and environmentally sound livestock production. Specifically, it builds on key ecological principles, including diversification of production systems, nutrient recycling, maximization of biological synergies, and valorization of local resources. Nevertheless, despite its strong potential, the development of an agroecological poultry sector in Benin remains severely constrained by a major structural gap: the absence of an organic certification system adapted to local realities and the specific characteristics of Beninese production systems. Indeed, as highlighted by Boko *et al*. (2015) and Pougoué *et al*. (2019), the available infrastructure, prevailing farming practices, and level of technical support provided to farmers remain far below international standards required for formal organic certification. Consequently, this lack of an appropriate certification system prevents commercial valorization of products derived from sustainable practices, undermines consumer confidence in agroecologically labeled products, and reveals a profound disconnect between producers' intentions and capacities on the one hand, and consumers' perceptions, expectations, and purchasing behaviors on the other. Therefore, this study seeks to contribute to establishing standards for a poultry certification system that is technically feasible, economically accessible, and culturally appropriate in the Beninese context. From a theoretical perspective, the analysis is anchored in two complementary conceptual frameworks. First, the functional typology approach is employed to characterize the diversity of poultry farming systems by identifying homogeneous groups of farms that share similar features and practices. This approach moves beyond a monolithic view of farming by recognizing the plurality of technical trajectories and productive rationales. Second, the Knowledge, Attitude, Practice (KAP) model, widely used in behavioral change studies, serves as a framework for systematically assessing producers' and consumers' perceptions and behaviors regarding agroecological certification. This model assumes that knowledge influences attitudes, which in turn shape practices, while acknowledging that this relationship is not always linear and can be mediated by various contextual factors.

1. Methodology

A mixed-methods design was adopted (Creswell & Plano Clark, 2018) to capture the complexity of perceptions, attitudes, and practices of poultry stakeholders regarding agroecological certification. The study was conducted in three agricultural development poles in Benin (4, 5, and 7), covering central, southern, and southwestern departments. These zones were selected because they concentrate poultry farms, represent dynamic areas of agroecological transition, and display socio-ecological heterogeneity, making them broadly representative of national poultry production (Yin, 2018).

Regarding sampling strategy, purposive sampling (Patton, 2015) was used for producers, identifying 78 individuals actively engaged in, or interested in, agroecological practices based on criteria including the use of local feed, reduced stocking density, limited synthetic inputs, and free-range management. For consumers, stratified random sampling yielded 100 respondents across six communes, stratified by location (urban, peri-urban, rural), education, and socio-professional category. Data collection was conducted through structured interviews using a pre-tested questionnaire digitized via Kobo Collect, with trained enumerators collecting data following ethical standards. Producer data included inputs, housing type, flock composition, space per animal, and sanitary practices, along with knowledge, attitudes, and practices on certification, while consumer data addressed knowledge (labels, benefits), attitudes (willingness to pay), and behaviors (purchasing habits, barriers). For data analysis, descriptive statistics summarized socio-demographic profiles, practices, and perceptions, while Chi-square and ANOVA tested associations and group differences using STATA and SPSS. Furthermore, Knowledge, Attitude, and Practice (KAP) scores were constructed to assess certification knowledge, attitudes, and reported practices, with correlation analyses (Pearson's test) examining interrelationships. Finally, qualitative responses were coded thematically, and triangulation of qualitative and quantitative results enhanced validity.

2. Results

3.1. Socio-demographic characteristics of respondents

The analysis of the socio-demographic characteristics of surveyed consumers reveals several significant trends that contribute to a better understanding of poultry product buyers' profiles in the study areas. Regarding gender distribution, results show that 66% of surveyed men regularly consume poultry products, compared to only 36% of women. This statistically significant difference highlights a marked trend: men are more frequent consumers of poultry products than women in the Beninese context. This disparity may be linked to socio-cultural factors, particularly the traditional role of men as main decision-makers in meat purchases, as well as differences in dietary preferences and consumption habits between genders.

Educational level also emerges as a key determinant of poultry consumption. A majority of respondents (61%) hold a university degree, and this group reports the highest consumption rates. Conversely, individuals without formal education or with only primary schooling consume poultry products less frequently. This positive correlation between education and consumption likely reflects several mechanisms: higher purchasing power, greater sensitivity to nutritional quality and food safety issues, and better knowledge of the benefits of animal protein.
Furthermore, a Chi-square test reveals a statistically significant association (10% threshold) between education level and prior awareness of poultry product certification. This suggests that both exposure to information on certification and the ability to understand its implications are positively influenced by educational attainment - an important consideration for awareness and communication strategies.

The literacy rate among surveyed consumers is high, reaching 87%, while the illiteracy rate remains relatively low at 9%. A minority (4%) report being able to read without having completed formal education, indicating some heterogeneity in literacy levels. From an ethnic perspective, the Fon and Lopka groups represent the largest proportions of respondents (28% and 27%, respectively), reflecting the demographic composition of the study areas and underscoring the importance of considering cultural specificities when designing promotion strategies for certified products.

3.2. Characterization of agroecological-oriented livestock systems

An in-depth analysis of breeding practices implemented by surveyed producers highlights distinctive features of agroecological-oriented systems, confirming the initial hypothesis of substantial diversity within the Beninese poultry sector. This diversity is expressed through technical and organizational dimensions that clearly differentiate agroecological systems from conventional intensive ones.

In terms of feeding, agroecological systems are characterized by higher feed consumption per bird, likely due to longer rearing periods and slower growth rates. Importantly, these systems rely almost exclusively on farm-compounded feed prepared from local raw materials (cereals, by-products, fodder), whereas conventional systems depend heavily on complete industrial feed or commercial concentrates. This feed autonomy both reduces reliance on external inputs and

valorizes local resources, but also presents challenges for certification, as feed composition and nutritional quality vary considerably across farms.

Regarding space management, agroecological systems operate at significantly lower stocking densities than conventional ones. Birds benefit from more space, reducing stress and fostering natural behaviors (scratching, dust bathing, perching) while improving sanitary conditions by lowering infectious pressure. Such practices align with the principles of agroecology and organic farming, which place animal welfare at the forefront.
Sanitary management also differs. In the event of mortality, burial is the predominant method in agroecological systems, whereas conventional farms may use incineration or external disposal services. Burial reflects an integrated waste management approach where carcasses are recycled into the soil-plant-animal system, consistent with the circularity principles of agroecology.

Finally, housing structures also diverge. Agroecological systems favor free-range or semi-open buildings, contrasting with the closed, climate-controlled structures typical of intensive farms. These allow regular outdoor access, natural light, and expression of foraging behaviors, promoting animal welfare despite certain biosecurity challenges. Such practices align closely with international organic farming standards.

3.3. Knowledge, Attitude, and Practice of producers

The analysis of Knowledge, Attitude, and Practice (KAP) scores among poultry producers reveals a critical gap between declared intentions and actual implementation of agroecological certification. This "intention-action gap," widely documented in behavioral change literature, constitutes a major obstacle to certification uptake in the Beninese poultry sector.

Table 1: Producers' KAP analysis result

Dimension	Mean score	Minimum	Maximum	Std. dev.
Knowledge score	3.11	1	4	0.85
Attitude score	2.05	0	3	0.42
Practice score	0	0	0	0

The knowledge dimension reveals strong foundational awareness, with an average score of 3.11±0.85 out of 4 points. This indicates that most farmers possess a substantive understanding of certification benefits and core requirements. The standard deviation of 0.85 suggests moderate variability, with scores ranging from 1 to 4. Producers scoring at the upper end of the scale demonstrated a comprehensive understanding of certification as a quality assurance mechanism, recognized its potential for market differentiation and premium pricing, and could articulate specific requirements such as restrictions on synthetic inputs, animal welfare standards, and traceability protocols. Those with lower scores possessed only basic awareness without detailed knowledge of practical implications.

The attitude dimension reinforces positive dispositions, with a mean score of 2.05±0.42 out of 3 points. Producers view certification as relevant, potentially advantageous for both individual farms and the broader sector, and aligned with sustainable agriculture values. The low standard deviation indicates considerable consensus, suggesting widely shared positive perceptions. Qualitative data reveal this favorable attitude stems from multiple perceived benefits: enhanced market access, product differentiation, alignment with environmental stewardship values, potential premium pricing, and contribution to consumer trust in local products. Critically, statistical analysis reveals a significant positive correlation between knowledge and attitude at the 1% threshold. This empirically confirms that greater knowledge fosters more positive attitudes toward certification. Producers with a deeper grasp of certification concepts consistently demonstrate more favorable evaluations of certification's relevance and desirability. This finding underscores the pivotal role of training and information dissemination in cultivating receptivity to certification processes.

However, despite this favorable combination, the practice dimension reveals complete implementation failure, with zero score for all respondents. This unanimous null score represents a stark disconnect between what producers know and believe versus what they actually do. Not a single producer has initiated certification steps despite expressed interest, pointing to powerful structural barriers preventing behavioral translation.

Qualitative analysis identifies several interrelated obstacles. First, economic constraints dominate, particularly high upfront and recurring certification costs, including inspection fees, annual renewals, infrastructure adaptation costs, and potential transitional productivity losses. For smallholders with limited capital and thin margins, these represent prohibitive barriers without financial support mechanisms. Second, technical constraints compound economic challenges. Producers lack specialized support to navigate complex certification requirements. Reliance on farm-compounded feeds, while agroecologically sound, creates standardization challenges since composition varies across farms, complicating nutritional documentation required by certification protocols. Many producers also lack necessary record-keeping systems and traceability mechanisms. Third, weak organizational capacity limits collective certification strategies that could reduce individual costs. Absence of strong cooperatives prevents resource pooling and economies of scale. Fourth, market uncertainties discourage investment. Producers perceive unclear market channels, uncertain price premiums, and absent guaranteed off take arrangements. Without assured market access, certification appears as a risky investment with uncertain returns.

These barriers create a "lock-in" situation where favorable dispositions cannot overcome structural constraints. This highlights that agricultural behavioral change requires not merely knowledge and attitudes, but enabling conditions, including financial support, technical assistance, organizational infrastructure, and functioning markets.

3.4 Knowledge, Attitude, and Practice of Consumers

While producers demonstrate a clear intention-action gap driven by structural barriers, the consumer perspective reveals an equally paradoxical but fundamentally different dynamic that challenges assumptions about the relationship between knowledge and purchasing behavior regarding certified products.

Table 2: Consumers' KAP analysis result

Dimension	Mean score	Minimum	Maximum	Std. dev.
Knowledge score	2.81	2	4	0.48
Attitude score	1.00	0	2	0.40
Practice score	2.18	1	3	0.94

The average knowledge score of 2.81±0.48 out of 4 indicates moderate awareness. Consumers possess basic familiarity - recognizing certification's general quality assurance purpose - but lack a comprehensive understanding of specific standards or verification procedures. The narrow range (minimum 2, maximum 4) and small standard deviation indicate fairly homogeneous knowledge levels. Qualitative responses reveal moderate-knowledge consumers typically recognize labels and understand certification implies quality guarantees, but cannot explain specific required practices or verification methods.

The attitude dimension shows a neutral to slightly positive disposition (1.00±0.40), notably more tepid than producers' enthusiasm. This lukewarm attitude may reflect limited personal experience with certified products, uncertainty about tangible benefits justifying price premiums, skepticism about certification credibility in weak regulatory contexts, or that certification is not salient relative to other purchase criteria like price, freshness, or convenience.

Interestingly, practice scores are relatively high (2.18±0.94), suggesting favorable purchasing behaviors despite moderate knowledge and neutral attitudes. The large standard deviation indicates substantial heterogeneity, with some actively seeking certified products while others rarely purchase them. This pattern could reflect social desirability bias, confusion between certification and other quality attributes, or genuine purchasing driven by factors beyond explicit attitudes.

However, the most striking finding emerges from cross-tabulation analysis across knowledge levels. Among consumers with moderate knowledge (scores 2-3), attitudes and practices are remarkably favorable, with adherence reaching 100%. This suggests basic awareness creates a strong appeal, consistent with assumptions that information promotes adoption.

Paradoxically, this enthusiasm collapses among consumers with deeper knowledge (score 4), where support plummets to merely 8%, representing more than a tenfold decline. This precipitous drop suggests that deeper knowledge paradoxically functions as a deterrent rather than an enabler.

Despite this non-linear relationship, overall KAP correlations remain positive and significant at 1% threshold across the full sample, confirming dimensions are interrelated though more complexly than linear models suggest.
Several mechanisms may explain why deeper knowledge reduces support. First, comprehensive knowledge exposes certification system complexity-multiple competing labels, technical standards variations, and potential green washing-generating confusion or skepticism about genuine quality guarantees. Second, informed consumers become acutely aware of substantial price premiums, leading to cost-benefit calculations deeming premiums unjustified given budget constraints or perceived marginal improvements. Third, deeper knowledge reveals gaps in enforcement, limited inspection frequency, or insufficiently rigorous standards, eroding trust in certification as a credible quality signal. Fourth, highly knowledgeable consumers may develop alternative quality assessment strategies based on direct producer relationships or informal reputation systems, rendering formal certification redundant.

This paradox carries profound implications for certification system design. Simply providing more information may backfire if it reveals complexity, undermining trust. An effective certification system must prioritize simplicity, transparency, and credibility. Labels must be comprehensible without extensive technical knowledge. Criteria must be clearly communicated and genuinely enforced. Pricing must balance quality with affordability. The certification system must build trust through transparent governance, rigorous verification, and accountability.

Consumer expectations reinforce these conclusions. Respondents emphasize clear, accessible information without overwhelming jargon, transparent labeling enabling quick product identification, and fair pricing reflecting quality without excluding price-sensitive consumers. These articulated needs align with the interpretation that complexity, opacity, and affordability barriers explain the paradoxical decline among knowledgeable consumers, underscoring the imperative for a user-friendly, accessible certification system alongside technical rigor.

Discussion

The findings highlight both opportunities and significant constraints for implementing agroecological certification in poultry farming in Benin, revealing complex dynamics that warrant careful interpretation. First and foremost, the study reveals a high diversity of poultry production systems, with a clear and encouraging trend toward agroecological practices. The distinctions observed between systems-particularly in terms of feed autonomy, stocking density, and sanitary management-are consistent with the work of Honvou *et al*. (2022), which demonstrated the heterogeneity of livestock systems in Benin. More broadly, this transition toward more sustainable practices reflects the global movement described by Tittonell (2020), who emphasizes the urgent need to move away from the intensive agriculture paradigm to build more resilient and ecologically sound systems. However, while this diversity represents a potential foundation for certification, it simultaneously poses challenges for standardization, a tension that must be carefully navigated.

Turning to the producer perspective, a critical paradox emerges. Despite possessing favorable attitudes and solid foundational knowledge about certification, producers show no concrete implementation whatsoever (null practice score). This substantial gap between intention and action is largely explained by economic and technical constraints that create insurmountable barriers to entry. Specifically, the observed reliance on farm-compounded feed illustrates both a strength and a significant challenge: on one hand, it valorizes local resources and reduces dependency on external inputs, aligning with agroecological principles; on the other hand, it complicates the standardization process, which is a key prerequisite for formal certification systems. Furthermore, the variability in feed composition across farms makes it difficult to establish uniform nutritional standards and quality benchmarks. These structural obstacles corroborate the findings of Boko *et al*. (2015) and Pougoué *et al*. (2019), who identified similar constraints-including inadequate infrastructure, insufficient technical support, and prohibitive certification costs-as major impediments to the development of organic poultry farming in Benin. Consequently, without targeted policy interventions and financial support mechanisms, the translation of positive attitudes into concrete practices remains highly unlikely.

On the consumer side, the results reveal an equally striking and counterintuitive paradox. While moderate knowledge strongly favors adherence to certified products, with adherence rates reaching 100%, more in-depth knowledge

paradoxically reduces support sharply to a mere 8%. This unexpected phenomenon, which contradicts the common assumption that more information leads to greater adoption, is akin to the "intention-action gap" theorized by Marsden (2013). Several mechanisms may explain this reversal. First, deeper knowledge may reveal the complexity of certification systems, potentially creating skepticism about their reliability or relevance. Second, better-informed consumers may become more acutely aware of the price premium associated with certified products, leading to affordability concerns that override their initial enthusiasm. Third, increased knowledge may expose perceived gaps in the credibility or transparency of certification labels, eroding trust. This finding aligns closely with Magrini *et al*., (2019), who argue that information alone is insufficient to drive behavior change if not accompanied by tangible accessibility, affordable pricing, and institutional credibility. Therefore, certification systems must prioritize not only awareness-raising but also trust-building and economic accessibility to prevent knowledge from becoming a barrier rather than an enabler.

Finally, the collective results underscore the absolute necessity of designing a participatory, locally adapted, and context-specific certification system. The dramatic decline in consumer support when knowledge deepens underscores the critical importance of transparent, simple labeling that avoids technical jargon, alongside accessible pricing strategies that do not exclude middle- and lower-income consumers. Moreover, producers' need for technical training, financial support, and collective organization mechanisms must be addressed systemically. This holistic approach confirms the arguments advanced by Salliou and Barnaud (2017) and Duru *et al*. (2015), who advocate for integrated approaches that combine farmer capacity-building, consumer education, supportive public policies, and systemic changes in both production practices and societal values. In essence, certification cannot be reduced to a mere technical standard; it must function as a comprehensive development tool that simultaneously strengthens producer capacities, builds consumer trust through simplicity and transparency, and receives robust backing from enabling policies. Only under these conditions can certification serve as an effective lever for agroecological transition in Benin's poultry sector..

3. Conclusion

This study shows that while agroecology holds strong potential for transforming Benin's poultry sector, its adoption remains hindered by significant structural and economic barriers. Producers display good knowledge and favorable attitudes but lack the means to implement certification, while consumers express interest yet are discouraged by complexity, price, and trust issues when more deeply informed. Certification alone cannot drive the transition; it must be participatory, adapted to local realities, and supported by training, collective organization, transparent labeling, affordability measures, and enabling public policies to foster resilient and sustainable poultry systems.

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Front Yard Vegetable Garden -A Great Starter for Organic Farming-

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Abstract
We have tried to promote and extend organics as well as organic stakeholders in Shizukuishi Town, Japan since getting IFOAM Recognized PGS Initiative in 2018. However, our activities have failed. This is due to the low organic awareness of consumers as well as local government people. Therefore, it requires a lifelong education/instruction about organics to everyone in our society. While in residential area in Japan, it is popular to grow flowers and vegetables in the garden. This is a good place to start organic farming by converting it into a small vegetable garden. They can start it at any time economically and grow safe and secure produce. The estimated organic land area of front yard vegetable garden in Japan is around 59,674 ha- 119,348 ha which is 3.2-6.3 times larger than JAS certified organic land area of 18,837 ha. The same approach could be applicable in African nations to promote and extend organic farming.

Keywords: Organic farming, increasing organic stakeholders' population, Front Yard Vegetable Garden

JARDIN POTAGER DE PRÉCINQUETTE
- UN EXCELLENT POINT DE DÉPART POUR L'AGRICULTURE BIOLOGIQUE -

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Résumé
Nous avons essayé de promouvoir et de développer l'agriculture biologique ainsi que les acteurs du secteur biologique dans la ville de Shizukuishi, au Japon, depuis que nous avons obtenu la reconnaissance de l'IFOAM en tant qu'initiative SPG en 2018. Cependant, nos activités ont échoué.
Cela s'explique par la faible sensibilisation des consommateurs et des représentants des autorités locales à l'agriculture biologique. Il est donc nécessaire de sensibiliser l'ensemble de la société à l'agriculture biologique tout au long de la vie. Au Japon, il est courant de cultiver des fleurs et des légumes dans le jardin devant sa maison. C'est un bon point de départ pour se lancer dans l'agriculture biologique en transformant ce jardin en petit potager. Il est possible de se lancer à tout moment sans investissement important et de cultiver des produits sûrs et sains.
La superficie estimée des potagers biologiques dans les jardins de devant au Japon est d'environ 59,674 ha à119,348 ha, soit 3.2 à 6.3 fois plus que la superficie certifiée biologique par le JAS, qui est de 18,837 ha. La même approche pourrait être appliquée dans les pays africains pour développer l'agriculture biologique.

Mots-clés: agriculture biologique, augmentation du nombre d'acteurs du secteur biologique, potager dans le jardin de devant

Introduction

The Organic land share in the world is 2.1%, in Japan it is 0.4% (FibL, 2025).
There are several programs in the world to promote organic farming:
- EU: Green Deal [Farm to Fork] (EU, 2019) organic land share: 25% to be completed by 2030

- US: Organic Transition Initiative, United States Department of Agriculture (USDA, 2022)
- Japan: Strategy for Sustainable Green Food Systems, Ministry of Agriculture, Forestry & Fishery (MAFF) (MAFF, 2021) copy of Green Deal, organic land share: 25% to be completed by 2050. We are twenty years behind EU countries.

These programs follow the three major elements of IFOAM ORGANIC 3.0 which are conversion, sustainability and inclusiveness (IFOAM 2020). The programs depend on the strong leadership of the central as well as local governments. However, even though the governments have been trying to accelerate organic farming in this country, it has been difficult to increase the number of organic stakeholders. In any case, we must make our best efforts to discover practical and effective alternatives to start organic farming with the people, by the people and for the people around the world. This article proposes Front Yard Vegetable Garden (FYVG) as one of the solutions to these problems.

MATERIALS AND METHODS

Background

In 2021, the MAFF in Japan announced the Strategy for Sustainable Green Food Systems. One of the programs, called the "Organic Village (OV) Declaration" by local governments can go ahead if its application to the MAFF has been accepted, then the local governments can get subsidies from the MAFF (MAFF 2022).

Although the Organic Shizukuishi IFOAM Recognized PGS Initiative (IRPI) has done a wide variety of PGS activities, local people's organic awareness is still low (Organic, 2022). Therefore, we need dedicated support from the local government to help promote organic farming. But our local governments have no interest in sending the OV application documents to the MAFF.

Organic farming in Shizukuishi Town

The situations of organic farming in Shizukuishi Town are as follows.

(1) General public: Low awareness of organic produce.
(2) Local government people: Busy helping conventional farmers in the district due to the high price of chemical fertilizers.
(3) Veteran conventional farmers: No interest in organic farming because they have already been making a living.
(4) Declining number of conventional farmers from 3,199 in 1990 to 1,305 in 2020 due to aging and recent skyrocketing chemical input costs to the soil (Shizukuishi town 2023).

The situations above are quite similar around the world.

IFOAM has been trying to change the organic situation by proposing various actions in ORGANIC 3.0.

However, the organic land share in the world is still 2.1 %.

Therefore, we must rethink or "invent" various alternatives to increase the organic land share as well as the number of organic stakeholders. Table 1 shows ORGANIC 3.0 practices in the agricultural sector of Japan.

Table 1 ORGANIC 3.0 has not been well developed as expected

Key elements of ORGANIC 3.0	Japan	Shizukuishi Town incl. Organic Shizukuishi	Remarks
Conversion (No progress)	No conversion data. Organic land share:0.4%	No conversion data. Organic land share Dry fields:0.07% Wet fields: 0.07%	Shizukuishi Town Hall people are not proactively promoting organic agriculture
Sustainability (No understanding for saving our planet earth)	Conventional farmers have low awareness of soil and environmental sustainability.	Same as on the left, except Organic Shizukuishi IRPI stakeholders.	Local governments, Japan Agricultural Cooperatives and Academic people have less knowledge about the soil and environmental sustainability.
Inclusiveness (PGS six key elements are not well understood by stakeholders)	IRPI, ALGOA, GAOD members are extremely small.	Organic Shizukuishi is a member of IRPI, ALGOA associate and GAOD (WGs 3&4) .	Inclusiveness is not well formed in Shizukuishi town as well as in Japan.

(Notes)
IRPI: IFOAM Recognized PGS Initiative
https://www.ifoam.bio/our-work/how/standards-certification/participatory-guarantee-systems/pgs-recognition-program
GAOD: Global Alliance for Organic Districts
https://gaod.online/
ALGOA: Asian Local Governments for Organic Agriculture
https://www.algoa-organics.org/
Japan Agricultural Cooperatives
https://www.zennoh.or.jp/english/cooperatives/jagroup.html

Discussion

Practical approaches to implement organic mindset among stakeholders

There have been four organic projects in this country (see Table 2).

They are organic village project led by the MAFF, agro-tourism enjoying organic stays in the countryside with family members, allotment garden where citizens rent plots growing vegetables and front yard vegetable garden (FYVG).The organic land areas are also described in Table 2.

The FYVG is easy and practical to start organic farming in these four alternatives. There is no paperwork, they can start at any time with small money and they can control everything what they would like to do in organic farming at home. And besides, they can figure out some counter measures to climate change such as using hydrogen-rich water (Bei Lin et al., MULTIIONIZER).

Front Yard Vegetable Garden (FYVG) is a great starter for organic farming

As said in the earlier sections, we have insisted too much on increasing organic areas as well as organic stakeholders in Shizukuishi Town through PGS activities since getting IRPI in 2018.

We have expected changes in thinking of local consumers and local government people about organic farming. But this requires some education/instruction to consumers and funding from public.

While in Japan, detached houses, they grow flowers and vegetables in the yards. This is a good place to start organic farming. Because the place is proper for them to convert yards into FYVG with ease. And besides, we can use hydrogen-rich water which has favorable effects on growing plants because in the home yard, there is at least a water tap. They can start it economically and grow safe and secure produce.

Table 2 Comparison of Four Organic Projects in Terms of Land Areas

Alternatives	Present available organic area data	Remarks
[1] Organic Village (OV) Project led by the MAFF since 2021	Current OV municipalities: 150 **(2,637 ha)** (as of August 2025) Target number of OV municipalities by 2030: 200 (target area: **63,000 ha**) https://www.maff.go.jp/j/seisan/kankyo/yuuki/organic_village.html	Total municipalities in Japan: **1,781** Almost all municipalities have no interest in the project. It will take some more years to increase organic land areas in cities, towns and villages.
[2] Agro-tourism	Twenty-five municipalities implement agro-tourism. https://countrysidestays-japan.com/ No area data available.	Farms in agro-tourism are made up of conventional and organic gardens.
[3] Allotment Garden (AG)	Number of AGs: 4,257 Number of totalplots: 187,804 Area: **1,283 ha** as of 2023 https://www.maff.go.jp/j/nousin/kouryu/tosi_nougyo/s_joukyou.html	Data includes conventional and organic gardens.
[4] Front Yard Vegetable Garden (FYVG)	Estimated organic land areas are ranging from **59,674 ha-119,348ha** as of 2025	The data is summarized in Table 3.

Estimated of FYVG area and its features

An estimate of organic area of FYVG in Japan based on the Home Garden Design document and TAKEI SEED report 2025 is shown in Table 3 (Home 2025) (Report 2025).

Table 3 Parameters used to estimate the FYVG organic land area

Parameters	Data	Remarks
Average FYVG area/household	33-66㎡	Sinchikupapa
Total detached house* numbers *: to be abbreviated as house	65,047,000	MLITT 2024
Houses doing FYVG over five years	27.8 %	Report 2025
Estimated houses doing FYVG	18,083,066	65,047,000x0.278
Expected total Organic FYVG area	59,674ha in case of 33㎡/household 119,348 ha in case of 66㎡/household	Depending on the rural/urban districts

Present JAS certified organic land area in Japan is18,837 ha (FibL 2025).

Therefore, 3.2-6.3 times larger organic FYVG area could be expected, provided each household has been cultivating organic ways. Growing the produce in FYVG is an effective method to learn about organic farming. The produce from the FYVG is for their eating so that they never use chemical inputs to the soil and they gradually know about healthy soil, healthy plants and healthy body.

Figures show author's 50 square metres FYVG growing fifteen types of crops. This is a small yard, but neighbors seem interested in my FYVG and sometimes they ask me "What are you doing?"This is a good opportunity for me to let them know about organic farming. In farms generally located far from residential areas this rarely happens.



Figure 1:My Original yard (May 2024)



Figure 2: My Front Yard Vegetable Garden (Under construction on May 4, 2025)



Figure3: Growing black azuki beans (on July 31, 2025)



Figure 4: Jew's mallows and cabbages (on July 31, 2025)



Figure 5 Tomatoes (on August 8, 2025)



Figure 6: Scarlett runner beans (on July, 2025)

The FYVG can be started at any time. Of course, you never use chemicals in the soil because the produce is eaten by their family members. It is obvious that we do not need third-party certification at all because it is "Home grown and home consumed". Whenever the FYVGs spread in the community and they would like to sell their produce locally, the movement might evolve into IFOAM PGS.

Conclusion

The Front Yard Vegetable Garden is a useful approach to promote and extend organic farming in residential areas because it is economical, easy to start with and no certification is needed. PGS introduction can be expected in the residential community in the future when they would like to sell their products at local organic farmers' markets (IFOAM PGS).

This would contribute to community development and to living long lives with many healthy people. In the end the organic Front Yard Vegetable Garden will contribute to the spread of organic farming in residential areas, local districts and all over the country. It is also expected to increase organic land share in Japan. The idea can widely be applicable to the world.

RECOMMENDATIONS

The recommendations of Front Yard Vegetable Garden can be summarized as below:

[1] The organic farming can start at any time with no public funding, a small amount of investment, no-distribution, no-sales. This should become one of the grass roots-movements around the world.
[2] Never use chemical inputs to the soil because the produce is your family's daily food.
[3] No need for the third-party certification.
[4] Discussions with the neighborhood people to exchange ideas about growing different crops with different organic fertilizers, green manures and even usage of the hydrogen-rich water.
[5] Learning about the relationship between global Front Yard Vegetable Garden acreage expansion and greenhouse gas emission reduction (Jay Squalli, Gary Adamkiewicz 2018).

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A Biostimulant as a Lever for Agroecological Intensification: Assessing Impacts on Maize (Zea mays L.) in Benin

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Abstract
In Benin, maize production is threatened by soil degradation and heavy reliance on chemical fertilizers, and this study tested an indigenous arbuscular mycorrhizal fungi bio stimulant as a potential agroecological alternative. Working with 200 farmers in southern Benin, the research compared a bio-stimulant-based system with local practices using a before-and-after approach to track agronomic, economic, and social changes. Baseline data showed stagnant yields of 1.29 t/ha and low gross margins of XOF 66,440/ha despite widespread use of synthetic inputs. In contrast, the on-farm trials showed strong adoption and satisfaction, with maize yields on treated plots rising to 6.2 t/ha and farmer gross margins increasing nearly nine-fold to about XOF 587,000/ha. Farmers also used less chemical fertilizer, a reduction confirmed by extension agents, highlighting environmental benefits alongside productivity gains. Overall, the results show that indigenous AMF bio stimulants are effective, economically attractive, and well accepted, offering a practical route to improve maize yields, farmer income, and soil health while supporting sustainable agricultural intensification and informing future policy and scaling efforts in Africa.

Keywords: Agroecology, Arbuscular Mycorrhizal Fungi (AMF), Biostimulant technology, Maize productivity

Résumé
Au Bénin, la production de maïs est menacée par la dégradation des sols et une forte dépendance aux engraischimiques. Cette étude a testé un biostimulant à base de champignons mycorhiziens arbusculaires indigènes comme alternative agroécologique potentielle. Menée auprès de 200 agriculteurs auSud-Bénin, la recherche a comparé un système à base de biostimulant aux pratiques locales, selon une approche avant-après permettant d'évaluer les changements agronomiques, économiques et sociaux. Les données initiales ont révélé des rendements en grains de maïs autourde 1,29 t/ha et de faibles marges brutes de 66 440 XOF/ha, malgré l'utilisation généralisée d'intrants de synthèse. En revanche, les essais en milieu paysan ont démontré une forte adoption et une grande satisfaction : les rendements en grains de maïs sur les parcelles traitées avec le biostimulant à base de champignons mycorhiziens arbusculaires (CMA) indigènes ont atteint 6,2 t/ha et les marges brutes des agriculteurs ont été multipliées par neuf, pour atteindre environ 587 000 XOF/ha. Les agriculteurs ont également utilisé moins d'engrais chimiques, une réduction confirmée par les agents de vulgarisation, soulignant ainsi les bénéfices environnementaux en plus des gains de productivité. Globalement, les résultatsmontrentque les biostimulants à base de CMA indigènessontefficaces, économiquementintéressants et bien acceptés. Ils constituent une solution pratique pour améliorer les rendementsen grains du maïs, les revenus des agriculteurs et la santé des sols, tout ensoutenantune intensification agricole durable et enéclairant les politiques et les efforts de déploiementfutursen Afrique.

Mots-clés: Agroécologie, Champignons mycorhiziensarbusculaires (CMA), Technologie des biostimulants, Productivité du maïs

Introduction

In Benin, continuous population growth exerts significant pressure on the agricultural sector to meet rising food demands. Current agricultural systems are heavily dependent on the continuous application of mineral inputs, a practice that, while boosting short-term yields, leads to long-term degradation of soil health, diminished food quality, and negative impacts on atmospheric and hydric systems (Plenchette *et al*., 2005; Yang *et al*., 2004). This dependency ultimately results in declining crop productivity, making it increasingly difficult to meet the population's nutritional needs. The imperative for sustainable agriculture has therefore shifted focus towards solutions that reduce high-input systems while ensuring sufficient food production (Thonar *et al*., 2017). Among these, technologies based on beneficial soil microorganisms have emerged as a key strategy to regenerate soil health and ensure long-term sustainability (Agbodjato *et al*., 2016).

Maize (Zea mays L.) is a critical staple in Benin, essential for both domestic consumption and regional trade (N'Da *et al*., 2014). Despite its importance, maize productivity is severely hampered by numerous constraints, chief among them being the constant decline in soil fertility due to land degradation (Saïdou *et al.*, 2012). As a modern and palliative solution to this challenge, the use of biostimulants based on indigenous arbuscular mycorrhizal fungi (AMF) offers a promising pathway. Numerous studies in Benin have already demonstrated the efficacy of this endomycorrhizal symbiosis in improving maize productivity (Akpode *et al.*, 2024; Alao *et al*., 2024; Aguegue *et al*., 2023, 2021, 2020; Assogba *et al*., 2020; Koda *et al*., 2020). The promotion and application of AMF-based bio stimulants are therefore expected to induce a sustainable improvement in maize yields, an increase in smallholder farmer incomes, and a progressive regeneration of soil microflora and fertility.

However, a critical knowledge gap remains regarding the performance, economic viability, and social acceptability of this technology under real-world, farmer-managed conditions. This study was therefore designed to bridge this gap., the main objective was to assess the real-world performance, economic viability, and social acceptability of the indigenous AMF bio stimulant under farmer-managed conditions.

MATERIALS AND METHODS

Study Area

The study was conducted at four Research-Development (R-D) sites: Eglimè, Zouzouvoun, Adakplamè, and Hayakpa. These sites were in the respective municipalities of Aplahoué, Djakotomey, Kétou, and Tori, belonging to the Departments of Couffo, Plateau, and Atlantique in Southern Benin (Figure 1). This region was chosen due to the predominance of maize cultivation and challenges related to declining soil fertility.

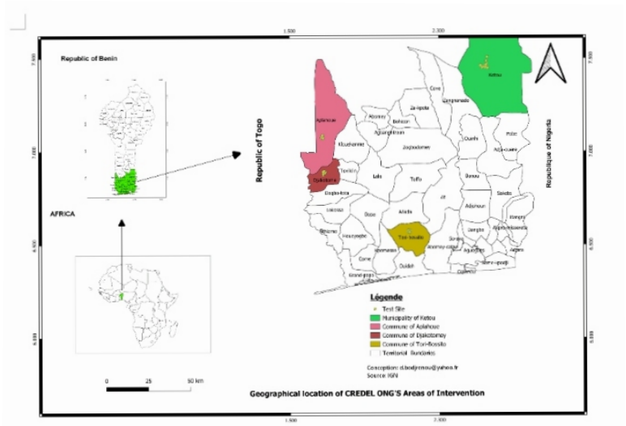


Figure 1: Geographical location of the intervention municipalities

Data Collection

The study was conducted using a participatory on-farm approach under farmer-managed conditions. Two production systems were compared: the farmers' conventional maize production practices and a system integrating the indigenous AMF-based bio stimulant. The trials were implemented directly on farmers' fields, following locally relevant management practices, with technical support from agricultural extension agents. Data were collected on agronomic performance, input use, production costs, and farmer perceptions throughout the cropping season, forming the basis for agronomic, economic, and social analyses.

A mixed-methods approach was used to collect data related to the study's objectives.
Agronomic Parameters
To assess crop growth and productivity, several parameters were measured. Plant height (using a measuring tape) and collar diameter (using a caliper) were recorded every 15 days, from 15 to 60 Days After Sowing (DAS). At 60 DAS, the leaf area of ten plants per plot was estimated using the formula:

Leaf Area = Length × Width × 0.75 (Ruget & Chatier, 1996).
At harvest (90 DAS), maize was collected, and grain mass was determined using a precision balance. The moisture content was measured with a moisture meter (LDS-1F), and the final grain yield (t/ha) was standardized to 14% moisture content according to the formula described by Ferro Valdés et al. (2013).

Economic and Social Parameters

To determine profitability, data on all production costs (labour, inputs) were collected in real-time throughout the season using individual data collection sheets. A partial budget analysis was then used to calculate the gross product value and the net agricultural income from each plot. Social acceptability and farmer perceptions were evaluated through structured surveys and interviews conducted at the end of the experimental period.

Data Analysis

The analysis followed a before-and-after (pre- vs. post-intervention) approach with a comparison group. First, a post-intervention descriptive analysis was conducted to profile the changes observed among beneficiary farmers using key variables such as yield, income, production costs, and perceptions of AMF. Means, standard deviations, and relative frequencies were used for comparisons. Second, a comparative before-and-after analysis was performed using paired Student's t-tests or Wilcoxon signed-rank tests (for non-normally distributed data) to evaluate significant variations in key indicators. Third, an analysis of adoption and perceptions was carried out, considering the AMF adoption rate and the number of trained users. Finally, a cost-benefit analysis was conducted to estimate the economic profitability of the technology by determining production costs, revenues, and gross/net margins.

Data processing was performed using several tools: Microsoft Excel was used for basic calculations, pivot tables, and graphs. SPSS software was used for descriptive statistics, t-tests, and regressions. Qualitative data from semi-structured interviews and focus groups were analysed using NVivo software.

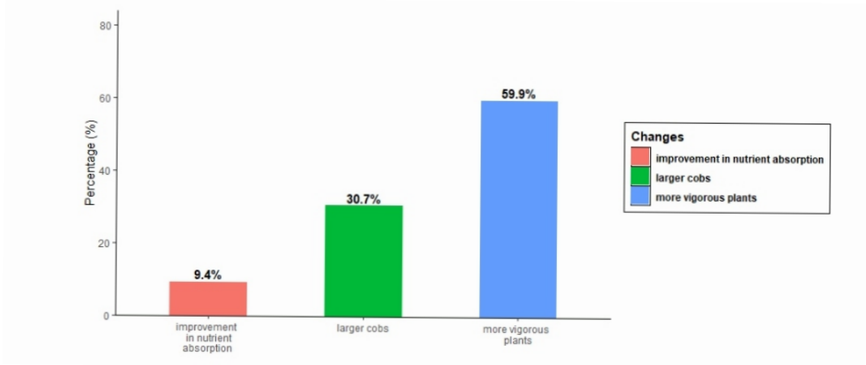
Results

The results of the on-farm trials are presented below, structured according to the three primary research objectives. Baseline data from the initial reference study are compared with post-intervention data to quantify the impact of the AMF-based bio stimulant.

Agronomic Performance of the Bio stimulant

Impact on Plant Growth and Farmer Perception

Following the application of the bio stimulant, farmers unanimously reported significant and visually apparent improvements in crop health and vigour on the treated plots. These qualitative observations were highly consistent across all study sites. Specifically, farmers noted the development of more robust stems and denser, greener foliage compared to the control plots. When asked to identify the most significant changes, 59.9% of farmers primarily attributed the improvements to enhanced overall plant vigour, while 30.7% pointed specifically to the development of larger cobs, and 9.4% perceived an improvement in



changes in plant growth after the use of arbuscular mycorrhizal

nutrient absorption (Figure 2). These perceptions collectively indicate that the bio stimulant induced a strong positive response in the vegetative and reproductive stages of the maize plants.

Figure 2: Assessment of changes in plant growth after the use of arbuscular mycorrhizal fungi (AMF)-based bio stimulants

Impact on maize grain yield

A dramatic increase in quantitative yield substantiated the positive agronomic perceptions. The on-farm trials demonstrated that the use of the bio-stimulant led to a highly significant improvement in maize productivity. The average grain yield on treated plots reached 6200 kg/ha, a stark contrast to the baseline average of 2743.4 kg/ha (Table 1). This represents more than a doubling of the yield, confirming that the technology successfully translated enhanced plant growth into a substantial increase in grain production under real-world farming conditions.

Table 1: Key Project Performance Indicators

Parameters	Before production	After production
Average quantity harvested (Kg)	2,743.4	6,200
Average total costs of chemical fertilizers (NPK, Urea) (FCFA/ha)	67,831	58,750
Average total production costs (FCFA/ha)	174,947.91	122,500
Average total revenue (FCFA/ha)	463,465	709,725
Gross margin per ha (FCFA/ha)	66,440.104	587,225–

Impact on Production Costs and Revenue

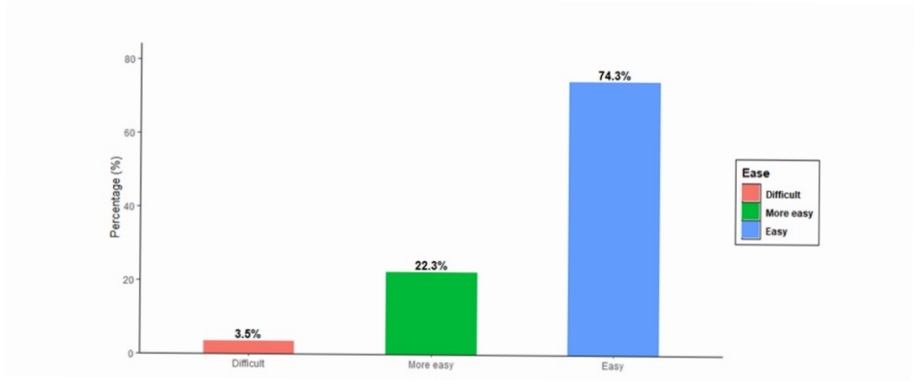
The introduction of the AMF-based bio stimulant had a transformative effect on the economic parameters of maize production. The technology enabled a significant optimization of the cost structure. Average total production costs were reduced to XOF 122,500 per hectare, notably driven by a decrease in expenditure on chemical fertilizers, which fell to XOF 58,750 per hectare (Table 1). Concurrently, the substantial yield increase led to a dramatic rise in income. The average total revenue generated per hectare surged from a baseline of XOF 463,465 to XOF 709,725 post-intervention (Table 1). This demonstrates that the technology simultaneously reduced expenses while significantly boosting gross income.

Impact on farmer profitability

The combined effect of reduced production costs and increased revenue resulted in a dramatic improvement in farmer profitability. By calculating the difference between the new total revenue (XOF 709,725/ha) and the new total costs (XOF 122,500/ha), the average gross margin for farmers using the bio stimulant reached XOF 587,225 per hectare. This represents a nearly nine-fold increase compared to the baseline gross margin of XOF 66,440 per hectare. This substantial enhancement of profitability provided a powerful economic incentive for adoption and demonstrated the technology's capacity to significantly improve the livelihoods of smallholder maize farmers.

Social acceptability and farmer adoption

Following the on-farm trials, farmer perceptions shifted dramatically, indicating high social acceptability. The technology was perceived as practical and easy to use, with 74.3% of farmers finding its application "easy" (Figure 3).



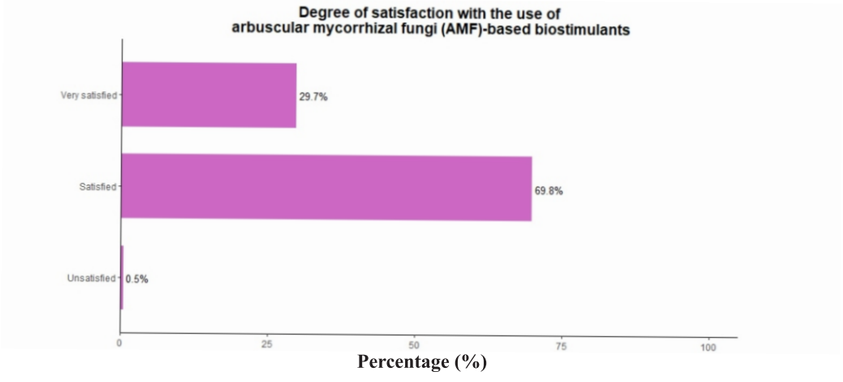
Ease of application of arbuscular mycorrhizal fungi (AMF)-based bio-stimulants

Figure 3: Evaluation of the ease of application of arbuscular mycorrhizal fungi (AMF)-based bio-stimulants

More importantly, the initial uncertainty regarding its effectiveness was overcome; an overwhelming majority of 98% of farmers judged the bio stimulant to be either "useful" (63%) or "very useful" (35%) for their maize production (Figure 4).

Figure 4: Assessment of the usefulness of arbuscular mycorrhizal fungi (AMF)-based biostimulants

This positive perception translated into an exceptionally high degree of overall



satisfaction, with nearly 100% of participants reporting being either "satisfied" (approx. 70%) or "very satisfied" (approx. 30%) with the results obtained (Figures 5 & 6).

Figure 5: Degree of satisfaction with the use of arbuscular mycorrhizal fungi (AMF)-based bio stimulants by municipality

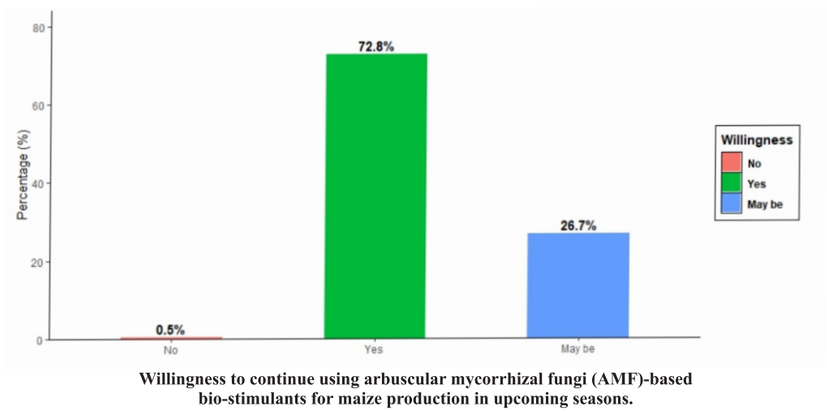
Figure 6: Degree of satisfaction with the use of arbuscular mycorrhizal fungi (AMF)-based bio stimulant

Drivers for future adoption

The high levels of satisfaction translated directly into strong indicators of future, long-term adoption. A significant majority of participants (72%) expressed a clear intention to continue using the bio stimulant for their maize production in the upcoming seasons (Figure 7).

Figure 7: Willingness to continue using arbuscular mycorrhizal fungi (AMF)-based bio-stimulants for maize production in upcoming seasons.

This personal commitment was further reinforced by a strong willingness to act as advocates for the technology, with 67% of farmers stating they would



recommend the AMF bio stimulant to other producers (Figure 10, Impact Study). Crucially, this perceived value was quantified through a willingness-to-pay (WTP) analysis. The study found that farmers were prepared to make a financial investment in the technology, with average accepted price of XOF 1,649 for a 1 kg package and XOF 41,225 for a 25 kg bag (Tables 2 & 3). Taken together, these behavioural intentions demonstrate that the technology is not only perceived as effective but is also considered a viable and desirable investment by smallholder farmers.

Table 2: Minimum and maximum purchase prices of arbuscular mycorrhizal fungi (AMF)-based bio stimulants per kilogram by producers

Price proposal	Aplahoué	Djakotomey	Kétou	Tori-Bossito	Overall
Average minimum purchase price of indigenous arbuscular mycorrhizal fungi (AMF)	1,540 (401)	1,668 (1,025)	1,816 (261)	188 (53)	1,305 (858)

Average maximum purchase price of indigenous arbuscular mycorrhizal fungi (AMF)	4,451 (884)	3,150 (1,270)	4,040 (493)	413 (529)	3,028 (1,789)

Table 3: Purchase formats of indigenous arbuscular mycorrhizal fungi (AMF) by producers Purchase format of indigenous arbuscular mycorrhizal fungi (AMF)

Purchase format of indigenous arbuscular mycorrhizal fungi (AMF)	Rank	Cost (FCFA)
Format 2: 1 Kg bag	3rd	1,649
Format 1: 25 Kg bag	1st	41,225
Format 3: 50 Kg bag	2nd	82,450

Discussion

This study successfully demonstrated that an indigenous AMF-based biostimulant can serve as a powerful lever for the agroecological intensification of maize systems in Benin. The on-farm results not only validate previous on-station findings but also prove the technology's effectiveness, economic viability, and social acceptability under the real-world conditions managed by smallholder farmers.

The dramatic doubling of maize yield observed in the treated plots can be attributed to the well-documented mechanisms of the mycorrhizal symbiosis. AMF act as an extension of the plant's root system, vastly improving its capacity to explore the soil and absorb nutrients, particularly phosphorus, which is often a limiting factor in weathered tropical soils (Aguegue *et al*., 2023; Smith & Read, 2008). The farmers' qualitative observations of more "robust stems" and "denser, greener foliage" are direct visual evidence of this enhanced nutrient uptake, which translates into greater biomass and, ultimately, higher grain yield. This confirms the crucial role of AMF as "ecosystem engineers" in improving soil health and plant nutrition (Van der Heijden *et al*., 2015).

From an economic standpoint, the nearly ninefold increase in gross margin is arguably the most powerful driver for adoption. This finding aligns with recent reports suggesting that bio stimulants can significantly enhance the economic resilience of smallholders (FAO, 2022). The high profitability provides a compelling "relative advantage," which, according to Rogers' Diffusion of Innovations theory, is a primary determinant of a new technology's adoption rate (Rogers, 2003). The technology also scored highly on other key attributes defined by Rogers: its application as a simple seed coating made it compatible with existing practices and low in complexity, while its rapid and visible effects ensured high observability.

The exceptionally high rate of social acceptability and the strong intention for future use can be linked to this combination of perceived efficacy and ease of use. The participatory action-research approach, which included comprehensive training, was also instrumental in building farmer trust and capacity, overcoming the initial scepticism revealed in the baseline study. The success of this study is also coherent with findings from other parts of sub-Saharan Africa. For instance. Crucially, the use of indigenous strains, as emphasized by Asghar *et al*. (2023), is a key factor in this success, as they are better adapted to local soil and climate conditions and avoid the ecological risks associated with introducing exotic microbial species.

Despite these compelling results, the primary challenge for scaling remains the large-scale production and distribution of a quality-controlled, affordable inoculum. While this study confirms the demand and willingness-to-pay, establishing a sustainable supply chain will require a concerted effort involving public-private partnerships.

Conclusion

This research concluded that the indigenous AMF-based bio stimulant is a technically effective, economically viable, and socially accepted innovation for maize production in Southern-Benin. The study provides robust on-farm evidence that this technology can simultaneously achieve three critical goals: (i) the sustainable intensification of maize production through a significant increase in yields; (ii) the enhancement of system resilience through improved soil health; and (iii) a tangible increase in farmer income through both cost reduction and higher revenue. The large-scale adoption of this biological innovation could therefore play a key role in achieving Benin's national objectives for food security and sustainable agricultural development.

Recommendations

Based on these compelling results, the following actions are recommended to facilitate the transition from successful research to widespread impact:

1. **Policy Support and Integration:** Agricultural policymakers should formally recognize and integrate AMF-based biostimulants into national strategies for sustainable agriculture and soil health. This includes establishing a framework for quality control and certification to ensure farmers have access to effective, high-quality products.

2. **Establishment of a Sustainable Supply Chain:** A public-private partnership model should be developed to support the creation of local bio-production units. This would ensure a decentralized and reliable supply of quality-controlled, affordable inoculum to smallholder farmers.

3. **Capacity Building and Extension:** The national agricultural extension system (ATDA) should incorporate training modules on the benefits and proper application of biostimulants into its standard curriculum to ensure knowledge is disseminated effectively and to support farmer decision-making.

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Modeling the Impact of Fertilizers on Maize and Rice Productivity in Tanzania: Pathways to Agricultural Transformation

Modeling the Impact of Fertilizers on Maize and Rice Productivity in Tanzania: Pathways to Agricultural Transformation

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Abstract
Agriculture is a central component of Tanzania's economy, supporting the livelihoods of more than 60% of the population. Among staple crops, maize (Zea mays L.) and rice (Oryza sativa) are vital for food security, household incomes, and national stability. However, yields remain below potential due to low fertilizer use, soil nutrient depletion, and climate variability. This study addresses the question: To what extent does fertilizer application improve maize and rice productivity in Zanzibar, Mainland Tanzania, and at the national level? The study employed a Stochastic Simulation Approach (SSA) based on non parametric Monte Carlo methods, using nationally representative data from the 2019/20 National Sample Census of Agriculture (NSCA). Yield probabilities were modeled under different fertilizer-use scenarios to estimate the likelihood of exceeding productivity thresholds and the risk of low yields. Fertilizer use significantly improved mean yields, enhanced yield stability, and reduced downside risk. For maize, the probability of exceeding 4.0 t/ha rose from 1% among non-fertilizer users to 6% among inorganic fertilizer users. For rice, the probability of surpassing 4.0 t/ha increased from 10% for non-users to 17% with the use of inorganic fertilizer at the national level .Fertilizer application also reduced the proportion of farmers producing below the national average, reflecting more stable production outcomes. Differences between Zanzibar and Mainland Tanzania further revealed that agroecological and management conditions influence the effectiveness of fertilizers. Fertilizer is a key driver for closing maize and rice yield gaps, but its effectiveness is maximized when integrated with improved seed varieties, irrigation, and extension services. Strengthening fertilizer access through targeted subsidies, efficient distribution, and farmer training can boost productivity, stabilize rural incomes, and advance food security. The study provides robust empirical evidence to inform agricultural policy, guide subsidy programs, and contribute to achieving SDGs 1, 2, 8, and 13 in Tanzania.

Keywords: Inorganic fertilizers, maize, productivity, rice, stochastic simulation, Tanzania.

Résumé
L'agriculture est un pilier de l'économie tanzanienne, assurant les moyens de subsistance de plus de 60 % de la population. Parmi les cultures vivrières de base, le maïs (Zea mays L.) et le riz (Oryza sativa) sont essentiels à la sécurité alimentaire, aux revenus des ménages et à la stabilité nationale. Cependant, les rendements restent inférieurs à leur potentiel en raison d'une faible utilisation d'engrais, de l'appauvrissement des sols en nutriments et de la variabilité climatique. Cette étude vise à déterminer dans quelle mesure l'application d'engrais améliore la productivité du maïs et du riz à Zanzibar, en Tanzanie continentale et à l'échelle nationale. L'étude a utilisé une approche de simulation stochastique (ASS) basée sur des méthodes non paramétriques de Monte Carlo, à partir de données représentatives au niveau national issues du Recensement national de l'agriculture par sondage (RNAS) de 2019/2020. Les probabilités de rendement ont été modélisées selon différents scénarios d'utilisation d'engrais afin d'estimer la probabilité de dépasser les seuils de productivité et le risque de faibles rendements. L'utilisation d'engrais a significativement amélioré les rendements moyens, renforcé leur stabilité et réduit le risque de baisse. Pour le maïs, la probabilité de dépasser 4,0 t/ha est passée de 1 % chez les agriculteurs n'utilisant pas d'engrais à 6 % chez ceux utilisant des engrais inorganiques. Pour le riz, cette probabilité a augmenté de 10 % chez les non-utilisateurs à 17 % avec l'utilisation d'engrais inorganiques à l'échelle nationale. L'applicationd'engrais a également réduit la proportion d'agriculteursdont la production étaitinférieure à la moyennenationale, témoignantd'une plus grande stabilité des rendements. Les différences observées entre Zanzibar et la Tanzanie continentale ont par ailleurs révélé que les conditions agroécologiques et les pratiques agricoles influencent l'efficacité des engrais. Si les engrais sont un facteur clé pour réduire les écarts de rendement du

maïs et du riz, leur efficacité est optimale lorsqu'ils sont associés à des semences améliorées, à l'irrigation et à des services de vulgarisation agricole. Améliorer l'accès aux engrais grâce à des subventions ciblées, une distribution efficace et la formation des agriculteurs peut stimuler la productivité, stabiliser les revenus ruraux et renforcer la sécurité alimentaire. Cette étude apporte des données empiriques solides qui permettront d'éclairer les politiques agricoles, d'orienter les programmes de subventions et de contribuer à la réalisation des ODD 1, 2, 8 et 13 en Tanzanie.
Mots-clés :Engraisinorganiques, maïs, productivité, riz, simulation stochastique, Tanzanie.

Introduction

Agriculture remains the backbone of Tanzania's economy, supporting livelihoods for over 60% of the population (FAO *et al*., 2020, 2022; Ofori et al., 2021). Two cereals, maize (Zea mays L.) and rice (Oryza sativa), are central to national food security, rural incomes, and economic stability (Mtembeji and Singh, 2021; Macauley and Ramadjita, 2015). Maize is the most widely cultivated crop, grown by about 83% of farming households and contributing up to 80% of daily caloric intake and 16% of household food expenditure (Rudolf, 2019; Chegere and Kauky, 2022). In 2022-23, production exceeded 7 million tonnes across more than 6 million hectares (URT, 2023). Rice follows closely, grown by over 2 million households across 60 districts, making Tanzania the leading producer in East Africa and the fourth-largest in Africa (Busungu, 2023; Nkuba *et al*., 2016). With annual per capita consumption of 25 kg, rice provides 21% of dietary energy while maize supplies nearly 60% (Mtembeji and Singh, 2021).

These cereals are crucial not only for nutrition but also for economic resilience, supporting household investments in education, health, and asset diversification. Although Tanzania is largely self-sufficient in maize, it remains a net importer of rice, underscoring the need for productivity growth (Rosen et al., 2015; Ofori *et al*., 2021; Wilson and Lewis, 2015a, 2015b). National strategies such as Kilimo Kwanza and the National Rice Development Strategy (NRDS) aim to narrow yield gaps and promote commercialization (URT, 2019). Yet yields remain low because of limited fertilizer use, erratic rainfall, and suboptimal agronomic practices. Only 28-40% of soil nutrient needs are met, and more than 90% of fertilizers are imported (USDA, 2023). Maize consumes about half of total fertilizer use, with rice and pulses each accounting for roughly 10% (AGRA, 2020). Despite subsidies, only 45% of farmers apply fertilizer across their entire farms, and rates remain below recommendations (Heisse and Morimoto, 2024).

Input access is further constrained by high prices (USD 23-28 per 50 kg bag) and inefficient distribution networks (USDA, 2025). Meanwhile, climate variability, manifested through rising temperatures, floods, and droughts, continues to threaten production. A 2 °C temperature rise by 2050 could reduce maize yields by 13% and rice yields by 7% (Rowhani et al., 2011; Hoffman et al., 2018). Given these pressures, fertilizers emerge as an affordable, scalable means of closing yield gaps and stabilizing output, particularly when combined with improved seeds, irrigation, and extension support.

This study models the effects of inorganic fertilizer use on maize and rice productivity using nationally representative data. It estimates yield responses across Tanzania, evaluates food security and income implications, and supports SDGs 1, 2, 8, and 13 through evidence-based policy insights on sustainable cereal intensification.

2.0 Materials and Methods

2.1. Study Area

This study was conducted across the entire United Republic of Tanzania, encompassing Mainland Tanzania and the semi-autonomous islands of Zanzibar (Unguja and Pemba). The country spans diverse agroecological environments between latitudes 1°-12°S and longitudes 29°-41°E, bordered by eight countries and the Indian Ocean. Figure 1 illustrates regional maize and rice production patterns for 2019/20 (URT, 2021). Maize is cultivated extensively across nearly all mainland regions, with major production in Ruvuma, Rukwa, Mbeya, Songwe, Njombe, and Manyara, each producing over 300,000 tonnes annually. Rice production is more concentrated in Morogoro, Shinyanga, Mwanza, Mbeya, Ruvuma, and irrigated pockets of Zanzibar. For analytical clarity, farms were grouped into three geographic strata: Zanzibar (ZNZ), representing coastal humid systems; Mainland Tanzania (MTZ), covering highland, mid-altitude, and semi-arid zones; and All Tanzania (ALL.TZ), combining both areas. This structure captures the full agroecological diversity necessary for robust comparisons of productivity. Figure 1 illustrates the maps of Tanzania showing production levels per region for maize (Panel A) and rice (Panel B).

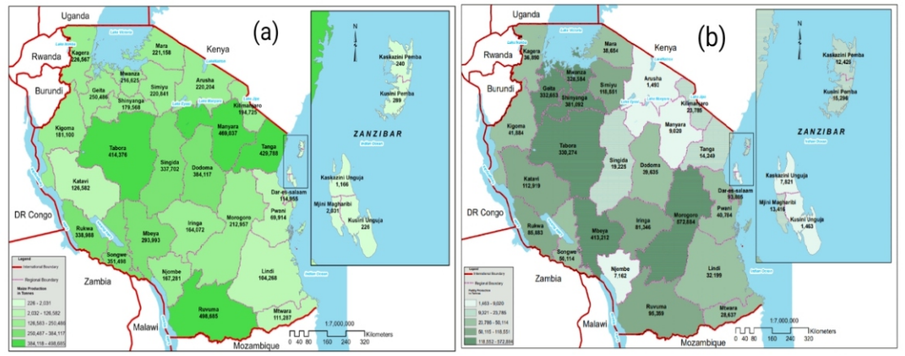


Figure 1: Production of Maize (Panel A) and Rice (Panel B) in Tanzania by Region During the 2019/20 Agricultural Year (URT, 2021)

2.2. Data Sources

Tanzania has undertaken multiple rounds of the National Sample Census of Agriculture.This study uses nationally representative data from the 2019/20 National Sample Census of Agriculture (NSCA), complemented by selected indicators from the 2007/08 census to contextualize historical patterns. Conducted by the National Bureau of Statistics (NBS), the NSCA is Tanzania's most comprehensive source of agricultural information, covering rural households' landholdings, crop production, livestock ownership, and use of inputs such as fertilizers and improved seeds. It also documents rural infrastructure and livelihood conditions, enabling assessment of agricultural performance and development outcomes. The survey employs a rigorous two-stage sampling design. First, Census Enumeration Areas (CEAs) from the 2012 Population and Housing Census are selected as Primary Sampling Units. Second, agricultural households within these CEAs are randomly sampled. The final sample includes 2,820 PSUs, 2,670 from Mainland Tanzania and 150 from Zanzibar, selected using Probability Proportional to Size (PPS) to ensure national representativeness (URT, 2021).

2.3. Data Processing and Simulation

2.3.1 Data processing

Maize and rice yield data from the 2019/20 NSCA were organized by fertilizer type and geographic location to enable consistent performance evaluation. Farms were classified into three fertilizer-use categories: no fertilizer (F0), organic fertilizer (F1), and inorganic fertilizer (F2), and only harvested plots were retained to ensure reliable yield comparisons. For geographic analysis, farms were grouped into Zanzibar (ZNZ), Mainland Tanzania (MTZ), and All Tanzania (ALL.TZ), covering the full range of coastal, highland, mid-altitude, and semi-arid production systems. Table 1 summarizes the number of farms within each fertilizer category. Nationally, the sample included over 10,000 maize farms and 4,500 rice farms that used no fertilizer, alongside smaller groups that used organic or inorganic fertilizer. This structured classification provided a robust basis for stochastic simulation of yield distributions and facilitated precise comparisons across fertilizer types and regions, supporting the study's objective of quantifying fertilizer impacts on productivity.

Table 1: Number of Observations for Mazie & Rice Farms Using Local vs Improved Seeds in Tanzania

Farm location (Zanzibar & Mainland)	# of Farms using no fertilizer (F0)	# of Farms using organic fertilizer (F1)	# of Farms using inorganic fertilizer (F2)
Maize farms in Zanzibar (ZNZ_MZ)	32	13	4
Rice Farms in Zanzibar (ZNZ_RC)	288	23	242
Maize farms in Mainland Tanzania (MTZ_MZ)	10,075	1,893	4,175
Rice farms in Mainland Tanzania (MTZ_RC)	4,222	76	99
All maize farms in Tanzania (ALL.TZ_MZ)	10,107	1,906	4,179
All Rice farms in Tanzania (ALL.TZ_RC)	4,510	688	930

2.3.2 Data analysis

This study applied a Risk Simulation Model (RSM) based on a nonparametric Monte Carlo approach (Richardson et al., 2003, 2006; Kadigiet al., 2020) to generate stochastic distributions of maize and rice yields. Monte Carlo simulation was selected for its ability to model randomness in yields and quantify production risks. Deterministic yields derived from observed data were first parameterized and then transformed into stochastic yields using empirical random shocks, thereby allowing realistic simulation of yield variability. The analysis employed the Multivariate Empirical (MVE) distribution, which captures joint variability across farming systems while ensuring that simulated yields remain within plausible limits. Residuals, defined as percentage deviations from mean yields, were used to estimate MVE parameters, enabling the model to reflect historical variability across fertilizer-use categories and locations.

Stochastic yields were generated using Equations 1-4, with Equation 4 simulated over 500 iterations using Latin Hypercube Sampling (LHC) to replicate the parent yield distributions efficiently (Kadigiet al., 2025). Validation involved comparing simulated and historical distributions to ensure accuracy and reliability. This framework provided a robust basis for assessing fertilizer impacts under Tanzania's diverse production conditions.

Deterministic yield ($\bar{y}$)

$$\text{yield } (\bar{y}_{c,i,w}) = \frac{\text{Tones harvested (tones)}}{\text{Hectares havested (a)}} \quad (1)$$

Stochastic yield (y)

$$\tilde{y}_{i,w} = \bar{y}_{c,i,w} * \varepsilon \quad (2)$$

$$\varepsilon = y_{i,w} \quad \bar{y}_{c,i,w} \quad * \quad (3)$$

$$y_{i,w} = \bar{y}_{c,i,w} * (1 + EMP(S_{y,i,w}, P(S_{y,i,w}), CUSD_{y,i,w})) * \beta_{y_0} \quad (4)$$

Where:

~ = A tilde represents a random (stochastic) variable.
I = Type of farming practices used (no-fertilizer, organic fertilizer, inorganic fertilizer).
w = Represents farms in three regions/area (Zanzibar, Mainland, All farms)
ai = Hectares (ha) allocated for farming practice I
y = Individual farm yield
$\tilde{y}_i$ = Stochastic mean yield per ha for farming practice I
$\bar{y}_i$ = Deterministic (mean) yield per ha for farming practice I
β_{y_0} = The normalization factor, which is given by $\frac{\tilde{y}_{c,i}}{y_{h,i}}$ and it is used to scale/adjust the 2019/20 NCSA mean yield.
y_c = Stochastic yield for the current survey (2019/20 NCSA)
y_h = Stochastic yield for the historical or previous survey (2007/08 NCSA) (URT, 2012)
S_y = Fraction deviations from the mean or sorted array of random yields for farming practice *i*
$P(S_y)$ = Cumulative probability function for the S_y values
CUSDy = Simetar function to simulate the correlated uniform standard deviation of random variables.
EMP() = Simetar function used to simulate a stochastic variable (yield)

2.4 Fertilizer Impact Evaluation and Ranking of Target Probabilities

Both PDFs and Stoplight charts were used to evaluate the performance of fertilizers on maize and rice productivity. The PDF compared the baseline system (no fertilizer application) with alternative systems (organic or inorganic fertilizers). The Stoplight Chart function was used to rank the probability that maize and rice farms would achieve the maximum yield thresholds and fall below the minimum yield thresholds per unit area (in hectares, or ha, in this study). The stoplight function calculates the probabilities of (a) exceeding the upper target (green), (b) being less than the lower target (red), and (c) falling between the targets (yellow). The views from various maize actors, particularly farmers, and the literature review, including the current National Sample Census of Agriculture (NSCA) URT (2021), revealed that the average yield for the two crops in Tanzania ranges between 1 - 2 t/ha. hence, we set our minimum threshold to be 2.0 t/ha. Nevertheless, since the aim of most national initiatives, such as the ASDP-II (URT, 2016, 2017) and the Tanzania Seed Sector Development Strategy - 2030 (TSSDS 2030), is to double the productivity of major crops like maize and rice by 2030, we tested another scenario with high threshold values of 4.0 t/ha.

- Unfavorable probability or the probability of falling below the lower target (2.0 t/ha)
- Cautionary probability or the probability of falling between the lower and upper targets
- Favorable probability or the probability of falling above the upper target (4.0t/ha)

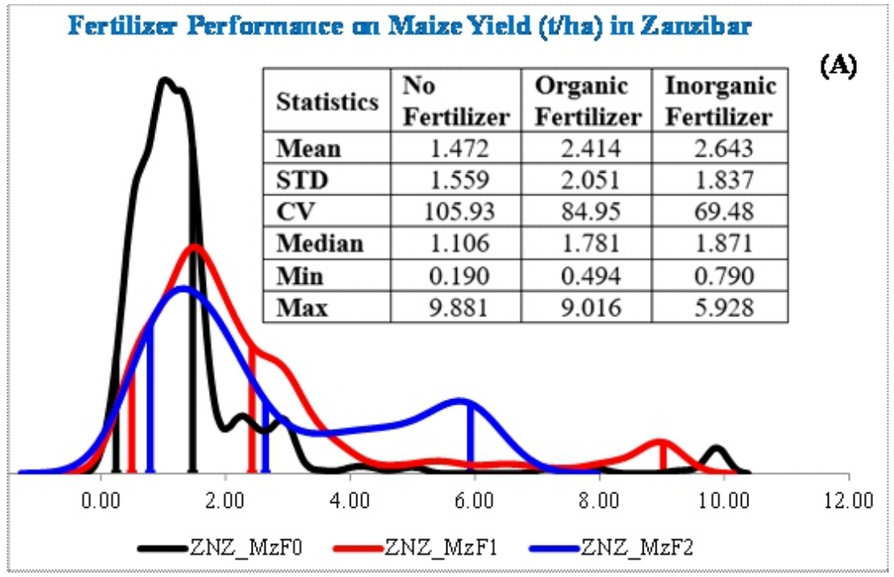
3.0 Results

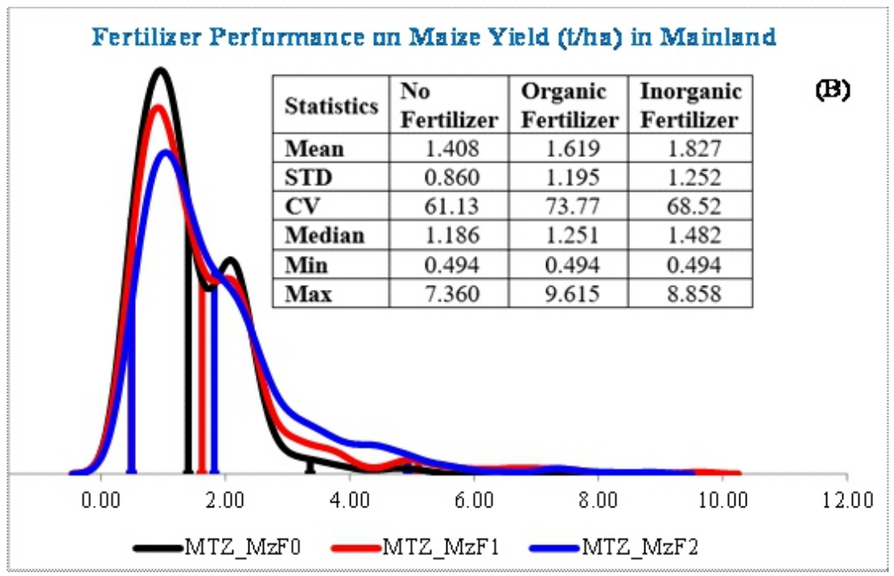
3.1. Impact of Fertilizers on Maize Productivity in Zanzibar, Mainland, and across all farms in Tanzania

Figure 3 illustrates the probability density functions of maize yields under three fertilizer regimes, no fertilizer, organic fertilizer, and inorganic fertilizer, across Zanzibar, Mainland Tanzania, and all farms combined. In Zanzibar, fertilizer use substantially increased yields, with mean productivity rising from 1.47 t/ha. for non-users to 2.41 t/ha. with organic fertilizer and 2.64 t/ha with inorganic fertilizer. Median yields showed similar improvements, and yield variability decreased markedly, indicating greater production stability.

On the Mainland, yields also improved with fertilizer application. Mean yields rose from 1.41 t/ha (no fertilizer) to 1.62 t/ha (organic) and 1.83 t/ha (inorganic). Median yields increased correspondingly, and coefficients of variation declined,

demonstrating enhanced yield consistency. Fertilizer also expanded the upper end of the yield distribution, raising maximum attainable yields. At the national level, fertilizer use consistently shifted the entire yield distribution upward. Mean yields increased from 1.40 t/ha to 1.61 t/ha (organic) and 1.82 t/ha (inorganic), while median yields also improved. Although occasional high yields occurred among non-fertilizer users, fertilizers yielded more reliably and stably. Both organic and inorganic fertilizers significantly enhance maize productivity and reduce variability, with inorganic fertilizer achieving the highest average performance.





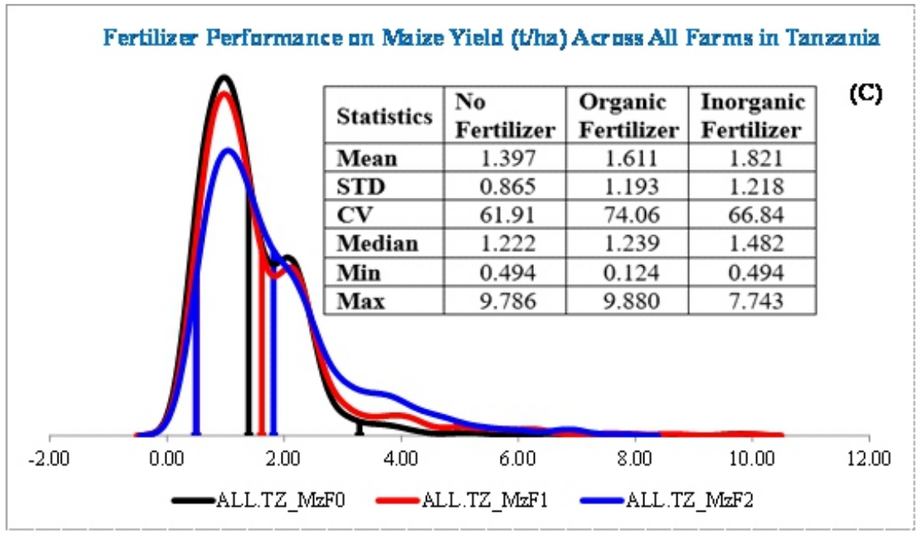


Figure 3: PDF charts showing the comparison of maize yield distributions for non-fertilizer users vs. farms using organic and inorganic fertilizers in Zanzibar (Panel A), Mainland (Panel B), and all farms across all regions of Tanzania (Panel C).

Figure 4 compares the probabilities of maize yields falling below 2.0 t/ha, lying between 2.0-4.0 t/ha, and exceeding 4.0 t/ha across Zanzibar, Mainland Tanzania, and the national sample for non-fertilizer users, organic fertilizer users, and inorganic fertilizer users. Non-fertilizer users face the highest risk: 85% of Zanzibar farmers, 77% of Mainland farmers, and 80% of farmers nationally produce ?2.0 t/ha, with only 1-4% exceeding 4.0 t/ha. These patterns highlight severe nutrient constraints and low productivity among non-users. Organic fertilizer users perform noticeably better. The probability of low yields declines to 55% in Zanzibar, about 73% on the Mainland, and nationally. Moderate yields (2.0-4.0 t/ha) become more common, and the share exceeding 4.0 t/ha rises modestly to 11% in Zanzibar and 4-5% elsewhere, reflecting the positive effects of soil organic matter and improved nutrient cycling.

Inorganic fertilizer users achieve the strongest outcomes. In Zanzibar, 54% produce below 2.0 t/ha, 19% fall between 2.0-4.0 t/ha, and 27% exceed 4.0 t/ha, the highest observed. Mainland and national patterns also show improved yield probabilities, with 6-7% surpassing 4.0 t/ha. The results confirm a consistent progression: from no fertilizer to organic to inorganic, demonstrating the critical role of nutrient inputs in reducing the risk of low yield.

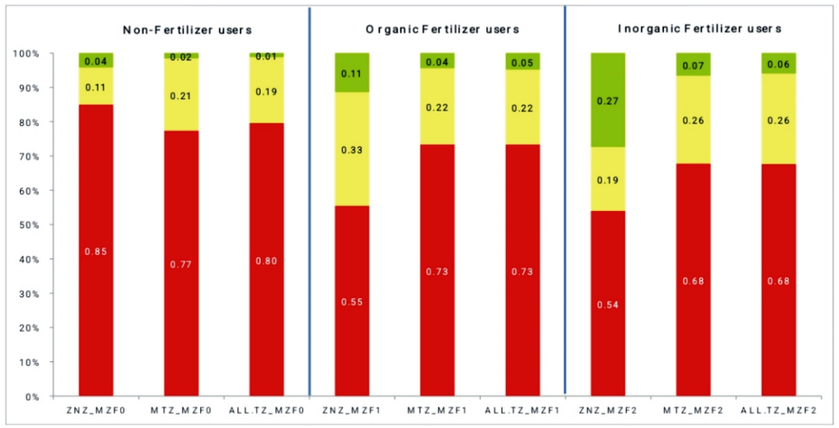


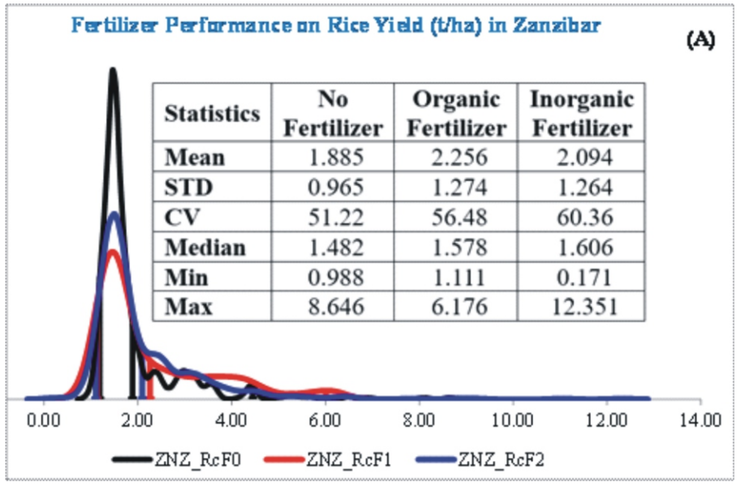
Figure 4: The probabilities of maize yield being above the potential maximum threshold of 4.0 t/ha (in green) and less than the national average yield of 2.0 t/ha (in red), and the probability of falling between the two thresholds for maize farmers using no fertilizers, vs. farms using organic and inorganic fertilizers a in Zanzibar, Mainland and across all farms in Tanzania. Note: ZNZ_MZF0 = non-fertilizer users in Zanzibar; MTZ_MZF0 = non-fertilizer users in mainland Tanzania; ALL.TZ_MZF0 = non-fertilizer users across all farms in Tanzania; ZNZ_MZF1 = organic fertilizer users in Zanzibar; MTZ_MZF1 = organic fertilizer users in mainland Tanzania; ALL.TZ_MZF1 = organic fertilizer users across all farms in Tanzania; ZNZ_MZF2 = inorganic fertilizer users in Zanzibar; MTZ_MZF2 = inorganic fertilizer users in mainland Tanzania; ALL.TZ_MZF2 = inorganic fertilizer users across all farms in Tanzania.

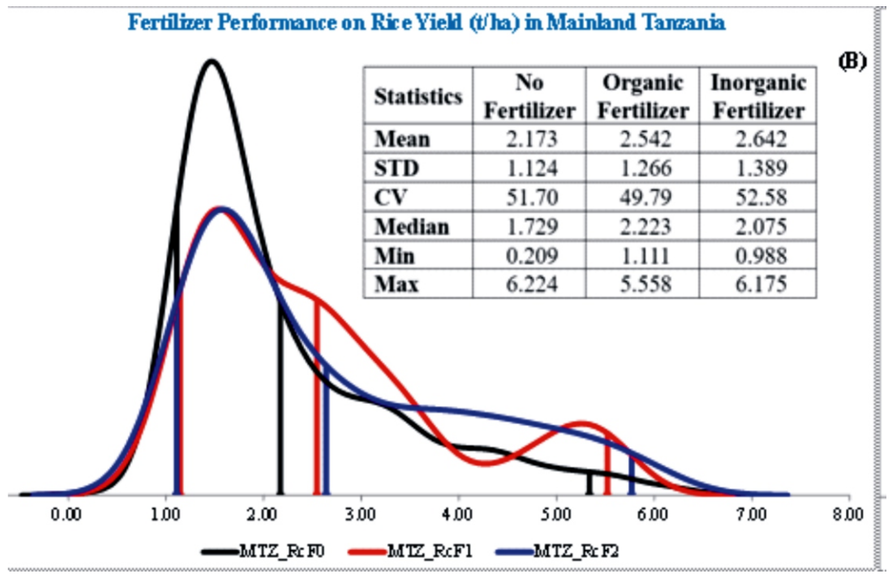
3.2. Impact of Fertilizers on Rice Productivity in Zanzibar, Mainland, and Across All Farms in Tanzania

Figure 5 compares rice yield distributions for non-fertilizer, organic fertilizer, and inorganic fertilizer users across Zanzibar, Mainland Tanzania, and the national sample. The probability density functions and descriptive statistics illustrate how fertilizer use affects average yields, variability, and yield extremes. In Zanzibar, fertilizer use increases average rice yields: mean yields rise from 1.89 t/ha (no fertilizer) to 2.26 t/ha (organic) and 2.09 t/ha (inorganic). Median yields follow a similar trend. Variability increases modestly with fertilizer, as CV rises from 51% to about 56-60%. Minimum yields are higher with organic fertilizer but drop to 0.17 t/ha with inorganic fertilizer, due to a few outliers. However, maximum yields rise sharply with inorganic fertilizer, reaching 12.35 t/ha. demonstrating its ability to drive exceptionally high performance in some fields.

On the Mainland, the benefits of fertilizer are clearer and more consistent. Mean yields increase from 2.17 t/ha for non-users to 2.54 t/ha with organic fertilizer and 2.64 t/ha with inorganic fertilizer. Median yields also rise, and minimum yields improve substantially, indicating reduced risk of extremely poor harvests. Maximum yields reach 6.18 t/ha under inorganic fertilizer, slightly above organic users, and comparable to the highest non-user performance. Variability remains relatively stable, suggesting fertilizer improves yields without substantially increasing risk. Nationally, fertilizer use raises mean yields from 2.16 t/ha to 2.49 t/ha (organic) and 2.51 t/ha (inorganic). Median yields improve similarly. Minimum yields increase dramatically with fertilizer, rising from 0.06 t/ha to nearly 1.0 t/ha for both fertilizer types. Inorganic fertilizer again delivers the highest maximum yields, over 11 t/ha, far exceeding outcomes for non-users or organic users.

Across all regions, fertilizer application improves mean and median yields and reduces the probability of extremely low rice production. Organic fertilizer yields moderate gains through gradual nutrient release and soil improvement. Inorganic fertilizers deliver the largest increases and the highest potential yields, though slightly higher variability suggests the need for complementary management practices. Overall, the results confirm the critical role of fertilizer, especially inorganic, in closing rice yield gaps and enhancing national food security.





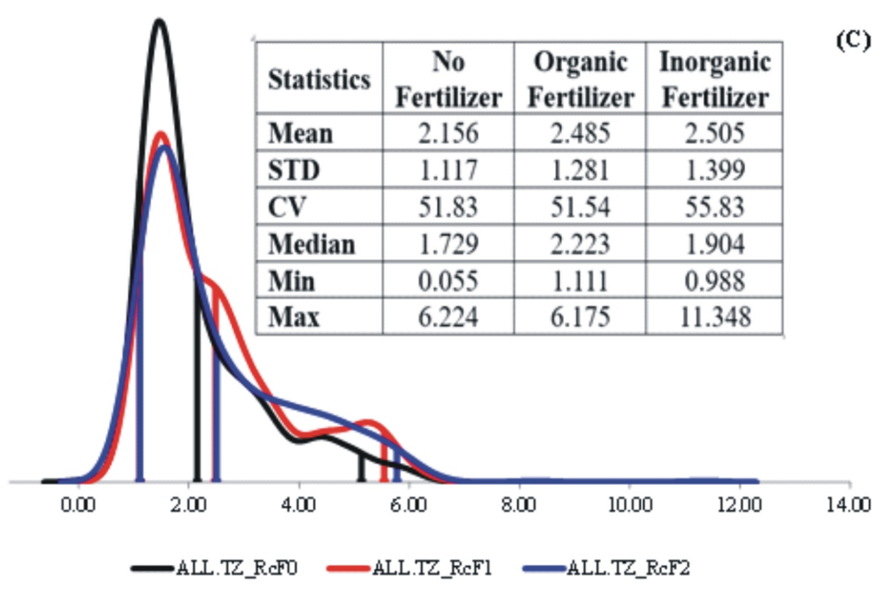


Figure 5: PDF charts showing the comparison of rice yield distributions for non-fertilizer users vs. farms using organic and inorganic fertilizers in Zanzibar (Panel A), Mainland (Panel B), and all farms across all regions of Tanzania (Panel C).

Figure 6 presents the probability distributions of rice yields for non-fertilizer users, organic fertilizer users, and inorganic fertilizer users across Zanzibar, Mainland Tanzania, and the national sample. The distributions show clear differences in low-yield risk, likelihood of achieving moderate yields, and the potential for high productivity. For non-fertilizer users, the probability of producing ?2.0 t/ha is very high-80% in Zanzibar, 62% on the Mainland, and 63% nationally, indicating severe nutrient limitations. Only 16-29% of farmers achieve moderate yields of 2.0-4.0 t/ha, and just 4-10% surpass 4.0 t/ha. These results highlight a substantial yield gap and the vulnerability of rice production when no nutrient inputs are applied.

Organic fertilizer users show notable improvements. Low-yield probabilities drop to 64% in Zanzibar, 43% on the Mainland, and 47% nationally. Moderate-yield outcomes increase substantially, reaching 24-43% across regions. The share of farmers exceeding 4.0 t/ha rises to 13% in Zanzibar, 14% on the Mainland, and 15% nationally. These improvements reflect the benefits of organic amendments in enhancing soil organic matter, moisture retention, and nutrient cycling. Inorganic fertilizer users achieve the best results. In Zanzibar, low yields decline to 69%, moderate yields increase to 25%, and high yields reach 6%. Much stronger responses appear on the Mainland, where low-yield risk drops to 47%, 32% achieve 2.0-4.0 t/ha, and 20% exceed 4.0 t/ha. Nationally, inorganic fertilizer users achieve 54% low yields, 30% moderate yields, and 17% high yields-nearly doubling the national high-yield probability compared to non-fertilizer users. A clear gradient emerges: non-fertilizer users perform the poorest, organic fertilizer users achieve moderate improvements, and inorganic fertilizer users perform best. Fertilizer use, particularly inorganic, raises the probability of high yields while reducing the risk of very low yields. These results underscore the importance of expanding fertilizer access and adopting integrated soil fertility management tailored to regional conditions to sustainably increase rice productivity across Tanzania.

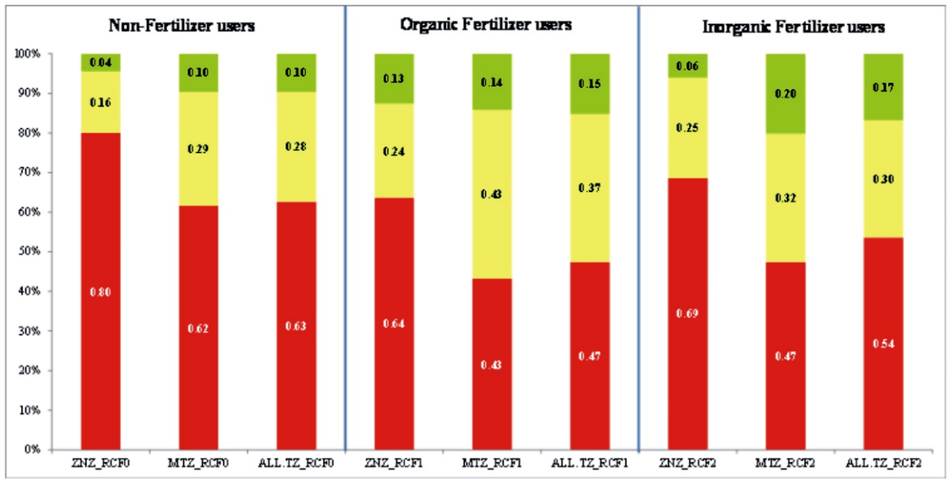


Figure 6: *The probabilities of rice yield being above the potential maximum threshold of 4.0 t/ha (in green) and less than the national average yield of 2.0 t/ha (in red), and the probability of falling between the two thresholds for rice farmers using no fertilizers, vs. farms using organic and inorganic fertilizers a in Zanzibar, Mainland and across all farms in Tanzania. Note: ZNZ_RCF0 = non-fertilizer users in Zanzibar; MTZ_RCF0 = non-fertilizer users in mainland Tanzania; ALL.TZ_RCF0 = non-fertilizer users across all farms in Tanzania; ZNZ_RCF1 = organic fertilizer users in Zanzibar; MTZ_RCF1 = organic fertilizer users in mainland Tanzania; ALL.TZ_RCF1 = organic fertilizer users across all farms in Tanzania; ZNZ_RCF2 = inorganic fertilizer users in Zanzibar; MTZ_RCF2 = inorganic fertilizer users in mainland Tanzania; ALL.TZ_RCF2 = inorganic fertilizer users across all farms in Tanzania.*

4. Discussion

The results clearly demonstrated that fertilizer use substantially increases maize yields across Zanzibar, Mainland Tanzania, and the national level. Non-fertilizer users consistently recorded the lowest yields (≈ 1.4 t ha^{-1}) and the highest probability (>75%) of falling below the national average of 2 t ha^{-1}, reflecting widespread soil nutrient depletion, particularly nitrogen deficiency, a dominant constraint in Sub-Saharan Africa (Vanlauwe *et al*., 2010; Smalingand Dixon, 2006). Inorganic fertilizer users achieved markedly higher mean yields (1.8-2.6 t ha^{-1}) and reduced the risk of low productivity to 55-68%, aligning with evidence that mineral fertilizer improves crop vigor and stabilizes yields under rainfall variability (Denning *et al*., 2009; Sheahan and Barrett, 2017). The results also reveal significant spatial heterogeneity. Zanzibar farmers experienced the largest relative yield gains from fertilizer, whereas Mainland farmers recorded moderate but consistent improvements. These differences reflect variations in soil fertility, climate, and farming practices, reinforcing the argument that uniform fertilizer recommendations are inefficient (Tittonell and Giller, 2013). Integrated soil fertility management (ISFM), combining fertilizers with organic inputs and tailored nutrient strategies, is therefore essential to sustain productivity (Vanlauwe *et al*., 2015; Negassa *et al*., 2007, 2012).

Rice productivity also responded strongly to fertilizer application but followed distinct patterns. Nationally, inorganic fertilizer increased mean yields from 2.16 t ha^{-1} to over 2.5 t ha^{-1}, while the probability of surpassing 4 t ha^{-1} rose from 10% to 17%. These outcomes are consistent with literature emphasizing the importance of nitrogen and potassium for rice growth in African and Asian systems (Fageria *et al*., 2011a, 2011b; Becker and Johnson, 2001). Organic fertilizer users, particularly on the Mainland, achieved median yields comparable to those of inorganic fertilizer users, reflecting the soil-conditioning benefits of organic inputs (Deep *et al*., 2018; Fungo *et al*., 2013). However, inorganic fertilizer delivered the highest maximum yields (>11 t ha^{-1}), confirming its critical role when combined with adequate water management (Dobermann and Fairhurst, 2000).

Regional variation again emerged, with Zanzibar showing a weaker response to inorganic fertilizer, likely due to salinity challenges or limited irrigation infrastructure (Hoffman et al., 2018). These findings underscore the need for zone-specific fertilizer and water management strategies (Wopereiset al., 2008). Together, the maize and rice results highlight fertilizers as a cornerstone for achieving Tanzania's food security and poverty reduction goals. Fertilizer use consistently raised mean and median yields while lowering the probability of sub-threshold performance, supporting national strategies such as Kilimo Kwanza and the NRDS (URT, 2021). However, fertilizers alone are insufficient to reach potential yields of 4 t ha^{-1} for maize and 5 t ha^{-1} for rice. Persistent under performance even among fertilizer users points to complementary constraints, including poor soil organic matter, low pH, limited irrigation, and insufficient extension support (Matsumoto and Yamano, 2010, 2012; Liverpool-Tasie *et al*., 2017). Climate variability further threatens yields, with projected reductions of 7-13% by mid-century (Ray *et al*., 2015; Rowhani *et al*., 2011).

Thus, achieving sustainable productivity gains requires ISFM, improved seeds, irrigation, and strengthened extension services (Vanlauwe *et al*., 2017). Policymakers must promote targeted subsidies, reliable supply chains, and tailored fertilizer recommendations to address agroecological diversity (Jayne and Rashid, 2013; Holden and Lunduka, 2013). Such measures directly advance SDGs 1, 2, and 13 by improving yields, incomes, and climate resilience.

5. Conclusions

This study demonstrated that fertilizer application is a decisive factor in improving the productivity and stability of Tanzania's two most important cereals, maize and rice. Across Zanzibar, the Mainland, and the national aggregate, both mean and median yields rose substantially when either organic or inorganic fertilizers were used, while the probability of low yields fell. For maize, the use of inorganic fertilizer increased the likelihood of surpassing the 4.0 t ha^{-1} benchmark from a negligible 1% among non-users to 6%, while reducing the probability of falling below the national average (2.0 t ha-1) from 80% to 68% at the national level. For rice, the use of inorganic fertilizer nearly doubled the probability of achieving ≥4 t ha^{-1}, from 10% to 17%, and consistently lowered the risk of crop failure. Nevertheless, the analysis also

reveals that fertilizer alone cannot close the yield gap. Even among farmers who use fertilizers, high proportions still fail to reach their national potential yields, reflecting constraints such as soil degradation, poor water management, and limited access to extension services. Regional variability highlights the necessity for site-specific nutrient management and integrated soil fertility strategies that incorporate both inorganic and organic inputs, along with improved seeds, timely application, and climate-resilient water management.

By providing nationally representative, zone-disaggregated evidence, this research strongly supports policy actions to scale fertilizer adoption through targeted subsidies, reliable input supply chains, and farmer training. Implementing integrated soil fertility management can significantly enhance smallholder incomes and food security, directly advancing Sustainable Development Goals 1 (No Poverty), 2 (Zero Hunger), and 13 (Climate Action).Overall, the findings leave little doubt: strategic fertilizer use, embedded in broader agronomic and climate-resilient practices, is essential for transforming Tanzania's maize and rice systems from low-input subsistence farming to productive, market-oriented agriculture capable of feeding a growing population and withstanding the pressures of climate change.

Data availability
Upon request

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Conflicts of Interest
The authors declare no conflicts of interest.

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Influence of Different Nitrogen Fertilizer Rates on the Growth and Yield of king of Bitters *(Andrographis paniculata)*

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Abstract
The global demand for medicinal plants as alternatives to conventional medicine has increased, with King of Bitters (Andrographis paniculata) gaining recognition for its health benefits. To meet this demand and promote sustainable production, fertilizer application is vital. However, information on the optimal use of fertilisers for King of Bitters remains limited. This study aimed to fill this knowledge gap by examining the effects of different nitrogen levels on the yield of King of Bitters under controlled conditions.
Conducted over two planting seasons at the University of Ibadan, Nigeria, the study employed a randomised complete block design, testing NPK rates (0, 20, 40, 60, 80 kg N ha?¹). Data on plant growth, yield, biomass, and phytochemical content were collected. Results showed that 20 kg N/ha yielded the highest fresh (3.63g/plant) and dry (0.87g/plant) weights of King of Bitters at 8 weeks after planting. A strong positive correlation was observed between leaf number for both fresh and dry weight. Excessive fertiliser application at 40,60, and 80kg/ha resulted in reduced yield, highlighting the importance of balanced and sustainable nutrient management in medicinal plant cultivation. These results provide evidence to guide nitrogen input strategies for maximizing medicinal crop productivity in organic and agroecological farming systems.Based on the findings, it is recommended that commercial King of Bitters cultivators apply 20 kg N/ha of NPK 15-15-15 to enhance plant yield and quality, ensuring optimal economic outcomes.

Keywords: King of bitters (Andrographis paniculata),Medicinal Plants,NPK 15-15-15 Fertiliser,Yield, Quality.

Résumé
La demande mondiale de plantes médicinales comme alternatives à la médecine conventionnelle a augmenté, et l'Andrographis paniculata (roi des amers) est de plus en plus reconnue pour ses bienfaits sur la santé. Afin de répondre à cette demande et de promouvoir une production durable, la fertilisation est essentielle. Cependant, les informations sur l'utilisation optimale des engrais pour l'Andrographis paniculata restent limitées. Cette étude visait à combler cette lacune en examinant les effets de différentes doses d'azote sur le rendement de l'Andrographis paniculata en conditions contrôlées. Menée sur deux saisons de culture à l'Université d'Ibadan, au Nigéria, l'étude a utilisé un dispositif expérimental en blocs complets randomisés, testant des doses de NPK (0, 20, 40, 60 et 80 kg N ha?¹). Des données sur la croissance, le rendement, la biomasse et la teneur en composés phytochimiques ont été collectées. Les résultats ont montré qu'une dose de 20 kg N/ha permettait d'obtenir les poids frais (3,63 g/plante) et sec (0,87 g/plante) les plus élevés d'Andrographis paniculata huit semaines après la plantation. Une forte corrélation positive a été observée entre le nombre de feuilles et le poids frais et sec. L'application excessive d'engrais (40, 60 et 80 kg/ha) a entraîné une réduction des rendements, soulignant l'importance d'une gestion équilibrée et durable des nutriments pour la culture des plantes médicinales. Ces résultats permettent d'orienter les stratégies d'apport d'azote afin d'optimiser la productivité des cultures médicinales en agriculture biologique et agroécologique. Il est donc recommandé aux producteurs

commerciaux d'Andrographis paniculata d'appliquer 20 kg N/ha d'engrais NPK 15-15-15 pour améliorer le rendement et la qualité des plantes, et ainsi garantir une rentabilité optimale.

Mots-clés : Andrographis paniculata, Plantes médicinales, Engrais NPK 15-15-15, Rendement, Qualité.

Introduction

Sustainable crop production is a fundamental concern, particularly in resource-poor regions of developing countries, where maintaining a delicate balance of nutrient availability over extended periods is crucial(Roberts & Mattoo, 2019;Sande *et al*., 2024). Fertilizers emerge as a linchpin in satisfying the ever-increasing food demands of the global population, particularly in areas with limited soil resources(Biramo, 2018;Daniel et al., 2022; Silver et al., 2021). Fertilizer directly provides essential nutrients, bolstering plant growth and enhancing nutrient use efficiency, which can be targeted to specific crops (Ali *et al*. 2025). This process not only cultivates healthier soils but also optimizes nutrient use, thanks to the provision of necessary nutrients and microbes that boost plant growth and maintain soil fertility(Reetz, 2016;Shabbir *et al*., 2019)
However, in the context of tropical soils, there is an inherent challenge since tropical soils typically lack the necessary macro- and micronutrients in adequate quantities to support plant growth (McGrath, 2014;Vallicrosa *et al*., 2023). The International Fertiliser Association's research indicates that approximately 85% of soils worldwide are deficient in nitrogen, highlighting the need for additional sources of nutrition (International Fertilizer Industry Association, 1992). In African soils, nitrogen and secondary micronutrients are scarce, limiting crop production capacity (Kihara *et al*., 2017). This deficiency underscores a critical issue. Therefore, addressing soil fertility depletion is essential, as it remains a persistent barrier to increasing food production in Africa, regardless of other efforts.



Shifting our focus from crop production to healthcare, we discover another vital facet of natural resources - indigenous medicinal plants. Among these, King of bitters (Andrographis paniculata) has a rich history as a medicinal plant, offering relief from various ailments(Bhaisareet al, 2023; Chen X *et al.*, 2023). Indigenous medicinal plants and derived drugs are powerful reservoirs of alternative medicine, widely recognized for their efficacy in managing a diverse range of health conditions(Ahmed *et al*., 2013). These remedies hold a special place in primary healthcare practices primarily due to their availability, acceptability, compatibility, and affordability. Astonishingly, they serve as the first line of treatment for an estimated 75-80% of the population in developing countries and 25% in developed countries, either directly or indirectly (Burkill *et al*.,1966;Hajiaghaee, 2012). The growing interest in these therapeutic botanicals has led to a burgeoning movement advocating the local cultivation and refinement of these invaluable plants, incorporating them into diverse cultural and religious practices, to manage an extensive spectrum of illnesses effectively.

Hence, the objectives of the study. To determine the effects of NPK 15-15-15 fertilizer levels on King of Bitters' growth parameters, yield, and some pharmaceutical qualities, to determine the optimum level of nitrogen to produce King of Bitters.

Materials & Methods

The experiment was conducted in a screen house at the University of Ibadan using a randomized complete block design with five NPK 15-15-15 fertilizer levels (0, 20, 40, 60, and 80 kg N/ha) applied to soil bags, and treatments were replicated four times. King of bitters stem cuttings were planted after fertilizer application, data were collected on plant height, stem girth, and leaf number biweekly over 8 weeks, with results analysed using ANOVA and LSD for significance ($p<0.05$).

Results

Pre-planting Soil Analysis of the Experimental Soils.
The physical and chemical properties of the soil before planting are shown in Table 1. The pH of the soil was measured to be 5.3, indicating that the soil is moderately acidic. The organic carbon content of the soils was found to be moderate at

13.70 g/kg, which is within the normal range for agricultural soil. The total nitrogen content of the soil was measured to be 1.50 g/kg,which is low. Based on the results of the soil analysis, it may be necessary to supplement the soil with nitrogen fertilizers to ensure optimal plant growth.

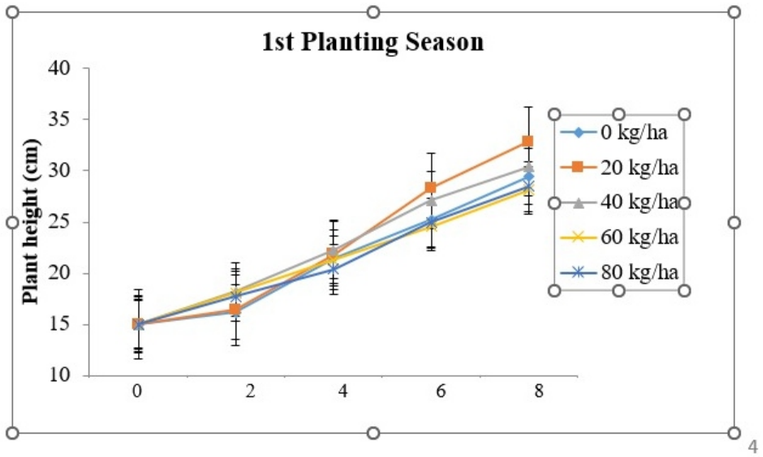
Parameters	Value	*Critical value(Chude*et al*, 2012
pH 1:1 (H_2O)	5.3	Moderately acidic
O C (g/kg)	13.7	Medium
N (g/kg)	1.5	low
(mg/kg) P	16	High
Cations (cmol/kg)		
K	0.3	Medium
Ca	5.5	High
Mg	4.5	
Na	0.2	
Micronutrients (mg/kg)		
Mn	96	
Fe	67	
Cu	1	High
Zn	3	High
Particle size analysis (g/kg)		
Sandy	800	
Silt	110	
Clay	90	
Textural Class	Loamy Sand	

(Source: Agboola and Ayodele, 1985)

Effect of NPK 15-15-15 fertilizer levels on the height of King of Bitters

Figures(I& ii)illustrate plant height variations across weeks for different fertilizer treatments. The resultrevealed that 20kg N/ha of NPK fertilizer led to the tallest plants at 8WAP (35 cm), followed by 40kg N/ha (30 cm), while the control reached 28 cm at 8WAP during the first planting season. Notably, the highest stem height occurred at 2WAP.During the

second planting season, 20kg N/ha resulted in the tallest plants (42cm at 8WAP), while the control treatment peaked with 34cm at 8WAP. Thesefindings highlight the significant



impact of Nitrogen treatments on plant growth during the second planting season.

WAP

Figure (i): Effect of NPK 15-15-15 fertilizer levels on the height of King of bitters

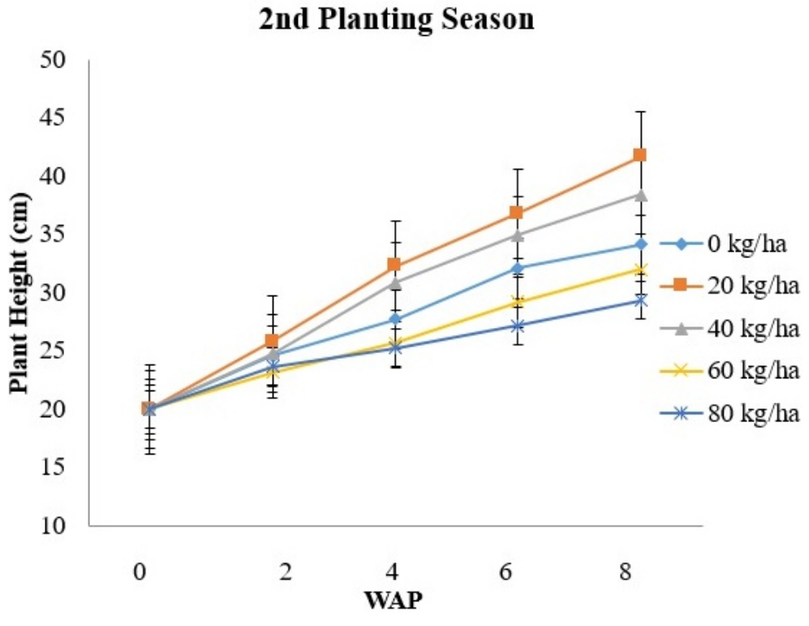


Figure (ii): Effect of NPK 15-15-15 fertilizer levels on the height of King of Bitters
WAP - Weeks after planting.

Effect of NPK 15-15-15 fertilizer levels on the Stem girth of King of Bitters.

Results presented in Figures(iii & iv) show that the application of NPK 15-15-15 fertilizer significantly affected stem girth in King of Bitters across treatments and planting seasons. In the first season, the highest stem girth at 8WAP was 0.30cm for 40kg N/ha, while control and 20kg N/ha both peaked at 0.24cm. During the second season, 60kg N/ha gave the maximum stem girth (0.32cm), followed by 40kg N/ha (0.28cm) and 20kg N/ha (0.27cm), whereas the control showed a decline from 0.22cm at 2WAP to 0.18cm at 4WAP.

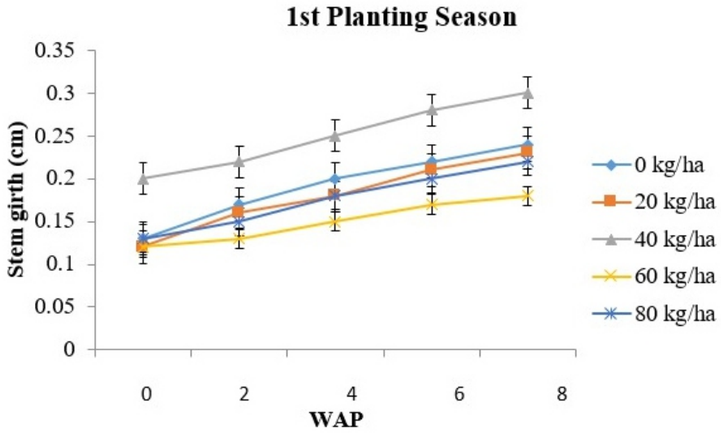


Figure (iii): Effect of different rates of NPK 15-15-15 fertilizer on the stem girth of King of bitters
WAP - Weeks after planting.

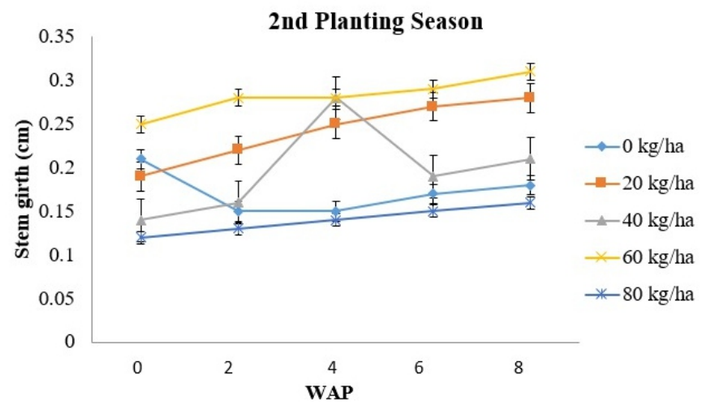
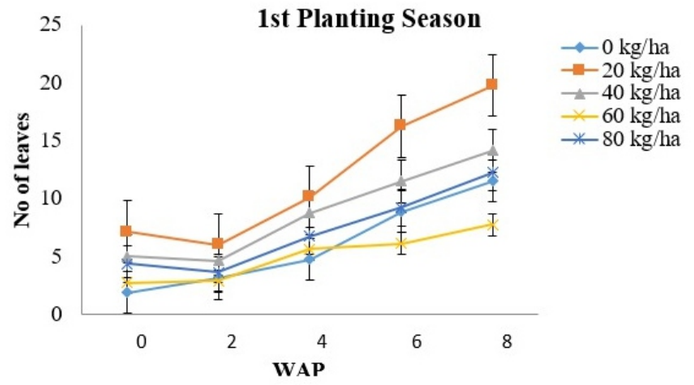


Figure (iv): Effect of different rates of NPK 15-15-15 fertilizer on the stem girth of King of Bitters
WAP - Weeks after planting.

Effect of different rates ofNPK 15-15-15 fertilizer on the Number of leaves of King of Bitters.

The results shown in (Fig.v & vi) revealed that the application of a fertilizer rateof 20 kg N /ha had the highest number of leaves in the first and second seasons,with 20 and 19 leaves,respectively,at 8 weeks after planting (WAP).Conversely, the control had the lowest number of 12 leaves at 8WAP for both seasons. The results also indicate that a higher dose of the treatment (80kg N /ha) may not necessarily lead to a higher number of leaves in the crop



compared to other rates within corresponding weeks.

Figure (v): Effect of NPK 15-15-15 fertilizer levels on the Number of leaves of King of bitters.
WAP - Weeks after Planting

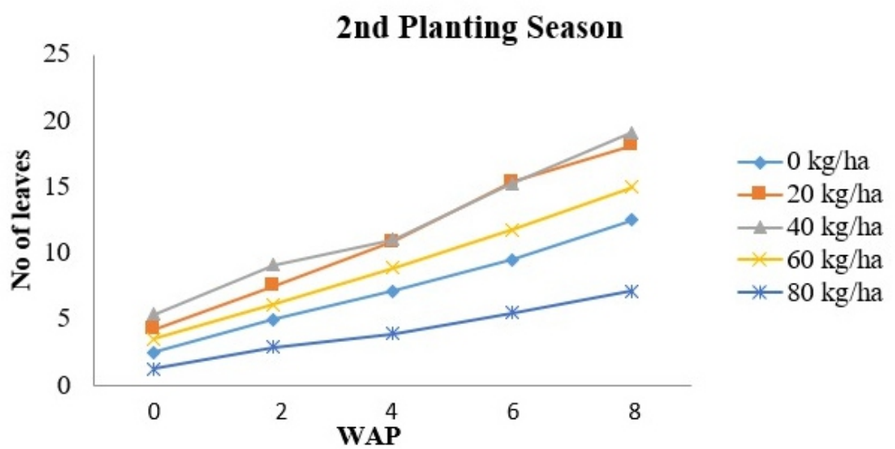


Figure (vi): Effect of NPK 15-15-15 fertilizer levels on the Number of leaves of King of Bitters.

WAP - Weeks after Planting

Effect of varying rates of NPK 15-15-15 fertilizer application on fresh and dry weight of King of Bitters.

The results shown inTable 2revealed that increasing NPK 15-15-15 fertilizer rates had varying effects on the fresh and dry weights of King of Bitters. In the first season, the highest fresh weight (3.51g/plant) occurred at 20 kg/ha, while in the second season, the highest fresh weight (4.75g/plant) was at 40 kg/ha. The maximum dry weight (1.08g/plant) was observed at 80 kg/ha for both seasons.

Table 2: Effects of differentNPK 15-15-15 fertilizer rates on fresh and dry weight of King of Bitters

	Fresh Weight(g/plant)		Dry weight(g/plant)	
Treatments	FPS	SPS	FPS	SPS
0 kg N /ha	2.21	4.78	0.63	1.00
20 kg N/ha	3.51	3.75	0.94	0.81
40 kg N /ha	2.64	4.75	0.74	1.06
60 kg N/ha	1.78	4.30	0.60	0.90
80 kg N /ha	2.54	2.66	1.08	0.56
LSD	*0.34*	*0.27*	0.21	*0.34*

FPS – First Planting Season,SPS – Second Planting Season,LSD – Least Significant Difference,N - Nitrogen

Correlation between growth parameters and the Yield of King of Bitters

Table 3 shows that there are notable positive correlations among growth and yield parameters in King of Bitters.Stem girth and plant height are negatively correlated (r = 0.424), while a strong correlation exists between leaf number and plant height (r = 0.680). Fresh weight strongly correlates with leaf number (r = 0.730), dry weight with leaf number (r = 0.572), and a strong correlation is observed between dry weight and fresh weight (r = 0.795).

Table 3. Correlation between growth parameters and the yield of King of bitter

	Plant Height	Stem girth	Leaf no.	Fresh weight
Stem girth	0.424			
Leaf no.	0.680**	0.382		
Fresh weight	0.371	0.361	0.730**	
Dry weight	0.053	0.262	0.572**	0.795**

Level of significance

Discussion

This present study focused on investigating the effect of NPK 15-15-15 fertilizer on the improvement of the yield and biomassof King of Bitters. The investigation showed that varied fertilizer quantitiesinfluence the yield and quality of King of Bittersused in this experiment. Findings from the results for bothfirst and second planting seasons revealed that the height of the King of bitters was significantly influenced by the application of treatment with 20kg N /ha of NPK 15-15-15which is like results from previous studies (Nishchithaet al., 2018. Nimatuet al., 2022, Sharma et al., 2024), where treatment of 20kg N /ha of NPK fertilizer resulted in the highest plant height of 35cm at 8WAP for the first season and treatment of 20kg N /ha resulted in the tallest plant height for the second season, reaching up to 42cm at 8 weeks after planting.

Furthermore, it was also observed from the results that the application of NPK 15-15-15 fertilizer caused a significant increase in the stem girth of medicinal plants, as in the case of King of Bitters(Oloyede,2012;Fagbenroet al., 2013). Treatment with 40kg N/ha of NPK fertilizer exhibited the highest peak stem girth of 0.30cm at 8WAP for the first season, while treatment with 60kg/ha gavethe highest stem girthfor all the treatments at 0.32cm in the second season. The number of leaves recorded for treatment at 20 kg N/ha was highest in both seasons of planting, with 20 and 19, respectively, which agrees with the report that the application of 20kg N/ha of the treatment is effective in increasing the number of leaves in King of bitters (Sulandjariet al., 2021;Aluko, 2021).

From the results, it was also shown that increasing the level of fertilizer tends to have different effects on the fresh weight and dry weight of the leaves. As such, the optimum fresh weight was observed at the treatment of 20 kg N/ha of fertilizer at (3.63g/plant) for both seasons, while the optimum dry weight for both seasons was observed as 0.87g/plant at 20kg N/ha. Overall, the results suggest that the application of 20kg N/ha of fertilizer may have the most significant effect on increasing the fresh weight of the studied plant species.

Also,plant height was noted to have a strong positive correlation of 0.680 with leaf number, indicating that an increase in leaf number is associated with an increase in plant height. A strong positive correlation between fresh weight and dry weight with leaf number, with a correlation coefficient of 0.730 and 0.572, respectively, indicating that an increase in fresh and dry weight is associated with an increase in leaf number (Safaa Najla et al., 2012). There is a strong positive correlation between Dry weight and Fresh weight, with a correlation coefficient of 0.795, indicating that an increase in dry weight is strongly associated with an increase in fresh weight. (Sharma et al., 2024)

Conclusion and Recommendation

Balanced fertilization with NPK nutrition is essential for the healthy growth of most plants, including medicinal plants. This investigation specifically focused on the influence of nitrogen fertilizer levels on the yield and quality of King of Bitters. These findings suggest that the application of 20kg N /ha of NPK 15-15-15 fertilizer significantly increased the yield of King of Bittersin terms of fresh and dry weight. The recommendation of applying 20 Kg N /ha of NPK 15-15-15 amendment is justified by the results of this research studyandindicates that this treatment is more cost-effective compared to the application of higher rates. Therefore, adopting the recommended treatment will not only improve the yield and quality of the crop but also maximize the farmer's profitability.

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Evaluation of Biofertiliser as a Sustainable Fertiliser In Crop Production

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Abstract
Recent decades have witnessed increased crop production to match the global demand for food, feed, and pharmaceuticals by the increasing human population. Conventional agricultural practices are heavily reliant on artificial fertilisers that have numerous human and environmental health effects. In-view of this, sustainability/Agroecologist researchers and environmentalists have increased their focus on sustainable crop fertilization mechanisms. Biofertilisers are microbial formulations constituted of indigenous plant growth-promoting microbes (PGPM) that directly or indirectly promote plant growth through the fixation, solubilization, and mobilization of soil nutrients, and the production of plant growth-stimulating hormones and iron-sequestering metabolites called siderophores. Biofertilisers have continually been studied, recommended, and even successfully adopted to produce many crops in the world. These microbial products hold massive potential as sustainable crop production tools, especially in the wake of climate change that is partly fueled by artificial fertilisers. Despite the growing interest in the technology, its full potential has not yet been achieved, and utilization still seems to be in its infancy. There is a need to shed light on the past, current, and prospects of biofertilisers to increase their understanding and utility. This review evaluates the history of PGPR biofertilisers, assesses their present utilization, and critically advocates their future in sustainable crop production and the global biofertiliser market. It, therefore, updates our understanding of the evolution of PGPR biofertilisers in crop production. Such information can facilitate the evaluation of their potential and ultimately pave the way for increased exploitation

Keywords: Bio-fertiliser, Crop production, Evaluation, Sustainable fertiliser

Résumé
Ces dernières décennies ont été marquées par une augmentation de la production agricole afin de répondre à la demande mondiale en alimentation humaine et animale, ainsi qu'en produits pharmaceutiques, liée à la croissance démographique. Les pratiques agricoles conventionnelles dépendent fortement des engrais artificiels, qui ont de nombreux effets néfastes sur la santé humaine et l'environnement. Face à ce constat, les chercheurs en développement durable/agroécologie et les environnementalistes se sont davantage intéressés aux mécanismes de fertilisation agricole durable. Les biofertilisants sont des formulations microbiennes composées de micro-organismes indigènes favorisant la croissance des plantes (PGPM), qui stimulent directement ou indirectement cette croissance par la fixation, la solubilisation et la mobilisation des nutriments du sol, ainsi que par la production d'hormones de croissance et de métabolites séquestrant le fer, appelés sidérophores. Les biofertilisants ont fait l'objet d'études continues, ont été recommandés et ont même été adoptés avec succès pour la production de nombreuses cultures à travers le monde. Ces produits microbiens présentent un potentiel considérable en tant qu'outils de production agricole durable, notamment dans le contexte du changement climatique, en partie alimenté par les engrais artificiels. Malgré l'intérêt croissant pour cettetechnologie, son plein potentieln'estpas encore atteint et son utilisation semble encore à ses débuts. Il est nécessaire de faire la lumière sur le passé, l'étatactuel et les perspectives d'avenir des biofertilisantsafind'améliorerleur compréhension et leur utilisation. Cette étude évaluel'historique des biofertilisants PGPR, analyse leur utilisation actuelle et défend de manière critique leur avenir dans la production agricole durable et sur le marchémondial des biofertilisants. Elle actualise ainsinotrecompréhension de l'évolution des biofertilisants PGPR en agriculture. Cesinformationspeuventfaciliterl'évaluation de leurpotentiel et, à terme, ouvrir la voie à une exploitation accrue.

Mots-clés: Biofertilisant, Production agricole, Évaluation, Engrais durable

Introduction

The potentials of biofertiliser in crop production for sustainable Agriculture

The global population will be 10 billion people by 2050, thus high pressure will be mounted on the existing food resources (United Nations, 2015). The global agriculture sector has been confronted with increasing challenges in its efforts to adopt environmentally sustainable methods in recent times (Assede *et al*., 2025). There are concerns about conventional fertilisers' environmental impacts and their contribution to soil degradation; the focus has shifted toward alternative, environmentally friendly solutions (Chakraborty *et al*., 2025; Odedra et al., 2025).

Although global crop production can be achieved through agricultural intensification, this will escalate reliance on chemical agro inputs like fertilisers that pose several environmental effects (Vassilev et al., 2015; Abhilash *et al*., 2016b). Although chemical fertilisers (which are mainly composed of N, P, or K) are widely used in contemporary farming methods, only a small portion (30-40%) of these nutrients is taken up by plants because of low fertiliser-use efficiency (Ye *et al*., 2025), the remainder is lost to the soil and pollutes the environment. By 2050, it is predicted that the global trend of synthetic N-fertiliser usage will have increased by 1.7 times (Akhtar *et al*., 2021). Hence, environmental problems are made even more pressing by the enduring presence of radio nuclides and heavy metals in chemical fertilisers (Kelepertzis, 2014)

For instance, chemical fertilisers are extensively associated with greenhouse gas emissions that fuel global warming and climatic changes (Kahrl *et al*., 2010; Mapanda *et al*., 2011; Carmo *et al*., 2013). Similarly, the eutrophication of several water bodies and the destabilization of aquatic ecosystems have several times been attributed to fertiliser runoffs from agricultural fields (Deepa and Venkateswaran, 2018; Zhang *et al*., 2018). Ironically, long-term artificial fertilization can also include the overall deterioration of soil productivity and quality through acidification (Neog, 2018; Bai *et al*., 2020; Yan *et al*., 2020). Owing to the aforementioned challenges, the exploration of alternative crop fertilization mechanisms is mounting worldwide in an attempt to develop sustainable food production systems. An innovative and promising solution to these problems has been the development of biofertilisers, which have ushered in a new era in agriculture (Debnath *et al*., 2019). It is essential to consider the biological health of the soil, nutrient availability, and soil quality while increasing crop production per unit area (Tilman *et al*., 2011)

The exploration of plant microbiomes has particularly gathered surmountable interest in this regard. Among the most interesting plant microbiomes are the plant growth-promoting Microbes (PGPM) that present several advantageous functions in plant rhizospheres, from nutrients solubilization (Ibarra-Galeana *et al*., 2017; Borgi *et al*., 2020; Verma *et al*., 2020), to suppression of plant diseases (Jayakumar *et al*., 2021), nitrogen (N2) fixation (Hara *et al*., 2020), and improved phytochemical composition (Rizvi *et al*., 2022a), among others. Probiotics, which are also called Biofertilisers, are microbial formulations of PGPM strains that can either be immobilized or trapped on inert carrier materials to enhance plant growth and soil fertility (Aloo *et al*., 2022a). Over the decades, considerable strides have been made to understand, investigate, and formulate various PGPM as alternative crop fertilization tools (Barin *et al*., 2022; Aloo *et al*., 2022b). The yield of various crops can be increased by about 25%, and the use of inorganic N and P fertilisers be reduced by about 25-50 and 25% through biofertiliser application (Saber *et al*., 2012).

The utilization of biofertilisers dates to ancient times when agricultural practices relied on organic amendments to enhance soil fertility. Today, a wide range of naturally occurring microorganisms, including bacteria, fungi, and algae, are referred to as biofertilisers because they stimulate plant development in different ways (Chakraborty and Akhtar 2021). Several developments have been made through the decades, and today, biofertiliser formulations are applied to produce several crops entirely or with reduced usage of artificial fertilisers. Despite these developments, biofertiliser technology is yet to be explored to its maximum potential. It is important to increase our knowledge of biofertilisers and their massive potential in the sustainability of food production systems to increase their utilization. This paper aims to explore the significant strides biofertilisers have made over the years, emphasizing their role as a sustainable and eco-friendly solution for modern crop production.

The review begins by delving into the concept and meaning of biofertilisers, analyzing their adoption rates, differences between biofertiliser and organic fertiliser and exploring the geographical distribution of their application. We aim to highlight successful instances of biofertiliser integration into conventional agricultural practices. Furthermore, we explore the underlying mechanisms through which these microorganisms enhance plant growth, unlocking the intricate interplay between soil-plant-microbe interactions. However, despite their potential, several issues surrounding

biofertilisers have hindered their widespread adoption. We critically evaluate the challenges of production, quality control, and formulation, which pose significant obstacles to their large-scale implementation. Additionally, the complex interactions between biofertilisers and other soil components necessitate a deeper understanding of their behaviour and efficacy in varying agro-climatic conditions.

The concept and definition

Biofertilisers are products that contain living microorganisms that exert direct or indirect beneficial effects on plant growth and crop yield through different mechanisms (Sharma and Kagdayet al., 2024).They are organic substances that contain living microorganisms or their metabolites, which can enhance nutrient availability and plant growth by various mechanisms. Biofertilisers are considered an eco-friendly and sustainable alternative to chemical fertilisers (Chakraborty and Akhtar 2021)

Biofertilisers can reduce greenhouse gas emissions and the dependence on fossil fuels for fertiliser production (Osorio-Reyes et al., 2023). They help to provide plants with essential nutrients such as nitrogen, phosphorus, and potassium. They can be applied to the soil either by soil application or seed priming, colonize the rhizosphere (Singh et al., 2021) or directly to the plant, and they work by improving the soil's ability to retain nutrients, thus making them more available to plants. Biofertilisers can also help improve soil structure and increase the presence of beneficial microbes in the soil (Sharma et al., 2012).

There are several types of Biofertilisers, each of which serves a specific purpose. For example, nitrogen-fixing Biofertilisers can help increase the nitrogen levels in the soil (Shridhar 2012). In contrast, phosphorus-solubilizing biofertilisers can help make the soil's phosphorus more available to plants (Kalayu 2019). Understanding the basics of biofertilisers is essential for any farmer looking to transition to organic farming or enhance the sustainability of their existing operation. By using Biofertilisers, farmers can improve soil health, increase crop yields, and reduce the environmental impact of their farming practices.

What is bio-fertiliser?

A bio-fertiliser is simply a substance that contains living microorganisms which, when applied to the soil, a seed or plant surface, colonizes the rhizosphere and promotes growth by increasing the supply or availability of nutrients to the host plant (Vessey, 2003). A bio-fertiliser is a modernized form of organic fertiliser into which beneficial microorganisms have been incorporated (Swathi, 2010). According to Hari and Perumal (2010) bio-fertiliser is most commonly referred to as selected strains of beneficial soil microorganisms cultured in the laboratory and packed in suitable carriers. In a large sense, the term biofertiliser may be used to include all organic resources for plant growth which are rendered in available form for plant absorption through microorganisms or plant associations or interactions (Khosro et al., 2012)

Importance of bio-fertilizers

Bio-fertilisers play an important role in improving the fertility of the soil. In addition, their application to soil improves the structure of the soil and minimizes the use of chemical fertilisers. Under low-land conditions, the application of blue-green algae (BGA) plus Azospirillum proved significantly beneficial in improving the yield of grain. Bio-fertilisers inoculation with Azotobacter and Rhizobium and Vesicular Arbuscular Mycorrhiza gave the highest increase in straw and grain yield of wheat plants with rock phosphate as phosphate fertiliser (Ritika et al., 2014). Azolla is inexpensive, economical, and eco-friendly, which provides benefits in terms of carbon and nitrogen enrichment of soil. It was recorded that microorganisms such as Bacillus subtilis, Thiobacillus thioxidans, and Saccharomyces species can fix atmospheric nitrogen symbiotically, and about 80-90% nitrogen demand could be supplied by soya bean through symbiosis (Ritika et al., 2014). Biocontrol, a modern approach to disease management, can play a significant role of bio-fertiliser in agriculture. Trichoderma-based bio-fungicides and fertiliser has been found promising to control root rot of mung bean (Ritika et al., 2014). Growth, yield, and quality parameters of certain plants significantly increased with bio-fertilisers containing bacterial nitrogen fixers, phosphate and potassium solubilizing bacteria, and microbial strains of some bacteria (Khosro et al., 2012). The importance of biofertilisers are highlighted below: Secretion of plant growth hormones which help in plant growth, protection of the plant against attack by pathogens, improvement soil fertility, no special care is necessary while using bio-fertiliser, reduction in the use of chemical fertilisers, bio-fertilisers are cost effective compared to synthetic fertiliser, promotes growth of plants, restore the soil's natural, nutrient cycle and build soil organic matter and provides protection against drought.

The role of bio-fertilisers in enhancing plant tolerance to environmental stress

Abiotic and biotic factors are the major constraints that affect the productivity of crops. Many tools of modern science have been widely applied for crop improvement under stress, of whichthe role of plant growth-promoting rhizobia PGPRs as bio-protectant has become of paramount importance in this regard (Chang and Yang, 2009). According to Hussain et al. (2002),Rhizobium trifoli inoculated with Trifolium alexandrium showed higher biomass and an increased number of nodulations under salinity stress conditions. Pseudomonas aeruginosa has been shown to withstand biotic and abiotic stress. Pseudomonas putida RS-198 enhanced germination rate and several growth parameters, including plant height, fresh weight, and dry weight of cotton under conditions of alkaline and high salt via increasing the rate of uptake of k^{2+}, Mg^{2+}, and $Ca^{2+}$and by decreasing the absorption of Na+. Few strains of Pseudomonas conferred plant tolerance via 2, 4-diacetylphloroglucinol. Mycobacterium phlei provides tolerance to high temperatures and salinity stress.

It has been demonstrated by Ansari *et al*. (2013) that inoculation of plants with Arbuscular mycorrhiza fungi also improves plant growth under salt stress. Ansari et al. (2013) also observed that a root endophytic fungus, Piriformospora indica, was found to defend the host plant against salt stress. A combination of AM fungi and nitrogen-fixing bacteria helps the legume plants in overcoming drought stress. Application of Pseudomonas Spp to basal plants under water stress improves their antioxidant and photosynthetic pigment content. Pseudomonas Spp was found to have a positive effect on the seedling growth and seed germination under water stress (Liddycoat, 2009). Ruiz-Sanchez *et al*. (2010) reported that the photosynthetic efficiency and the anti-oxidative response of rice plants subjected to drought stress were found to increase after inoculation of arbuscular mycorrhiza. The beneficial effect of mycorrhizae has also been reported under both drought and saline conditions. PGPRs as biological agents proved to be one of the alternatives to chemical agents for providing resistance against various pathogens' attacks. Apart from acting as growth-promoting agents, they can provide resistance against pathogens by producing metabolites (Backman and Sikora, 2008). *Bacillus subtilis* GBO can induce defence related path ways. *Bacillus subtillis* N11, along with mature compost, was found to control Fusarium infestation on banana root. By and large, the exploitation of PGPRs was found to be very significant in managing spotted wilt viruses in tomato, cucumber mosaic virus of tomato and pepper, and banana bunchy top virus.

In some cases, it was observed that along with bacteria, mycorrhizae can also confer resistance against fungal pathogens and inhibit the growth of many root pathogens such as R. solani and Pythium Spp. and by decreasing the absorption of Na+. Few strains of Pseudomonas conferred plant tolerance via 2, 4-diacetylphloroglucinol. Mycobacterium phlei provides tolerance to high temperatures and salinity stress. It has been demonstrated by Ansari *et al*. (2013) that inoculation of plants with Arbuscular mycorrhiza fungi also improves plant growth under salt stress. Ansari *et al.* (2013) also observed that a root endophytic fungus, *Piriformospora indica,* was found to defend the host plant against salt stress. A combination of AM fungi and nitrogen-fixing bacteria helps the legume plants in overcoming drought stress. Application of Pseudomonas Spp to basal plants under water stress improves their antioxidant and photosynthetic pigment content. *Pseudomonas Spp* was found to have a positive effect on the seedling growth and seed germination under water stress (Liddycoat, 2009). Ruiz-Sanchez et al. (2010) reported that the photosynthetic efficiency and the anti-oxidative response of rice plants subjected to drought stress were found to increase after inoculation of *arbuscular mycorrhiza*. The beneficial effect of mycorrhizae has also been reported under both drought and saline conditions. PGPRs as biological agents proved to be one of the alternatives to chemical agents for providing resistance against various pathogens' attacks. Apart from acting as growth-promoting agents, they can provide resistance against pathogens by producing metabolites (Backman and Sikora, 2008). Bacillus subtilis GBO can induce defence related path ways. *Bacillus subtillis* N11, along with mature compost, was found to control Fusarium infestation on banana root. By and large, the exploitation of PGPRs was found to be very significant in managing spotted wilt viruses in tomato, cucumber mosaic virus of tomato and pepper, and banana bunchy top virus. In some cases, it was observed that along with bacteria, mycorrhizae can also confer resistance against fungal pathogens and inhibit the growth of many root pathogens such as *R. solani* and *Pythium Spp.*

Biofertiliser as a Phytostimulator or Biostimulant

Still, other biofertilisers can promote plant growth through phytohormone production and plant growth stimulation in many ways. Such biofertilisers are largely known as phytostimulators owing to the various roles they play in stimulating the growth of crops through the production of phytohormones. The most common phytohormones are auxins, gibberellins, and cytokinin. Although very small amounts of phytohormones are produced by PGPR, they are still very crucial for plant metabolic processes, including those that modulate plant growth (Kalimuthuet al., 2019; Haeraniet al., 2021) and plant tolerance to various abiotic stresses (Mahmoody and Noori, 2014; Santhi et al., 2021). Among the most

promising PGPR that can function as biofertilisers due to phytohormone production are *Azospirillum* (Coniglio *et al*., 2019) and Bacillus spp. (Kang *et al*., 2019; Bandopadhyay, 2020), and many others. Owing to the importance of phytostimulation, such PGPR are viable candidates for PGP as biofertilisers, especially if they can also solubilize plant nutrients and/or fix N to improve plant nutrition

Difference between bio-fertiliser and organic fertiliser

Before now, the term bio-fertiliser was used to include organic fertiliser. However, technically, there is a big difference between them. Vishal and Abhishek, (2014),to distinguish between bio-fertiliser and organic fertiliser said "bio-fertilisers are microbial inoculants consisting of living cells of microorganisms like bacteria, algae, fungi, alone or in combination, which may help in increasing crop productivity. Biological activities are markedly enhanced by microbial interactions in the rhizosphere of plants. Organic fertilisers, on the other hand, are obtained from animal sources such as animal manure or plant sources like green manure.

CAUTION IN THE USE OF BIO-FERTILISERS

a) Never mix bio-fertilisers with nitrogen fertilisers.
b) Never apply bio-fertilisers with fungicides.
c) Never expose bio-fertilisers to sunlight directly.
d) Bio-fertilisers are stored at room temperature, not below 0 °C and above 350 °C
f) Do not keep the used solution overnight (Hari *et al*., 2010)

Soil fertility

Soil refers to the part of the earth on which plants grow (Purves *et al*., 2000). It consists of three layers: topsoil, subsoil, and parent material. However, we are more concerned with the topsoil since it is the part that supports plant growth. It contains minerals, air, water, living organism and inorganic and organic matter, all of which must be in a particular ratio with at least a medium pH to constitute a fertile soil. According to Purves *et al*. (2000), a good quality soil is one that is 45% minerals (sand, silt, and clay), 25% water, 25% air, and 5% organic and living matter. The mineral portion of a soil, which makes up half of the volume, contains about 93% silica, aluminium and iron oxides: 4% calcium, potassium, and magnesium oxides, and 3% titanium, sodium and a very small amount of nitrogen, sulphur, phosphorous, boron, manganese, zinc, copper, chlorine, molybdenum and many other elements. However, of all these minerals, only fourteen are essential to plant and these are called essential elements (Purves *et al*., 2000). According to Barak (Barak 1999), the essential nutrients are divided into micronutrients and macronutrients. The macronutrients are required in larger quantities, whereas the micronutrients are required in small quantities by plants. The first six elements shown in Table 1 are macronutrient while the rest are micronutrients. The macronutrients are further divided into primary macronutrients (those that are always limited in the soil) and secondary macronutrients (those that are rarely limited). The primary nutrients are nitrogen, phosphorous and potassium.

Nitrogen:

Nitrogen is one of the primary macronutrients that is required by plants in large quantities. Its functions include formation of base pair for RNA and DNA, formation of phosphate group of protein (example hemp group of chlorophyll) and hormones such as cytokines, metal uptake (phytosiderorphores), transport in xylem and phloem (example copper with amines), as osmoregulation (example in lettuce and spinach), alkaloids, miscobiochemicals e.g., mescaline, quinine (Barak, 1999). Nitrogen is absorbed by plants in the form of nitrates, ammonium, and sometimes urea (Ifokweet al., 1988) and is added to the soil through fertiliser, biological nitrogen fixation, rainfall and thunder, and decomposition of organic matter. According to Barak (1999) a plant deficient in nitrogen shows the following symptoms: stunted growth and light green or yellow leaves. Severe deficiency symptoms include necrosis starting from the tip of the older leaves and developing a 'v' pattern.

Phosphorus:

Phosphorus is needed in relatively large amounts, but at a quantity lower than that of nitrogen and potassium. It promotes legume growth and yield, nodule number, and nodule mass. Its functions include Phospholipids in the membrane, phosphoproteins for life functions, and improvement of crop yield and quality. It is important in seed formation. Analysis has shown that it forms a substantial component of seeds and fruits (Scalenghe *et al*., 2012). Phosphorus is absorbed by plants in the form of phosphates and is added to the soil through fertilisers, bone meal, and superphosphates. Barak (1999) stated that phosphorus is phloem mobile and its deficiency symptoms are evenly spread throughout the plant. However, stunted growth and late maturity are often associated with its deficiency. In severe cases, grassy species such

as corn show reddening of the leaves. According to Scalenghe *et al*. (2012), excess phosphorus is not good as plants cannot properly assimilate it because most phosphorus is in inorganic form. Excess phosphorus is characterized by early maturation of plants and low crop yield in plants.

Potassium

Plants' requirement for this element is only second to that of nitrogen. Potassium influences the water economy and crop growth through its effects on water uptake, root growth, maintenance of turgor, transpiration, and stomatal regulation (Mfilinge *et al*., 2014). The functions of potassium include the following. It enhances the cold endurance of some plants as well as their resistance to fungal and bacterial diseases; It intensifies the synthesis of high molecular carbohydrates resulting in cell walls of the straw of cereals thicker, It catalyses the activities of some enzymes and promotes the synthesis and accumulation of certain vitamins in plants (Thiamin and Riboflavin), It is essential for the activity of guard cells, It aids in photosynthesis, building up of protein and improving fruit quality (Ifokwe *et al*., 1988, Barak ., 1999). Potassium is absorbed by plants in the form of potassium ions, which are insoluble in water. It is added to the soil by fertiliser, decaying organic matter, and wood ash. According to Ifokwe (1988), potassium deficiency upsets the plant's metabolism, inhibits the activity of some enzymes, and disrupts carbohydrate and protein metabolism. The author also stated that inadequate potassium supply reduces the viability of seeds, makes plants more prone to diseases, and, when harvested, they become difficult to preserve in marketable conditions. Other elements required by plants in large quantitiesinclude oxygen, carbon, and hydrogen. These are obtained through air and water and therefore are bountiful in nature (Barak 1999).

Global demand for biofertiliser

The use of biofertilisers has gained significant attention in recent times due to the increasing focus on sustainable agriculture and environmental management, with rhizobia and PSB being the most in-demand biofertilisers (Nath Bhowmik and Das 2018). Rhizobia accounts for approximately 79% of the global market share, while PSB holds a 15% share (Garcha, 2023). India and China have significant areas under organic farming, with around 4.2 million hectares and 167 million hectares, respectively (Horo and Das, 2019). This trend has led to an increased demand for biofertilisers in these regions, particularly in India, where the government has actively encouraged organic farming through various policies and initiatives. The use of biofertilisers offers several benefits, including increased soil fertility, reduced soil erosion, and improved crop yield, making them an attractive option for farmers looking to adopt sustainable farming practices. Around the world, biofertilisers are growing in popularity, particularly in developed nations such as Spain, Italy, and Germany, where they are seen as a sustainable alternative to chemical fertilisers (Raimi *et al*., 2021; Ibanez ~ *et al*., 2023).

According to market analysis, the global biofertiliser market had a value of US$1.06 million in 2016 and is projected to reach US$3.8 billion with an 11.2% compound annual growth rate between 2020 and 2025 (Raimi *et al*., 2021;Aloo *et al*., 2022). The global biofertiliser market is forecast to be valued at USD 2.3 billion in 2019 and is expected to increase at a compound annual growth rate (CAGR) of 11.6% between 2020 and 2027, according to a Grand View Research report (Raut et al., 2023). The biofertiliser market is segmented by product type, crop type, application, and region. The product type segment includes nitrogen-fixing, phosphate-solubilizing, potash-mobilizing, and others. The nitrogen-fixing biofertilisers accounted for the largest market share in 2019, owing to their wide application in various crops and their ability to fix atmospheric nitrogen into plant-available forms (Soumare *et al*., 2020). These biofertilisers are expected to grow at the fastest pace over the predicted period because they can increase phosphorus availability and uptake in low-phosphorus soils.

Types of bio-fertilisers and how they work

Bio-fertilisers are classified into different types depending on the type or group of microorganisms they contain. The different types of bio-fertilisers include:

1) Nitrogen fixing bio-fertilisers (NFB):

Nitrogen-fixing biofertilisers are currently the most common in the global market and their demand is anticipated to grow by a further 11.9% compounding annual growth rate (CAGR) to reach about USD 4.5 billion by 2026 up from the current USD 2.1 billion (Markets and Markets, 2020). Nitrogen-fixing biofertilisers comprise bacteria that carry out biological N2 fixation (BNF) and boost soil N supply to crops. The legume N2-fixing rhizobia have been researched for

decades and shown to increase the quantity of fixed N in inoculated plants relative to uninoculated ones (Koskey *et al*., 2017; Sanyal *et al*., 2020; Gedamu *et al*., 2021; Ketema and Tefera, 2022). Previous inputs of fixed N for red clover, alfalfa, soybean, pea, and cowpea were estimated to range from 23 to 335kgha^{-1} year^{-1} (Thies *et al*., 1995; Wani *et al*., 1995). The variabilities in terms of quantities of fixed N depend much on the type of legume-rhizobia symbiosis which is dictated by several factors like the legume cultivars and genotypes (Gunnabo *et al*., 2020; Riah *et al*., 2021), as well as the geographical distributions (Ramoneda *et al*., 2020

Earlier studies by Melchiorre *et al*., (2011) and Hungria *et al*., (2006) both established that the yield of grains in Brazil, and Argentina, respectively, could reach close to 5 t ha^{-1} each season through rhizobia-mediated BNF. Similarly, annual N2 fixation rates of approximately 40 kg N ha^{-1} are documented in Australian soils (Unkovich and Baldock, 2008). Nevertheless, the contribution of asymbiotically fixed N in crop fields largely remains unestablished. More research is necessary, especially for crops like cereals, vegetables, and tubers, considering how they contribute to the bulk of human food.

Examples include Rhizobium Spp., Azospirillum Spp. and blue-green algae; these work by fixing atmospheric nitrogen and converting them to organic (plant usable) forms in the soil and root nodules of legumes, thereby making them available to plants. Nitrogen fixing bio-fertilisers are crop specific bio-fertlilizers (Choudhury *et al*., 2004).

2) Phosphate solubilizing bio-fertiliser(PSB):

Examples include Bacillus Spp., Pseudomona Spp. and Aspergillus Spp. These work by solubilizing the insoluble forms of phosphate in the soil, so that plants can use them. Phosphorus in the soil occurs mostly as insoluble phosphate which cannot be absorbed by plants (Gupta, 2004). However, several soil bacteria and fungi possess the ability to convert these insoluble phosphates to their soluble forms. These organisms accomplish this by secreting organic acids, which lower the pH of the soil and cause the dissolution of bound forms of phosphate, making them available to plants (Chang and Yang, 2009).

3) Phosphate-mobilizing bio-fertilisers (PMB):

Examples are Mycorrhiza. They work by scavenging phosphates from soil layers and mobilizing the insoluble phosphorus in the soil to which they are applied. Chang and Yang (2009) stated that phosphorus-solubilizingbiofertiliser (PSB) sometimes acts as a phosphate mobilizer. Phosphate-mobilizing bio-fertilisers are broad-spectrum bio-fertilisers.

4) Plant growth-promoting bio-fertiliser (PGPB):

Examples of plant growth rhizobacteriaare Pseudomonas Spp. etc: these work by producing hormones and anti-metabolites which promote root growth, decomposition of organic matter, which helps in mineralization of the soil, thereby increasing availability of nutrients and improving crop yield (Khosro *et al*.,2012, Bhattacharyya *et al*., 2012). PGPB are crop-specific bio-fertilisers.

5) Potassium solubilizing bio-fertiliser (KSB):

Examples include Bacillus Spp and Aspergillus niger. Potassium in the soil occurs mostly as silicate minerals, which are inaccessible to plants. These minerals are made available only when they are slowly weathered or solubilized. Potassium-solubilizing microorganisms solubilize silicates by producing organic acids, which cause the decomposition of silicates and help in the removal of metal ions, thereby making them available to plants. Potassium-solubilizing bio-fertilisers are broad-spectrum bio-fertilisers.

6) Potassium mobilizing bio-fertiliser (KMB):

An example of potassium mobilizing bio-fertiliser is Bacillus Spp. These work by mobilizing the inaccessible forms of potassium (silicates) in the soil. Some phosphate-solubilizing bio-fertilisers, such as Bacillus Spp and Aspergillus Spp. has been found to mobilize potassium and solubilize phosphorus.

7) Sulfur-oxidizing bio-fertiliser (SOB):

An example of a sulphur-oxidizing microorganism is Thiobacillus Spp. These work by oxidizing sulfur to sulfates, which are usable by plants.

MICROORGANISMS USED IN BIO-FERTILISER

Organisms that are commonly used as bio-fertiliser components include nitrogen fixers (N-fixers), potassium solubilizers (K-solubilizers), phosphorus solubilizers (P-solubilizers), phosphorus mobilizers (P-mobilizers), used solely or in combination with fungi. Most of the bacteria used in bio-fertilisers have a close relationship with plant roots. Rhizobacterium has symbiotic interactions with legume roots, and Rhizobacteria inhabit root surfaces or rhizosphere soil (Khosro 2012). The phospho-microorganisms, mainly bacteria and fungi, make insoluble phosphorus available to the plants (Gupta, 2004). Several soil bacteria and a few species of fungi possess the ability to convert insoluble phosphate in soil into soluble forms by secreting organic acids. These acids lower the soil pH and bring about the dissolution of bound forms of phosphate (Gupta 2004). While Rhizobium, blue-green algae, and Azolla are crop-specific, bio-inoculants such as Azotobacter, Azospirillum, phosphorus-solubilizing bacteria (PSB), and Vesicular Arbuscular Mycorrhiza (VAM) could be regarded as broad-spectrum bio-fertilisers (Gupta 2004). VAM are fungi that are found associated with most crops and enhanced accumulation of plant nutrients (Khosro, 2012; Wani *et al*., 2013). It has been suggested that VAM stimulate plant by physiological effects or by reducing the severity of diseases caused by soil pathogens. Examples of free-livingnitrogen-fixing bacteria are obligate anaerobes, Clostridium pasteurinnum obligate aerobes, facultative anaerobes, photosynthetic bacteria, Rhodobacter, cyanobacteria (Azotobacter), and some Methanogens. The most usedK-solubilizer is Bacillus mucilaginous, while P-solubilizers are Bacillus megaterium, Bacillus circulans, Bacillus subtilis, and Pseudomonas straita (Gupta 2004)

THE CURRENT STATE OF BIOFERTILISER

There is a burgeoning literature on the current application of microbial products as biofertilisers and agricultural inputs. Nearly 170 establishments in 24 countries commercialize biofertilisers and possess factories that produce and market microbe-based fertilisers at both small and large scales (Bharti *et al*., 2017). The marketing of rhizobial inoculants has been practiced for several decades now to partially eliminate the application of artificial fertilisers (Paudyal and Gupta, 2018). However, the full potential of many biofertilisers is largely untapped. Likewise, biofertiliser commercialization remains low globally, albeit steadily increasing. In developed countries where artificial agricultural inputs are a bit cheap, the use of PGPR is less prioritized but is albeit growing. In 2013, the highest demand for biofertilisers was highest in North America and projections were that the entire Asia-Pacific biofertiliser market would show the maximum growth from 2014 to 2019 and lead in biofertiliser consumption worldwide (Markets and Markets, 2014). The consumption of biofertilisers is reportedly growing in countries such as Canada, Argentina, China, India, Europe, and the United States of America (USA) due to tax exemptions and input subsidies, among other incentives (Markets and Markets, 2019).

Such approaches have generally served to expand the global biofertiliser market, but more efforts are still required. The advancement of research around the globe on the diversity, functions, and potentials of native rhizobacteria has stimulated the selection and isolation of efficient PGPR, and several biofertiliser formulations are already produced and commercialized for use in different countries across the globe. The most progressive and dominant biofertiliser market in the world is Europe, where biofertiliser demand has grown at a CAGR of 12.3% from approximately US$2566 million in 2012 to US$4582 million in 2017 (Chandrasekhar, 2014). The global biofertiliser market was worth US$1.06 million in 2016 and was estimated to hit US$2 billion in 2019 and over US$3.8 billion in 2026, at a CAGR of 11.2% (Markets and Markets, 2020). The global increase in demand for biofertilisers has greatly been greatly influenced by the growing demand for organic food products. Although there exist many reports on the formulation and/or commercialization and application of rhizobacterial biofertilisers in several parts of the world, only a few reports indicate their application and commercialization in Africa. The PGPR inoculant technology has little or no impact on crop productivity in developing countries since it is either not practiced or the poor quality of available inoculants (Bashan, 1998). According to Aloo et al. (2021), the potential benefits of biofertilisers have largely been untapped in Africa due to inadequate regulatory frameworks and several other challenges. Most biofertilisers are commercialized for use in Asia, Europe, and the USA but in Africa, most commercialization and application occur only in South Africa. In East Africa, the production and use of biofertilisers are pronounced in Kenya,where Biofix is the manufacturer of Biofix, which can effectively inoculate 15kg of common bean seeds per ha at approximately US$1.25 in comparison to 90kg of artificial N fertiliser required for the same number of seeds per ha at US$12.50 (Raimi *et al*., 2021). However, Biofix and other biofertilisers are still largely underutilized in Kenya, probably due to a lack of awareness and other technology adoption challenges.

Current and future initiatives are anticipated to improve the uptake of biofertilisers in Africa (Raimi *et al*., 2021). However, more efforts are needed to boost the consumption of these microbial products and promote the sustainability of global food production systems (Aloo *et al*., 2021). The worldwide market for biofertilisers is presently largely dominated by legume and N2-fixing inoculants (Vassilev et al., 2015). While rhizobial inoculants currently dominate the global biofertiliser market, PSB and other bioinoculants occupy less than 30% altogether (Transparency Market Research, 2022). Nevertheless, P-, K-, and Zn-based biofertilisers are now developing into significant bioinoculants to address soil nutrient deficiencies, and KSM are already commonly used as inoculants in some countries with K-deficient crop lands (Teotia *et al*., 2016). India is reportedly the 4th largest consumer of K bioinoculants globally, while countries like Brazil, the USA, and China come first in the overall consumption of these microbial products (Matich, 2016). Unlike rhizobialbiofertilisers, PSB, like Pseudomonas, Bacillus, and diazotrophs like Azospirillum, have not been used as much nor at a large scale (Lesueur *et al*., 2016). Most of the commercially available non-rhizobial PGPR inoculants consist of Azospirillum as free-living N2 fixers or Bacilli as PSB (Herrmann and Lesueur, 2013). The application of non-rhizobialbiofertilisers has a less significant impact on global food production, probably because of several bottlenecks that exist in biofertiliser uptake and use relative to well-documented PGP functions. Yet, PGPR like PSB, are essential candidates for improving legume P nutrition for efficient nodulation (Zaidi *et al*., 2017). The global biofertilisers market for crop production is projected to grow from US$2.02 billion in 2022 to US$4.47 billion by 2029, at a CAGR of 12.04% from 2022 to 2029 (Fortune Business Insights, 2022). Still, there is a need for more efforts for adequate market infiltration and application.

The future of biofertilisers

The incorporation of biofertilisers as fundamental components of agricultural practices is quickly gathering momentum globally. These microbial products are already in use in some countries and are expected to become more popular in the future. The global and future expansion of the biofertiliser market will largely be driven by the need to increase food production sustainably. With an ever-increasing demand for organic food products, growing awareness of sustainable agricultural practices, and promotion of cleaner production methods for reducing soil contamination, land degradation, and water pollution, the market growth for biofertilisers will continue to grow over the coming years (Abhilash *et al*., 2016a; Anand *et al*., 2022; Vaishnav *et al*., 2022). Forecasts are that the present global market for biofertilisers, which was approximated at US$396 million in 2018, will grow at a CAGR of 10.9% to escalate to US$4,448.97 million (or roughly US$4.45 billion) by 2028 (Vintage Market Research, 2022). Further indications are that the global biofertiliser market, which was valued at close to US$ 3.0 billion in 2020, will grow at a CAGR of 12.2% and reach about US$5 billion by 2031 (Transparency Market Research, 2022). The number of investigations targeting the isolation, identification, and evaluation of the capacity of PGPR with the potential of being transformed into inoculants for a variety of crops is equally expanding (Koskey *et al*., 2017; Anand *et al*., 2022; Aloo *et al*., 2022b).

It is, therefore, realistic to expect that widespread biofertiliser usage will soon offer countless approaches to the progression of sustainable crop production systems. For the extensive utilization of biofertilisers, proper regulatory and legal frameworks will be required in place of the existing ones that are currently stringent and hinder their proper utilization. Fortunately, regulatory authorities are increasingly encouraging the implementation of alternative crop fertilization mechanisms to promote the development of sustainable agricultural technologies. Recognizing the need for a specific legislative framework for biofertilisers in Europe, the European Commission has proposed to amend existing regulations (European Parliament and Council of the European Union, 2016). Such initiatives will eventually relax the stringent regulatory frameworks and enable the widespread adoption of these microbial resources. While several of the existing biofertilisers are mainly composed of natural rhizobacterial strains chosen for their PGP qualities, the development of genetically-modified inoculants that are likely to bemore efficient at plant growth stimulation is required. Still, the biggest hurdle will be for scientists to convince society and regulatory authorities worldwide that such geneticallyengineered organisms are harmless. Our current ability to manipulate and exploit the plant microbiome in situ similarly remains limited, and more investigations are required to facilitate their large-scale application and commercialization. The inoculant industry is faced with various challenges in making formulations with prolonged shelf lives. Progress into developing formulations with improved shelf lives, broad spectra of action, and reliable field

performance will therefore hasten the commercialization of this technology (Nakkreen *et al*., 2005). In this regard, new approaches should be evaluated to develop formulations with longer shelf lives. Micro-encapsulation is one viable approach, but most experiments in this regard have been restricted to laboratories and the standardization of this technology for industrial and field applications should be pursued. The future of biofertiliser technology depends a lot on developing efficient PGP strains.

CONCLUSION

The dependence on chemical fertilisers and pesticides has encouraged the thriving of industries that are producing life-threatening chemicals, which are not only hazardous for human consumption but can also disturb the ecological balance. The attention is now shifting from consuming food grown with chemical fertilisers to food grown with organic fertilisers due to harmful effects posed to both human and other living organism, it has also been linked to various ailments in humans and livestock. Biofertilisers can help solve the problem of food needs of the ever-increasing global population while not polluting the environment. It is important to realize the useful aspects of bio-fertilisers to apply it in modern agricultural practice. The application of bio-fertilisers containing beneficial microbes largely promotes crop productivity. These potential biological fertilisers would play a key role in the productivity and sustainability of soil and protect the environment as eco-friendly and cost-effective inputs for the farmers. Using biological and organic fertilisers, a low-input system can help to achieve the sustainability of farming. The new technology, when developed using the tool of molecular biotechnology, can enhance the biological pathways of production of phytohormones if identified and transferred to the useful plant growth-promoting rhizobacteria. This technology will help provide relief from environmental stresses. However, the ignorance regarding improved protocols of bio-fertiliser application to the field is one of the few limiting factors to bio-fertiliser usage.?

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An Evaluation of the Impact of Post-Harvest Management Practices on the Nutritional Quality and Health Benefits of Horticultural Crops.

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Abstract
This research paper evaluated the impact of post-harvest management practices on the nutritional quality and health benefits of horticultural crops, specifically fruits and vegetables, in Zaria, Kaduna State, Nigeria. The outcome of the study identifiedkey post-harvest practices such as cleaning, sorting, and packaging, and how these practices contribute to improving the nutritional quality and health benefits of horticultural produce.Furthermore, post-harvest practices like drying, freezing, fermenting, and canning were reported to be crucial for maintaining nutritional quality and extending the shelf life of horticultural crops, although drying (61.6%) was the predominant preservation method. Temperature control was reported to moderately affect crop quality by 41.1% of respondents, while 83.6% considered post-harvest management practice essential for maintaining the health benefits of horticultural crops. More than half of the respondents (58.91%) of respondents advocated better storage conditions. The effectiveness of these practices is enhanced with proper storage conditions, suitable packaging, and efficient transportation methods.The study recommends providing training for farmers on best post-harvest practices, investing in better storage facilities and transportation infrastructure, and continuous research and development to develop new technologies and methods for post-harvest management. These recommendations aim to enhance the nutritional quality and health benefits of horticultural crops in Zaria.

Key words: Post-Harvest Management Practices, Nutritional Quality, Health Benefits, Horticultural Crops.

Résumé
Cette étude a évaluél'impact des pratiques de gestion post-récolte sur la qualiténutritionnelle et les bienfaits pour la santé des cultures horticoles, notamment les fruits et légumes, à Zaria, dans l'État de Kaduna, au Nigéria. Les résultatsontpermisd'identifier des pratiques post-récoltecléstellesque le nettoyage, le tri et le conditionnement, et leur contribution à l'amélioration de la qualiténutritionnelle et des bienfaits pour la santé des produitshorticoles. De plus, des pratiques post-récoltecomme le séchage, la congélation, la fermentation et la mise en conserve se sontrévéléesessentielles pour maintenir la qualiténutritionnelle et prolonger la durée de conservation des cultures horticoles, le séchage (61,6 %) étant la méthode de conservation prédominante. Le contrôle de la température a été jugé modérément influent sur la qualité des récoltes par 41,1 % des répondants, tandis que 83,6 % ont considéré les pratiques de gestion post-récolte comme indispensables au maintien des bienfaits pour la santé des cultures horticoles. Plus de la moitié des répondants (58,91 %) ont préconisé de meilleures conditions de stockage. L'efficacité de ces pratiques est renforcée par des conditions de stockage appropriées, un conditionnement adapté et des méthodes de transport efficaces. L'étude recommande de former les agriculteurs aux meilleures pratiques après récolte, d'investir dans des infrastructures de stockage et de transport plus performantes, et de poursuivre les efforts de recherche et développement afin de mettre au point de nouvelles technologies et méthodes de gestion après récolte. Ces recommandations visent à améliorer la qualité nutritionnelle et les bienfaits pour la santé des cultures horticoles à Zaria.

Introduction

Horticultural produce plays a vital role in human nutrition by providing essential vitamins, minerals, dietary fibre, and antioxidants (Kader & Rolle, 2004). Beyond its nutritional contributions, horticulture is a critical sector for economic development, enhancing food security and improving the nutritional intake of populations, particularly in developing regions (Melkamu & Melkamu, 2021). However, horticultural crops are highly perishable due to their short natural shelf life, leading to significant challenges in post-harvest handling, which has been a persistent issue for farmers. The need for effective post-harvest management is paramount to prevent deterioration, which often begins immediately after harvest (Omobowale, 2021).

Post-harvest management practices significantly influence the nutritional quality of fruits and vegetables by mitigating deterioration and preserving essential compounds. These practices aim to extend shelf life and maintain the delicate balance of carbohydrates, proteins, minerals, vitamins, and dietary fibre that fruits and vegetables provide. In general, these practices range from temperature and humidity regulation, which can slow down enzymatic reactions that degrade nutrients and prevent moisture loss, preserving vitamins like C and A. Optimal humidity and storage conditions help prevent spoilage and nutrient degradation, maintaining phytochemical content.

Post-harvest management practices significantly affect the health benefits of fruits and vegetables by influencing their nutrient retention, safety, and overall quality. In regulating the temperature, proper refrigeration slows down the degradation of vitamins and antioxidants, particularly in sensitive produce (Kader, 2005).Gentle handling reduces damage to fruits and vegetables, preventing nutrient loss that can occur due to tissue breakdown. Proper washing removes pesticide residues and microbial contaminants, enhancing food safety and health benefits. Using protective packaging can limit exposure to light, air, and moisture, preserving vitamins and minerals. Quality packaging reduces spoilage and exposure to light and air, which can protect sensitive nutrients from degradation.(Ragaert *et al*., 2004). Effective drying methods can concentrate certain nutrients but may lead to losses of volatile vitamins such as vitamin C. (Muniandy & Chan, 2015)

Poor and ineffective PMPs often lead to high post-harvest losses of particularly horticultural crops. Post-harvest loss is a global problem, butit is especially severe in developing countries. The Food and Agriculture Organization of the United Nations (FAO) estimates that one-third of the food produced for human consumption is wasted globally, amounting to approximately 1.3 billion tons per year (Goletti & Wolff, 2000). Accurately estimating post-harvest losses in fruits and vegetables is challenging, but it is known that these losses occur at various stages, including transportation, storage, and marketing (Gouthami *et.al*., 2024). Globally, post-harvest losses of fruits and vegetables range from 30-50%, with even higher rates reported in some developing countries. Losses are attributed to several factors across the post-harvest chain, such as improper handling, inadequate storage, inefficient processing, poor packaging, and issues during transportation and marketingIrene *et. al*., n.d.).

To increase food availability, it is not sufficient to focus solely on enhancing agricultural productivity. It is equally important to understand the major causes of post-harvest losses and implement strategies to mitigate them (Hornick, 2010). Effective post-harvest management practices (PMPs) can improve the shelf life, nutritional value, and marketability of horticultural crops, contributing to economic growth and better nutrition outcomes (Mustapha Bada *et.al*., 2021). This study aims to examine post-harvest management practices, identify key challenges faced by producers, and explore potential solutions for reducing post-harvest losses in horticultural commodities and their extended availability for consumers

METHODOLOGY

This study evaluated the impact of post-harvest management practices on the quality and health benefits of horticultural crops through an online survey targeting producers and consumers. The methodology includes survey design, target population, data collection, and analysis methods, with a sample size of approximately 73 participants.

Research Design

A cross-sectional study design was employed to gather information on variables of interest from producers and consumers at a single point in time using questionnaires. The survey aimed to assess producer and consumer perceptions

and knowledge regarding the quality and health benefits of horticultural crops, as influenced by post-harvest management practices.

Target Population

The target population consisted of producers and consumers who regularly produce and consume horticultural crops, such as fruits and vegetables. Key demographic criteria include:

Sample Size and Sampling Technique

The sample size for this study was approximately 73 participants, which falls within the range of more than 50 but less than 100. Convenience sampling was used to recruit participants through digital platforms. This sample size is sufficient to capture a range of producer and consumer perspectives while remaining manageable for data analysis.

Data Collection

The online survey was distributed via:

- Social Media: Platforms like WhatsApp.
- Online Forums: Consumer and health forums where food quality and health are discussed.

The survey was left open for two weeks, with reminders sent periodically to encourage participation.

Data Analysis

Data collected was analysed using descriptive statistics (frequencies, percentages, means) with Microsoft Excel

Ethical Considerations

Ethical approval was obtained, and participants were provided with informed consent before participating. All responses were anonymized, and confidentiality was ensured throughout the study.

Limitations

Potential limitations include:

- **Self-Reporting Bias:** Some responses may not accurately reflect consumer experiences.
- **Convenience Sampling:** The sample may not be fully representative of the wider producer and consumer population.

Results

The study revealed that the largest age group among respondents was 20-30 years (35.6%), with females (56.1%) making up a greater proportion of the population. The majority held a BSc/HND (53.4%), while a smaller proportion had MSc (24.7%) and PhD (19.2%) degrees (Table 1). Factors limiting access to crops, types of horticultural crops used post-harvest, and nutritional quality assessment methods used by respondents in Zariaare shown in Table 2. Outcomes indicate that cost (46.6%) and lack of storage facilities (39.7%) were identified as the main barriers to accessing horticultural crops. Post-harvest, vegetables (58.9%) were the most used horticultural products. Visual inspection (64.4%) was the primary method for assessing the nutritional quality of crops, and most respondents (69.9%) applied common post-harvest management practices such as cleaning, sorting, and packaging. Temperature control was reported to moderately affect crop quality by 41.1% of respondents. Drying (61.6%) was the predominant preservation method (Table 3). Most respondents conducted quality assessments occasionally (46.6%) or weekly (28.8%) (Table 4), and 83.6% considered post-harvest management extremely important for maintaining crop health benefits. Positive changes in nutritional quality were observed by 52.1% of respondents, while 30.1% reported negative changes. Challenges such as lack of resources and poor infrastructure were common (54.8%), and 50.7% of respondents did not use post-harvest technologies. Pests such as insects and weevils (52.1%) were frequently encountered (Table 5). Satisfaction with post-harvest practices was moderate, with 46.6% rating their satisfaction as 3 on a scale of 5, and respondents suggested improvements like better storage conditions (58.9%) and education on nutrition preservation (20.5%) towards improving the nutritional quality of fruits and vegetables post-harvest (Table 6).

Discussion

The results highlight several key challenges and opportunities in post-harvest management practices of horticultural crops and their subsequent effects on nutritional quality and health benefits. Access to horticultural crops is primarily restricted by economic factors, such as cost and inadequate storage facilities, underscoring the need for interventions to improve both affordability and infrastructure. Despite the challenges, most respondents implement basic post-harvest practices like cleaning, sorting, and packaging, indicating a baseline awareness of the importance of these processes. However, the reliance on visual inspection for assessing crop quality suggests a lack of access to advanced testing methods, which could lead to less accurate quality control.

Temperature control during storage was seen as a critical factor in maintaining nutritional quality, yet many respondents indicated that it only moderately affected their crops, suggesting room for improvement in the implementation of temperature management. Wills (1998)observed that temperature management is a critical factor, as low temperatures generally reduce respiration and ethylene production, preserving sensitive compounds like vitamin C and various antioxidants. However, chilling injury in some tropical fruits can lead to a loss of flavour and nutritional quality, while optimal cold storage can maintain these attributes in temperate fruits (Wang 1990). The wide spread use of drying as a preservation method reflects its simplicity and cost-effectiveness, though the prevalence of pests such as insects and weevils indicates a need for improved pest control strategies.

The fact that half of the respondents do not use any post-harvest technologies points to significant barriers, potentially related to cost, awareness, or availability of such technologies. Nevertheless, those who did use innovative packaging and climate control systems reported better outcomes, signalling that the adoption of these technologies could offer substantial benefits. The choice of packaging material can also influence the stability of health-promoting compounds by protecting against light, oxygen, and moisture (Roberson 2016). The moderate satisfaction with current practices, combined with the respondents' suggestions for improvements in storage conditions and education, demonstrates a strong demand for enhanced post-harvest management practices.

Conclusion

This study underscores the importance of effective post-harvest management practices in maintaining the quality and nutritional value of horticultural crops. While many respondents are already implementing basic practices, challenges such as cost, lack of storage, and pest infestations hinder optimal outcomes. The moderate use of advanced technologies suggests that there is considerable potential for improving crop quality through better storage and the adoption of innovative solutions. Increased education on post-harvest techniques and nutrition preservation could further enhance the health benefits of these crops. To address these challenges, targeted interventions in resource allocation, training, and infrastructure development are needed, along with greater promotion of advanced technologies in post-harvest management.

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Table 1: Age, sex and educational level of respondent in Zaria

Age	N=73	%	Sex	N=73	%	Educational level	N=73	%
20 - 30	26	35.6	Female	37	56.1	BSC/HND	39	53.4
51 - 60	17	23.3	Male	29	43.9	MSc	18	24.7
31 - 40	16	21.9				PhD	14	19.2
41 - 50	14	19.2				Diploma	2	2.7

Table 2: Factors limiting access to crops, types of horticultural crops used post-harvest and nutritional quality assessment methods used by respondents in Zaria

Factors limiting access	N=73	%	Types of horticultural crops	N=73	%	Nutritional quality assessment	N=73	%
Cost	34	46.6	Vegetables	43	58.9	Visual inspection	47	64.4
Lack of storage facilities	29	39.7	Fruits	19	26.0	Sensory evaluation	12	16.4
Unavailability	7	9.6	Root crops	10	13.7	Laboratory testing	8	11.0
Distance	3	4.1	Herbs	1	1.4	Nutritional analysis software	6	8.2

Table 3: Post-harvest practices implemented, perception of effect of temperature control and preservation methods used by respondents in Zaria

Post practice	N=73	%	Temperature control	N=73	%	Preservation method	n	%
All of the above	51	69.9	Moderately affects quality	30	41.1	Drying	45	61.6
Cleaning	11	15.1	Significantly enhances quality	25	34.2	Freezing	26	35.6
Sorting	9	12.3	Decreases quality	14	19.2	Fermentation	2	2.7
Packaging	2	2.7	Little to no impact	4	5.5			

Table 4: Frequency of quality assessment adopted, changes in nutritional quality observed and challenges faced by respondents in Zaria

Frequency of quality assessment	N=73	%	Changes in nutritional quality	N=73	%	Challenges	N=73	%
Occasionally	34	46.6	Yes, positive changes	38	52.1	All of the above	40	54.8
Weekly	21	28.8	Yes, negative changes	22	30.1	Lack of resources	13	17.8
Daily	16	21.9	Not applicable	8	11.0	Poor infrastructure	13	17.8
Monthly	2	2.7	No changes	5	6.8	Insufficient training	7	9.6

Table 5: Perception of Importance of post-harvest management, technologies used, pests and diseases observed by respondents in Zaria

Importance of postharvest management	N=73	%	Technologies used	N=73	%	Pests and diseases	N=73	%
Extremely important	61	83.6	No, we do not use any technologies	37	50.7	Insects and weevils	38	52.1
Moderately important	10	13.7	Yes, climate control systems	17	23.3	Fungal infections	22	30.1
Not important	1	1.4	Yes, innovative packaging solutions	16	21.9	Bacterial contamination	10	13.6
Slightly important	1	1.4	Yes, quality analysis software	3	4.1	'No significant pest/disease issues	3	4.1

Table 6: Food safety risk management, satisfaction score and suggested improvements by respondents in Zaria

Food safety risk management	N=73	%	Satisfaction score	N=73	%	Suggested improvements	N=73	%
Regular inspections	34	46.6	3	34	46.6	Better storage conditions	43	58.9
All of the above	26	35.6	4	16	21.9	Educating people on nutrition preservation	15	20.5
Adhering to safety protocols	16	21.9	5	11	15.1	Implementing advanced technologies	10	13.7
Training on post-harvest practices	6	8.2	2	6	8.2	Enhanced handling techniques	05	6.8
			1	6	8.2			

Yield and yield attributes of sunflower (Helianthus annuus L.) grown after a 5-year organic diversified crop rotation in the tropics

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Abstract

Long-term crop rotation is known to improve soil fertility, disrupt pest and disease cycles, and enhance crop yields. This study evaluated the yield and yield attributes of sunflower (Helianthus annuus L.) following a 5-year diversified crop rotation involving sesame (Sesamum indicum L.), soybean (Glycine max (L.) Merrill), cotton (Gossypium hirsutum L.). The five cropping systems evaluated were continuous cropping without fertilizer (CS1), continuous cropping with organic fertilizer (CS2), crop rotation with organic fertilizer (CS3), crop rotation without organic fertilizer (CS4), and conventional cropping with synthetic inputs (CS5). Field trials were conducted during the late cropping seasons of 2023 and 2024 at the Organic Research Farm of the Federal University of Agriculture, Abeokuta, Nigeria, using a randomized complete block design with three replicates. Data were collected on head diameter, sunflower head weight, seed weight per head, 100-seed weight, number of seeds per head, grain yield, and threshing percentage. Cropping system significantly ($P < 0.05$) influenced all yield traits in both years. CS2 consistently produced superior yield components, with grain yields of 1,376.0 kg ha^{-1} in 2024 compared to 564.0 kg ha^{-1} in the unfertilized control (CS1). The highest yield in 2023 was recorded under CS5 (573.6 kg ha^{-1}). Yield advantages under CS2 and CS3 were attributed to improved nutrient supply, particularly from organic fertilizer and nitrogen-fixing soybean in rotation. These findings demonstrate that organic sunflower production under CS2 and CS3 can achieve competitive yields in the tropics, offering a sustainable pathway for sunflower production.

Keywords: Helianthus annuus L., crop rotation, yield components, organic fertilizer, tropical agriculture

Résumé

Il est reconnuque la rotation des cultures à long termeaméliore la fertilité des sols, perturbe les cycles des ravageurs et des maladies et accroît les rendements. Cette étude a évalué le rendement et sescomposantes chez le tournesol (Helianthus annuus L.) après une rotation diversifiée de cinq ansincluant le sésame (Sesamum indicum L.), le soja (Glycine max (L.) Merrill) et le coton(Gossypium hirsutum L.). Les cinq systèmes de culture évaluésétaient la monoculture sans fertilisation (CS1), la monoculture avec fertilisation organique (CS2), la rotation des cultures avec fertilisation organique (CS3), la rotation des cultures sans fertilisation organique (CS4) et la culture conventionnelle avec intrants de synthèse (CS5). Les essais au champ ont été menés en fin de campagne agricole 2023 et 2024 à la Ferme de recherche biologique de l'Université fédérale d'agriculture d'Abeokuta, au Nigéria, selon un dispositif en blocs aléatoires complets avec trois répétitions. Des données ont été recueillies sur le diamètre et le poids des capitules de tournesol, le poids des graines par capitule, le poids de 100 graines, le nombre de graines par capitule, le rendement en grains et le pourcentage de battage. Le système de culture a influencé significativement ($P < 0,05$) tous les paramètres de rendement au cours des deux années. Le système CS2 a systématiquement produit des composantes de rendement supérieures, avec un rendement en grains de 1 376,0 kg ha?[1] en 2024, contre 564,0 kg ha?[1] pour le témoin non fertilisé (CS1). Le rendement le plus élevé en 2023 a été enregistré avec le système CS5 (573,6 kg ha?[1]). Les avantages de rendement observés avec les systèmes CS2 et CS3 ont été attribués à un meilleur apport en nutriments, notamment grâce à l'engrais organique et au

soja fixateur d'azote en rotation. Cesrésultatsdémontrentque la production biologique de tournesol avec les systèmes CS2 et CS3 peutatteindre des rendementscompétitifs sous les tropiques, offrantainsiunevoie durable pour la production de tournesol.

Mots-clés: Helianthus annuus L., rotation des cultures, composantes du rendement, engraisorganique, agriculture tropicale

1. Introduction

Sunflower (Helianthus annuus L.) stands out as a crucial oilseed crop valued for its high-quality edible oil and protein-rich meal globally. It is cultivated over 27 million hectares worldwide, with major production concentrated in Europe, the Americas, and parts of Asia (FAOSTAT, 2025). In the tropics, sunflowers are recognized for their adaptability to diverse soil and climatic conditions (Bassegioet al., 2016). Sunflower is well-suited to low-input systems due to its deep taproot, moderate nutrient requirements, and tolerance to intermittent drought (Debaekeet al., 2017).

In Nigeria and much of sub-Saharan Africa, yields often remain below the global average of 1.94 t ha?¹ (FAOSTAT, 2025), primarily due to constraints like inadequate soil fertility, limited access to better varieties, and poor management practices (Adeleke and Babalola, 2020). These challenges are exacerbated by the prevalent practice of continuous cropping, which accelerates nutrient depletion in the soil and diminishes productivity over time (Khaledianet al., 2017). Therefore, strategies aimed at restoring soil nutrients while ensuring continued productivity are vital for sunflower cultivation in the tropics.

Diversified crop rotation (DCR), which involves the planned alternation of three or more crops in sequence, has been recognized as an effective method to enhance soil fertility, disrupt pest and disease cycles, and optimize nutrient utilization (Wang, 2019; Renaud and Tilman, 2019). Incorporating legumes, such as soybeans, into a rotation contributes to biological nitrogen fixation, thereby decreasing reliance on external nitrogen sources and enhancing the yields of subsequent non-legume crops (Olowe et al., 2023). Oilseeds, such as sesame and cotton, also provide advantages within rotation, including nematode suppression and improved soil structure (Pettigrew et al., 2016). When paired with effective nutrient management practices, DCR can lead to both immediate and long-term productivity gains.

Research in temperate and subtropical regions has demonstrated that sunflower responds positively to crop rotation, particularly when organic nutrient sources are incorporated (Cui et al., 2022; Thompson et al., 2023). However, long-term field-based evidence from tropical environments remains limited, especially in systems integrating organic fertilizer management with diversified crop rotation. In the Nigerian forest-savanna transition zone, studies on sunflowers have focused primarily on planting dates, genotype evaluation, and fertilizer effects (Olowe et al., 2014; Oshundiyaet al., 2012), with less emphasis on how multi-year rotation histories influence yield attributes. This represents a critical knowledge gap, as yield components such as flower head diameter, number of seeds, and seed weight are directly linked to final grain yield and can be strongly influenced by prior cropping history and soil fertility status (Villalobos et al., 2023).

Therefore, this study evaluates the effects of a 5-year diversified crop rotation involving sesame, soybean, cotton, and sunflower under contrasting fertilization regimes on the yield and yield attributes of sunflower in Abeokuta, Ogun state, Nigeria (forest-savanna transitory zone). The objective was to determine the effects of preceding diversified crop rotation on the yield and yield attributes of sunflower. This is aimed at providing evidence-based recommendations for improved sunflower production in the tropics.

2. Materials and Methods

Study Site

The field experiment was conducted during the late cropping seasons (July-November) of 2023 and 2024 at the research plots of the Institute of Food Security, Environmental Resources, and Agricultural Research (IFSERAR), Federal University of Agriculture, Abeokuta, Nigeria (7°13?51?-53? N; 3°23?49?-51? E; 131.5 m above sea level). The site lies

within the forest-savanna transition zone of southwestern Nigeria, characterized by a bimodal rainfall pattern and a mean annual rainfall of 635.4 mm (1987-2022 average). Total rainfall during the experimental periods was 615.4 mm in 2023 and 398.3 mm in 2024. Mean daily temperatures ranged from 26.0 to 26.6 °C, with relative humidity between 79% and 88%.

Table 1: Growth Condition during the Experimental Period

Weather Parameter	July		August		September		October		November		Total	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
Mean temperature (°C)	23.8	25.2	25.9	24.6	26.1	26.5	27.1	28.3	27.1	28.6		
Total rainfall (mm)	148.9	35.1	56.4	50.4	135.5	95.3	236.2	207.8	38.5	9.7	615.4	398.3
Relative humidity (%)	80.8	88.4	79	80.1	82.3	82	84.1	84	82.1	88.2		
Sunshine (hours)	3.1	3.2	2.4	3.2	2.4	4.1	3.9	2.7	4.9	5.0	16.7	18.2

Soil and Preceding Rotation History

The experimental plots had been maintained under a 5-year diversified crop rotation involving sesame (Sesamum indicum L.), soybean (Glycine max (L.) Merrill), cotton *(Gossypium hirsutum L.)*, and sunflower *(Helianthus annuus* L.). Before planting in 2023, composite soil samples (0-15 cm) were collected from each plot, air-dried, and analysed for pH, organic matter, total N, and available P, following standard procedures.

Table 2: Pre-Cropping Soil Properties across Cropping Systems In 2023

Cropping System	pH	Total N (g/kg)	Available P (mg/kg)	Organic Matter (g/kg)	K (cmol/kg)
CS1	5.5	0.10	22	5.39	0.3
CS2	5.5	0.10	23	6.51	0.3
CS3	5.4	0.10	26	6.12	0.3
CS4	5.4	0.10	25	5.16	0.3
CS5	5.3	0.10	27	5.78	0.3

Experimental Design and Treatments

The experiment was laid out in a randomized complete block design (RCBD) with three replicates. Five cropping system treatments were evaluated:

CS1: Continuous cropping without fertilizer
CS2: Continuous cropping with organic fertilizer
CS3: Crop rotation with organic fertilizer
CS4: Crop rotation without organic fertilizer
CS5: Conventional cropping (synthetic inputs)

No fertilizer was applied during the experiment

Planting and Crop Management

The sunflower cultivar 'Favourite' from Bulgaria was used in this study. Seeds were sown at a spacing of 60 cm × 30 cm, giving a target plant population of 55,000 plants ha?¹. Weeds were manually controlled at 3 and 6 weeks after sowing (WAS).

Data Collection

a. Head diameter (cm): The diameter of five (5) sunflower heads harvested from the tagged plants was measured using a metre rule, and the average was recorded.
b. Head weight (g): The weight of five (5) heads harvested from the tagged plants was measured using an electronic scale, and the average was recorded.
c. Weight of seeds/head (g): The average weight of the achene of five (5) heads was recorded.
d. 100 seed weight (g): Hundred seeds were randomly counted and weighed using the sensitive scale.
e. Number of seeds/head: The average number of achenes on the harvested heads was counted
f. Grain yield (kg/ha): The threshed seeds were weighed to determine the yield per plot and later extrapolated to kg/ha.
g. Threshing percentage (%): The weight of seed/plant and seed weight of five randomly selected plants was determined, and the threshing percentage was calculated thus:
SH (%): (Weight of seed/head ÷ Head weight) × 100

3. Results

In 2023, grain yield ranged from 202.2 kg ha?¹ (CS1) to 652.7 kg ha?¹ (CS5) when sunflower was sown after sunflower in rotation. CS5 sunflower plants raised in this treatment recorded the highest flower head weight and seed weight, alongside the highest number of seeds. CS3 and CS4 also recorded a higher number of seeds per head, while CS1 consistently had the lowest values (Table 3). Sunflowers sown after cotton, yields varied more widely, with sunflowers sown under treatment CS4 achieving the maximum grain yield, significantly ($p > 0.05$) outperforming other treatments. Sunflowers sown under treatment CS4 also produced the highest seed weight and number of seeds. When sesame preceded sunflower, CS2 produced the highest grain yield and flower head diameter. The number of seedsrecorded the highest value under treatment CS4, while sunflowers sown in CS1 had the smallest head diameter and the lowest yield. Soybean as a preceding crop resulted in sunflower with notable yield improvements under CS2 and CS3, both exceeding 560 kg ha?¹ grain yield. Treatment CS3 significantly ($p > 0.05$) recorded a higher number of seeds per head, while CS2 achieved the largest head diameter and seed weight.

In 2024, yields were higher across treatments. CS2 achieved a grain yield far exceeding CS1. Sunflower head weights were highest in CS2, and the number of seeds peaked at 465. CS3, despite lower head weight, maintained competitive yields of 937 kg ha?¹ (Table 4).

Grain yield ranged from 493 kg ha?¹ (CS1) to 816 kg ha?¹ (CS4). The number of seeds per sunflower head recorded the highest value in treatment CS2, while CS5 recorded the highest sunflower head weight.

The combination of sesame rotation and organic fertilization in CS2 produced the largest yield (1,536 kg ha?¹) and number of seeds per head, more than triple that of the control (CS1). CS3 also yielded well (1,167 kg ha?¹) but with fewer seeds than CS2 in the combination of sesame rotation and organic fertilization.

Sunflowers sown after soybean in CS2 recorded the highest grain yield of all treatments and years (1,714 kg ha?¹) and the highest number of seeds. CS3 and CS5 also achieved yields above 975 kg ha?¹, compared to CS1 at 280 kg ha?¹.

Across both years, CS2 (continuous cropping with organic fertilizer) and CS3 (rotation with organic fertilizer) consistently produced high yields, large flower head diameters, and a high number of seeds per sunflower head, particularly when soybean or sesame planting preceded sunflower sown. The poorest performance was consistently observed under CS1, regardless of preceding crop (Tables 3 and 4).

Table 3: Effects of cropping system based on preceding crop on yield and yield parameters of sunflowers in 2023

Treatments	100 seed weight (g)	Flower Head weight (g)	Flower Head diameter (cm)	Grain yield (kg/ha)	Seed weight (g)	Number of seeds (g)	Shelling percentage (%)
Sunflower							
CS1	3.0	11.9	6.4	202.2	3.9	138.3	35.0
CS2	4.7	18.2	8.5	385.0	7.0	153.3	38.7
CS3	4.3	22.0	8.6	532.0	9.8	227.3	45.0
CS4	3.7	20.8	11.1	495.3	9.0	251.9	45.3
CS5	4.7	23.6	9.6	652.7	12.4	270.3	52.3
LSD (0.05)	Ns	5.50	ns	84.99	1.45	78.08	Ns
Cotton							
CS1	3.7	15.4	8.4	241.7	4.8	120.8	38.4
CS2	4.3	17.4	8.6	570.2	10.4	243.3	62.6
CS3	5.0	24.4	8.6	440.0	8.0	160.2	35.1
CS4	5.0	22.7	8.0	825.0	13.7	288.6	57.3
CS5	4.0	21.6	9.8	630.7	11.5	297.7	53.7
LSD (0.05)	Ns	Ns	ns	233.37	ns	97.17	Ns
Sesame							
CS1	3.0	8.1	4.8	201.7	3.9	141.1	50.7
CS2	5.3	21.5	9.9	550.0	10.0	192.8	46.7
CS3	4.0	21.9	8.7	443.7	8.1	194.8	35.3
CS4	3.7	16.1	10.4	507.8	9.2	275.3	54.0
CS5	4	18.6	8.4	450.1	8.2	175.3	46.6
LSD (0.05)	1.21	6.49	ns	ns	ns	164.36	Ns
Soybean							
CS1	3.7	12.9	5.3	275.5	4.2	115.3	37.0
CS2	5.3	19.3	8.4	562.8	10.2	189.2	53.0
CS3	3.7	19.7	9.3	570.3	10.4	289.7	52.6
CS4	4.3	19.9	7.6	432.7	7.6	173.5	40.6
CS5	4.0	16.5	7.0	561	6.9	255.0	61.7
LSD(0.05)	Ns	Ns	Ns	136.69	Ns	53.86	Ns

Table 4: Effects of cropping system across preceding crops on yield and yield parameters of sunflower in 2024

Treatments	100 seed weight (g)	Head weight (g)	Head diameter (cm)	Grain yield (kg/ha)	Seed weight (g)	Number of seeds (g)	Shelling percentage (%)
Sunflower							
CS1	5.0	19.0	8.1	1030	18.7	334	16
CS2	7.5	124.0	12.3	1676	30.5	465	27
CS3	5.5	59.0	10.8	937	17.0	250	30
CS4	5.0	91.0	12.3	1040	18.9	339	27
CS5	7.0	84.0	10.6	879	16.0	244	24
LSD (0.05)	0.88	Ns	Ns	ns	ns	Ns	Ns
Cotton							
CS1	4.33	29.2	7.3	493	9.0	225	31.7
CS2	3.0	40.3	10.4	578	10.5	403	27.1
CS3	6.67	45.5	12.3	807	14.7	191	28.4
CS4	5.67	56.3	9.7	816	14.8	264	26.4
CS5	6.0	97.6	10.5	779	14.2	241	20.3
LSD (0.05)	ns	Ns	Ns	ns	ns	Ns	Ns
Sesame							
CS1	4.33	26.0	6.7	453	8.2	206	30.3
CS2	6.67	115.0	13.8	1536	27.9	412	25.7
CS3	5.33	98.0	10.7	1167	21.2	447	22.8
CS4	5.67	44.0	10.2	473	8.6	149	22.0
CS5	6.33	79.0	9.7	809	14.7	244	19.9
LSD (0.05)	ns	Ns	Ns	ns	ns	Ns	Ns
Soybean							
CS1	4.33	19.0	7.2	280	5.1	129	26.3
CS2	7.33	135.0	13.9	1714	31.2	497	28.8
CS3	6.0	55.0	11.3	1021	18.6	305	34.9
CS4	6.0	46.0	8.3	924	16.8	262	36.2
CS5	5.33	58.0	8.9	975	17.7	342	34.8
LSD(0.05)	Ns	Ns	Ns	696.4	14.38	Ns	Ns

4. Discussion

The present study demonstrates that both the type of preceding crop and the cropping system significantly influence sunflower yield and yield components in the forest-savanna zone of Nigeria. The consistent superiority of cropping systems with organic inputs (CS2 and CS3) and, in some cases, CS4, highlights the combined benefits of diversified crop rotation and improved nutrient management.

When sunflower was sown after sunflowers under treatment CS5 in 2023 and continuous cropping with organic fertilizer, CS2 in 2024 produced the highest yields, suggesting that even in monoculture sequences, fertility management can offset some of the yield penalties typically associated with continuous cropping. However, the lower yields of sunflower in CS1 in both years indicated that nutrient depletion remains a limiting factor, in line with Villalobos et al. (2023), who noted that continuous sunflower reduces productivity without adequate nutrient replenishment.

On the other hand, rotation with cotton showed yield advantages in CS4 (2023) and CS2 (2024). This indicated thatcotton's deep rooting habit may improve subsoil structure and nutrient cycling, benefiting subsequent crops (Pettigrew et al., 2016), thereby contributing to subsequent sunflower performance when paired with improved fertility management. The variability between years suggests that climatic differences and nutrient management interact strongly with cotton's rotational effects.

Sunflower plants in sesame preceding sunflower rotation consistently performed well under CS2 and CS3, with CS2 producing triple the control yield in 2024. Sesame residues may decompose more rapidly, contributing available nutrients early in the season, while also reducing certain soil-borne pathogens (Langham et al., 2008). This aligns with rotation benefits reported by Renaud and Tilman (2019), where non-legume broadleaf crops reduced disease pressure and improved yield stability.

Sunflowers sown after soybeans in rotation produced the highest yields overall, particularly under CS2 in 2024 (1,714 kg ha?¹). The effects of chemical fertilization on sunflower yield and quality have been studied scientifically since nitrogen is a vital nutrient for plants that aids in improving total biomass production and yield (Ashok et al. 2018). The biological nitrogen fixation from soybean (Mpeperekiet al., 2000) boosted soil nitrogen availability, which is crucial for sunflower's early vegetative growth and reproductive development. Enhanced soil nitrogen may explain the higher number of seeds and larger flower head diameters observed, consistent with the findings of Cui et al. (2022) and Thompson et al. (2023) on legume-oilseed rotations. The superior performance of sunflower plants sown under treatment CS2 and CS3 can be explained by the combined effects of nutrient enrichment from organic manure and the rotational benefits of preceding crops. In humid tropical Nigeria, sunflower yields vary considerably depending on genotype, planting date, and fertility management. Oshundiyaet al. (2014) reported seed yields ranging from 850 to 1,526 kg/ha when sunflower was grown under organic fertilizer regimes with staggered sowing dates in Abeokuta, Southwestern Nigeria. This performance aligns with the national average of 1,000 kg/ha, the African average of 812 kg/ha, and the global average of approximately 1,520 kg/ha (FAOSTAT, 2020). Between 2001 and 2005, trials in the humid tropics of Nigeria demonstrated average organic sunflower yields of 1.03 to 1.26?t/ha, indicating that organic systems could support productivity levels close to or exceeding national averages (Oshundiyaet al., 2012). These results highlight the potential of organic nutrient sources, especially in integrated systems that improve soil fertility and moisture retention. Organic manure provides a slow-release source of N, P, and K, as well as micronutrients, improving chlorophyll content, leaf area duration, and assimilate translocation to developing seeds (Ashok et al., 2018). The superior performance of CS2 and CS3 compared to CS1 and CS4 may be partly explained by the enrichment of beneficial soil microbial populations under organic fertilization and crop rotation, which enhance nutrient cycling and root health, thereby supporting larger flower heads and a higher number of seeds (Hu et al., 2025). Rotational diversity interrupts pest and disease cycles, improves root zone aeration, and promotes beneficial soil microbial populations (Palm et al., 2001; Wang et al., 2023).

These findings reinforce that diversified crop rotations incorporating legumes and oilseeds, coupled with regular organic amendments, can maintain or enhance soil fertility while supporting high yields. This approach reduces reliance on synthetic fertilizers, which is particularly important for smallholder farmers in the tropics who face cost and availability constraints. Moreover, the long-term application of organic inputs enhances soil organic matter and cation exchange capacity, contributing to system resilience under rainfall variability (Wang et al., 2023).

5. Conclusion

This study shows that both the type of preceding crop and the cropping system influence sunflower yield and yield attributes in the forest-savanna zone of Nigeria. The most productive outcomes were achieved when sunflowers followed soybeans under continuous or rotational systems with organic fertilization (CS2 and CS3). These combinations consistently produced larger sunflower heads, more seeds, and significantly higher grain yields than continuous unfertilized cropping. The benefits are linked to improved soil fertility from organic amendments and nitrogen enrichment from legumes. For tropical smallholder farmers, integrating soybean into crop rotations and application of organic fertilizer offers a sustainable pathway to higher sunflower productivity while maintaining soil health. Avoiding continuous unfertilized monoculture is essential to prevent soil degradation and yield decline. Long-term adoption of legume-inclusive rotations with organic inputs can support both productivity and environmental sustainability in the tropics.

Note: The sunflower cultivar 'Favorit', originally bred in Bulgaria, represents an exotic variety that nonetheless demonstrated strong adaptability to the Nigerian forest-savanna environment. This aligns with previous reports that exotic sunflower germplasm can thrive in tropical systems when supported by diversified crop rotations and organic fertilization (Nigerian Seed Portal Initiative, 2010).

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Influence of Ibadan Brewery Waste-Based Compost on the Growth and Yield of Cabbage

Influence of Ibadan Brewery Waste-Based Compost on the Growth and Yield of Cabbage
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Abstract

In Nigeria, waste management and disposal have become a significant cost factor and an important aspect in the running of a brewery operation. Composting brewery waste could be a major way of disposing of the waste, and it could be a good source of organic fertilizers for crop production. This study aimed to assess the influence of Ibadan Brewery Waste-Based Compost (IBWBC) on the yield of cabbage and on the chemical properties of soil. The experiment was conducted at the Organic Vegetable Garden Teaching and Research Farm, University of Ibadan, Ibadan. The field study was laid out in a Randomized Complete Block Design with two treatments and four replicates. A nursery operation, which lasted for 4 weeks, began the field trial; this was later transplanted. There were sixteen beds measuring 1.8 m x 2.4 m for each and were spaced 50 cm apart. The IBWBC was obtained from an ongoing experiment on the farm, and the application was done two weeks before transplanting. Harvesting was done after 13 weeks of transplanting. Growth and yield parameters, as well as soil properties of the experimental site, before and after planting, were determined.
The yield of cabbage planted with IBWBC was (14.81t/ha), and it was significantly higher than the control (4.93 t/ha), where no fertiliser was used. The fertilizer application increased the organic matter of the soil and influenced other chemical properties of the soil after planting. The pH of the soil was in the neutral zone.
In conclusion, Ibadan brewery waste-based composts can serve as a good organic fertilizer in crop production and can be used to improve the fertility status of the soil over time.

Keywords: Brewery waste, Cabbage, Compost, Ibadan brewery waste-based composts, and Soil fertility.

Résumé
Au Nigéria, la gestion et l'élimination des déchets représentent un poste de dépenses important et un aspect essentiel de l'exploitation d'une brasserie. Le compostage des déchets de brasserie pourrait constituer une solution efficace pour leur élimination et constituer une source intéressante d'engrais organiques pour les cultures. Cette étude visait à évaluer l'influence du compost à base de déchets de brasserie d'Ibadan (IBWBC) sur le rendement du chou et les propriétés chimiques du sol. L'expérimentation a été menée à la ferme pédagogique et expérimentale de l'Université d'Ibadan, à Ibadan. Le dispositif expérimental était un bloc complet randomisé à deux traitements et quatre répétitions. Une pépinière, d'une durée de quatre semaines, a servi de point de départ à l'essai en plein champ, suivie d'un repiquage. Seize planches de 1,8 m x 2,4 m, espacées de 50 cm, ont été aménagées. L'IBWBC provenait d'une expérimentation en cours sur la ferme et a été appliqué deux semaines avant le repiquage. La récolte a eu lieu 13 semaines après le repiquage. Les paramètres de croissance et de rendement, ainsi que les propriétés du sol du site expérimental, ont été déterminés avant et après la plantation.
Le rendement du chou cultivé avec le compost à base de déchets de brasserie d'Ibadan (IBWBC) était de 14,81 t/ha, soit significativement supérieur à celui du témoin (4,93 t/ha) sans apport d'engrais. L'engrais a augmenté la teneur en matière organique du sol et a influencé d'autres propriétés chimiques du sol après la plantation. Le pH du sol était neutre.
En conclusion, le compost à base de déchets de brasserie d'Ibadan peut constituer un bon engrais organique pour la production agricole et contribuer à améliorer la fertilité du sol sur le long terme.

Mots-clés: Déchets de brasserie, Chou, Compost, Compost à base de déchets de brasserie d'Ibadan, Fertilité du sol.

Introduction

An increase in industrial activities has led to pollution of our major rivers and streams in Nigeria, including the streams in a densely populated area of Ibadan (Ibekwe *et al*., 2004). Waste management and disposal have become a significant cost factor and an important aspect in the running of a brewery operation (Fillaudeau *et al*.,2006). Every brewery tries to keep waste disposal costs low, whereas the legislation imposed for waste disposal by the authorities becomes more stringent (Knirsch *et al*.,1999). An alternative use of brewery waste, which could reduce both waste disposal costs and environmental pollution, is its utilisation in composting as a source of organic fertiliser. This approach is particularly important because the availability of alternative organic fertiliser sources remains a major challenge in most organic crop production systems, and it could also contribute to improving the fertility status of many Nigerian soils.
The challenge of improving the fertility and increasing the productivity of the soil for increased agricultural production has become significant (Azagaku and Anzaku 2002). The status of soil fertility in the tropics is therefore of considerable importance for food security, given the increase in global population, with most of this growth occurring in the tropics (Thangavel *et al*., 2017). An adequate nutrient supply is an essential factor in plant growth; plants are likely to grow well and produce high yields (Fageria *et al*., 2008). Organic sources of plant nutrients, such as organic amendments could remain the principal sources for the maintenance of soil fertility and environmental quality, and this may also be accomplished through the application of fertilisers (Aytenew *et al*., 2020).

Organic fertilizers (such as manure and compost) are valuable for any farming operation and have been used for centuries to supply needed nutrients for crop growth. Manure and compost do not only supply many nutrients for crop production, including micro nutrients, but they are also major sources of organic matter (Smith *et al*., 2007). Increasing soil organic matter improves soil structure, increases the water-holding capacity of coarse-textured sandy soils, improves drainage in fine-textured clay soils, provides a source of slow-release nutrients, reduces wind and water erosion, and promotes the growth of earthworms and other beneficial soil organisms. (Favoino and Hogg 2008; Albaladejo *et al*., 2008). Adding compost to soil increases soil fertility and cation exchange capacity (Ndubuaku and Lucas 2000). Compost, added to agricultural soil as a fertilizer to improve soil fertility and promote the growth of crops and microorganisms, and as a soil amendment to relieve heavy metal pollution (Huang et al., 2016).Compost has been used to increase the yield of crops, especially vegetables such as amaranth, celosia, pepper, etc. (Oworu *et al*., 2009; Komolafe *et al*., 2021)

Cabbage *(Brassica oleracea L.)*, a member of the Cruciferae and a useful vegetable, belongs to the genus Brassica. This group may be cultivated for edible qualities but also grown ornamentally for its colourful leaf forms. (Jim and Tony, 2006). The health benefits of cabbage, such as treatment for constipation, obesity, skin disorders, heart disease, rheumatism, eye disorders, aging, etc. has made it a sought-after crop (Grubben and Denton, 2004). Increasing the availability of high-quality cabbage throughout the year and reducing its price requires the use of organic fertilizers such as compost. However, much work has not been done on the use of brewery waste-based compost as a fertiliser source on plant growth, yield, and soil properties.

The objectives of this study are to determine the effects of brewery waste-based composts on the growth and yield of cabbage, and to determine the effects of brewery waste-based compost on some fertility properties of the soil.

MATERIALS AND METHOD

Experimental sites

The experiment was carried out at the Organic Vegetable Garden Teaching and Research Farm. It is in the derived savannah zone of Western Nigeria, which lies between latitude 7 ° 24 'N and longitude 3 ° 54' E with an elevation of 62 m above sea level. The mean monthly temperature ranges between 24 °C and 30oC and the mean annual rainfall ranges between 1800 mm and 2100 mm. The soil texture ranges from sandy to loamy sand, which is slightly acidic. The nursery exercise was carried out at the screen house of the Department of Agronomy, University of Ibadan (70 24'N, 3054'E, 234m above sea level).

Sources of materials: The compost used was obtained from an ongoing experiment at the teaching and research farm of the University of Ibadan. Seeds were obtained from PIONEER Seeds.

Experimental design, methodology, and treatments
The experiment was conducted between October and December 2016, following the establishment of cabbage seedlings in a nursery for four weeks in September 2016. The study was laid out using a randomized complete block design (RCBD) with four replications. Each experimental plot measured 9.2 m × 11.6 m and comprised sixteen beds, with individual beds measuring 1.8 m × 2.4 m and spaced 50 cm apart. Two treatments were evaluated: Ibadan Brewery Waste-Based Compost (IBWBC) and a control treatment without fertilizer application. Cabbage *(Brassica oleracea var. capitata)* was used as the test crop. The compost was applied at a rate equivalent to 200 kg N ha^{-1}, with the first application incorporated into the soil two weeks before transplanting and the second applied as a top dressing at eight weeks after transplanting. Seedlings were transplanted into the main field at a spacing of 0.6 m between rows and 0.30 m within rows, at a depth of approximately 0.05 m, resulting in sixteen plants per bed. Routine agronomic practices were carried out throughout the experimental period; weeds were controlled manually, and irrigation was applied as required to maintain adequate soil moisture. Insect pests and rodents were controlled five weeks after transplanting using neem oil applied at a rate of 10 mL per litre of water. Harvesting of cabbage heads was carried out at thirteen weeks after transplanting.

Experimental design and treatments: The experiments were laid out in a randomized complete block design (RCBD) with four replications. The plot size was 9.2 m x 11.6 m with sixteen beds. Each bed was 1.8 m x 2.4 m, spaced 50 cm apart.

Treatments: Ibadan Brewery Waste-Based Compost (IBWBC) and Control- no fertilizer added were the treatments used.

Test crop: the test crop for the experiment was Cabbage *(Brassica oleracea var. capitata)*
Fertilizer application rate and time:Fertilizer was applied at the rate of 200 kgN/ha, and it was applied 2 weeks before transplanting and top dressed at the 8th week after transplanting.

Planting spacingcabbage seedlings were spaced 0.6 m between rows and 0.30 m between seedlings, 0.05 m deep, making a total of sixteen seedlings per bed.

Planting period: Nursery, September 2016;field trial: October- December 2016.
Cultural practices: Weeds were controlled manually. Plots were irrigated as needed. Insects and rodents were controlled five weeks after transplanting using neem oil at a rate of 10ml of neem oil to1litre of water.

Harvesting: The crop was harvested 13 weeks after transplanting.
Data collection: Four plants per bed were tagged and selected as representative samples; the number of leaves and head diameter were measured and used in yield estimations. Plants were harvested from the roots, and their fresh weights were taken. Dry weights were determined after drying the plant materials at 70°C in a forced air oven for 72 hours.

Soil Analysis: Effects of the Compost on the physical and chemical properties of the soil were determined by collecting soil samples from different portions of the field before planting and after harvest. The soil samples before planting were mixed to form a composite sample, which was air-dried and taken to the laboratory for physical and chemical analyses. The soil samples were subjected to routine analysis using standard procedures (Okalebo et al., 1993).

Statistical Analysis: analysis of variance (ANOVA) was used to analyse the data collected on the morphological parameters and yield of the cabbage. The analysis was carried out using Genstat Discovery Edition 4. Significant means were separated using Fisher's least significant difference at 5% probability as outlined by Obi (2002).

Results
The result in Table 1 indicates the nitrogen, phosphorus, and potassium content of the compost used in the study. The nitrogen content of the compost was 1.80 g/kg, phosphorus was 1.93 g/kg, and potassium was 2.10 g/kg.

Pre- cropping physical and chemical analysis of the soil used
The result in Table 2 indicates the physical and chemical properties of the soil before application of soil amendment (brewery waste-based compost). The textural class of the soil is loamy sand soil with a pH of 7.1; total organic carbon,

nitrogen, and calcium were 10.5 g/kg, 0.8 g/kg, and 2.1 cmol/kg, respectively. The total phosphorus level is moderate at 17 mg/kg. The potassium is moderate at (0.5 cmol/kg).

Effect of composts on the number of leaves of cabbage
The effect of Ibadan brewery waste-based compost (IBWBC) on the number of leaves is shown in Table 3.The number of leaves increased with the age of the plant and reduced as the head began to form. The IBWBC had the highest number of leaves for week 2, 4, 6, 8, and 10 after transplanting (4.3, 8.0, 13.8, 16.0, and 18.8, respectively), while the control had the least (3.0, 4.1, 8.2, 10.0, and 10.4). Control had the highest mean at week 12 (15.9) and was not significantly different from IBWBC (14.5).

Effect of composts on the head diameter of cabbage
Table 4 shows the effect of organic fertilizers on the head diameter of cabbage. IBWBC had the highest mean for head diameter across the production period; IBWBC (37.0 cm) wasnot significantly higher than control in week 12 (31.6 cm).
Effect of composts on the weight of the whole plant, root, and shoot of cabbage

The effect of Ibadan brewery waste-based composts (IBWBC) on the plant, root, and shoot weight of cabbage is shown in Table5. IBWBC had the highest mean plant weight (308.8 g/plant), root weight (20.9 g/plant), and shoot weight (287.9 g/plant) of cabbage and was significantly higher than the control (82.1 g/plant, 7.1 g/plant, 72.3 g/plant), respectively.

Table 1: Composition of Ibadan Brewery Wastes-Based Composts (IBWBC)

Nutrient (Total) (%)	IBWBC
Nitrogen	1.80
Phosphorus	1.93
Potassium	2.10

Legend

IBWBC-Ibadan Brewery Waste Based Compost

Table 2: Pre-cropping chemical and physical analysis of soil used

Parameter	**Measured value**
pH (H_2O1:1)	7.1
OC (g/kg)	10.5
N (g/kg)	0.8
(mg/kg) P	17

Cations (cmol/kg)	
Ca	2.1
Mg	0.5
K	0.5
Na	2.4
Micronutrients (mg/kg)	
Mn	48
Fe	37
Cu	1
Zn	8
Particle size analysis (g/kg)	
Clay	48
Silt	94
Sand	858
Textural class	Loamy Sand soil

Table 3: Effect of composts on the number of leaves of cabbage

TREATMENT	WEEKS AFTER TRANSPLANTING					
	2	4	6	8	10	12
IBWBC	4.3a	8.0a	13.8a	16.0a	18.8a	14.5a
CONTROL	3.0b	4.1b	8.2b	10.0b	10.4b	15.9a

Table 4: Effect of composts on head diameter (cm) of cabbage.

TREATMENT	WEEKS AFTER TRANSPLANTING				
	9	10	11	12	13
IBWBC	16.1a	31.0a	40.4a	37.0ab	22.1a
CONTROL	8.6b	16.1b	24.1b	31.6b	12.0b

Table 5: Effect of composts on the weight of the whole plant, Root and Shoot of cabbage

TREATMENT	Plant weight	Root weight	Shoot weight
		(g/plant)	
IBWBC	309.0a	20.9a	287.9a
CONTROL	82.1b	7.1b	72.3b

Legend

IBWB-Ibadan Brewery Waste Based Compost

Effect of composts on fresh and dry fruit yield of cabbage

The effect of Ibadan brewery waste-based compost on the fruit yield of cabbage is shown in Fig. 1. IBWBC had the highest fruit yield of (14.81 t/ha), which was significantly higher than the control with a fruit weight mean of (4.93 t/ha). The dry fruit yield also followed the same trend as the fresh fruit.IBWBC had the highestmean of 0.56 t/ ha, which differed significantly from the control (0.27 t/ha).

Post- cropping chemical analysis of the experimental soil

The effect of the compost on the soil after planting is shown in Table 6. The pH of the soil after cropping for all treatments has a mean of 7.1;the treatments left the soil at the neutral zone. The treatment increased the organic carbon of the soil, invariably increasing the organic matter of the soil. The brewery waste- based composts had higher values for total nitrogen, Phosphorus and potassium(1.68, 25, and 1.6), which are greater than the critical levels. The textural class remainsloamy sand soil.

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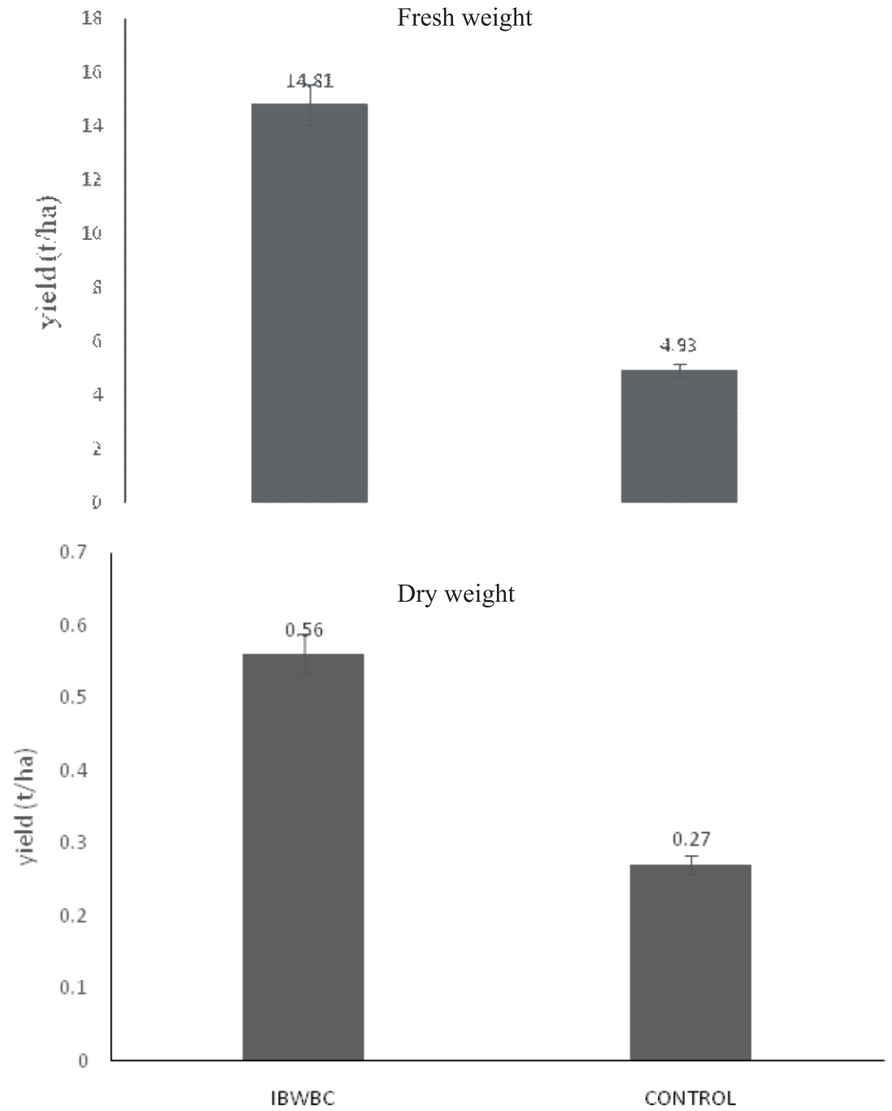

Figure 1: Effect of compost on fresh and dry fruit yield o cabbage

Table 6: Post- cropping chemical and physical analysis of the experimental soil

Parameters	IBWBC	CONTROL	Critical levels
pH (H_20) 1:1	7.2	7.0	5.5- 6.5
O.C (g/ kg)	12.11	1.89	4.0-10.0
N (g/kg)	1.68	0.28	0.6-1.0
(mg/ kg) P	25	4	7.0-20.0
Cations (Cmol/kg)			
Ca	3.2	1.8	5-10
Mg	0.5	0.3	1-3
K	1.6	0.5	0.31-0.6
Na	1.2	2.2	0.3-0.8
Micronutrients (mg/kg)			
Mn	53	15	
Cu	29	25	
Fe	3	2	
Zn	8	2	1.0-5.0
Particle size analysis (g/ kg)			
Sand	856	858	
Silt	96	94	
Clay	48	48	
Soil texture (USDA)	Loamy Sand soil	Loamy Sand soil	

Discussion

The use of compost in crop production not only has the potential to improve food security but can also enhance environmental sanitation (Aina and Adedipe, 1992). Waste disposal has become a significant cost factor and an important aspect in the running of a brewery operation (Fillaudeau *et al*., 2006), with spent grain being the major waste. Ebido *et al* (2024 revealed that Brewery waste-based compost has improved the yield of amaranth when compared to the control. The application of IBWBC increased the number of leaves of cabbage, and this is like the report of Atta-Poku et al. (2014) that there was a significant increase in the number of leaves of cabbage grown with organic fertilizers. Also, the IBWBC increased the head diameter of cabbage, which is in alignment with Gamal *et al*. (2009) that N-fertilizer tends to increase the head diameter of cabbage. The compost treatment gave three times the yield obtained from the control. This confirms the work of Maheshbabu *et al*. (2007) that organic materials act as nutrient reservoirs and, upon decomposition, are released slowly during the entire growth periods leading to higher seed yield and yield components.

The compost treatment maintained the soil at the neutral zone; observation that the organic residues generally increased soil pH compared with the control is in tandem with the reports of previous workers (Opala *et al*., 2012, and Kolawole, 2016). The composts had a significant increase in the organic carbon of the soil. The application of compost was observed to increase the organic matter; this may be due to the high amount of organic matter present in the organic materials (Bayu *et al*., 2005). The result also showed that the application of compost had significant effect on the nitrogen content of the soil as the compost increased the total nitrogen of the soil This may be due to supply of N in the compost through mineralization associated with improved soil condition for microbial activities as a result of increased organic matter, This is in line with Adenawoola and Adejoro, (2005) who reported that organic residues increased the nitrogen content of the soil with time.

IBWBC had a significant increase on the potassium content of the soil after cropping. This agrees with the report of (Urkurkar *et al.*, 2010) that organic input increases the available potassium in the soil. The increase of soil organic matter resulted in a decrease in K fixation and subsequently increased K availability (Singh *et al*., 2002).

CONCLUSION AND RECOMMENDATION

In conclusion, the results obtained revealed that Ibadan Brewery Waste-BasedCompost had a significant increasein the Physical and chemical properties of soil, growth, and yield of cabbage compared to the control. Brewery waste-based compost could be used successfully as a soil amendment to increase yield as well as maintain a good soil fertility status for sustainable organic crop production.

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Application Rates of Poultry Manure and Seed Size Effects on the Growth and Yield of Fluted Pumpkin (Telfairia Occidentalis Hook F.)

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Abstract
Fluted pumpkin (Telfairia occidentalis Hook F.) is economically important and a nutritionally dense leafy green vegetable in West Africa, valued for its protein-rich seeds and edible leaves. Productivity in farmers' fields, however, remains low because of poor soil fertility, inadequate knowledge and application of agronomic practices, as well as limited access to fertilizers. This study, therefore, evaluated the effects of poultry manure (PM) application and the size of seed on the growth and yield of T. occidentalis under humid tropical conditions. The study was conducted at the University of Uyo Teaching and Research Farm during the 2011 early cropping season, using a 3 × 4 factorial experiments arranged in a Randomized Complete Block Design (RCBD). Treatments comprised three seed sizes from small (<14 g), medium (14-20 g), to large (>20 g); and four rates of PM (0, 5, 10, and 15 t ha^{-1}), replicated three times. From the results, PM significantly ($P \leq 0.05$) improved vine length, number of leaves, tendrils, and foliar yield, with PM at 5 t ha^{-1} producing the highest values. Similarly, pod number, girth, and total foliar yield increased with increasing PM rates, attaining a maximum of 13.15 t ha^{-1} at 15 t ha^{-1} PM. Seed size significantly influenced early vegetative growth, as large seeds produced more vigorous seedlings and higher leaf biomass, but had no significant effect on pod yield. The interactive effect between manure application rate and seed size was not significant, showing independent treatment effects. Overall, the application of 15 t ha^{-1} poultry manure is recommended to enhance soil fertility, growth, and yield of T. occidentalis under sandy loam conditions. Adoption of this practice offers a sustainable, low-cost pathway to boost productivity among smallholder farmers.

Keywords: Fluted pumpkin, leafy greens, seed technology, yield

Résumé
La courgecannelée (Telfairia occidentalis Hook F.) est un légume-feuille vert à haute valeur nutritive et économiquement important en Afrique de l'Ouest, apprécié pour sesgraines riches enprotéines et sesfeuilles comestibles. Cependant, la productivité des cultures reste faible en raison de la faible fertilité des sols, de connaissances et d'applications agronomiques insuffisantes, ainsi que d'un accès limité aux engrais. Cette étude a donc évalué les effets de l'application de fumier de volaille et de la taille des graines sur la croissance et le rendement de T. occidentalis en conditions tropicales humides. L'étude a été menée à la ferme d'enseignement et de recherche de l'Université d'Uyo au début de la saison de culture 2011, selon un dispositif expérimental factoriel 3 × 4 en blocs aléatoires complets (BAAC). Les traitements comprenaient trois tailles de graines : petites (< 14 g), moyennes (14-20 g) et grandes (> 20 g) ; et quatre doses de fumier de volaille (0, 5, 10 et 15 t ha?[1]), répétées trois fois. D'après les résultats, l'application de fumier de volaille (FV) a significativement amélioré (P ? 0,05) la longueur des tiges, le nombre de feuilles et de vrilles, ainsi que le rendement foliaire, les valeurs les plus élevées étant obtenues avec une dose de 5 t ha?[1]. De même, le nombre de gousses, leur circonférence et le rendement foliaire total ont augmenté avec la dose de FV, atteignant un maximum de 13,15 t ha?[1] à 15 t ha?[1]. La taille des graines a influencé significativement la croissance végétative précoce : les grosses graines ont produit des plantules plus vigoureuses et une biomasse foliaire plus importante, mais n'ont pas eu d'effet significatif sur le rendement en gousses. L'interaction entre la dose de fumier et la taille des graines n'était pas significative, ce qui indique des effets indépendants des traitements. En conclusion, l'application de 15 t ha?[1] de fumier de volaille est recommandée pour améliorer la fertilité des sols, la croissance et le rendement de *Triticum occidentalis* en conditions de sol sablo-limoneux. L'adoption de cette pratique offreune solution durable et économique pour accroître la productivité des petits exploitantsagricoles.

Mots-clés: Courgecannelée, légumes-feuilles, technologie des semences, rendement

Introduction

Fluted pumpkin (*Telfairia occidentali*s Hook F.), known in local Nigerian parlance as Ugwu, Ikong Ubong, or Apiroko, is important in West African cuisine and agriculture. This perennial, dioecious vine, of the Cucurbitaceae family, is prized not only for its highly nutritious leafy greens but also for its protein- and oil-rich edible seeds. While traditionally cultivated across the humid lowland tropics of Nigeria, Ghana, and Sierra Leone, its potential for addressing food and nutritional security is gaining renewed scientific and commercial interest (Adewumi and Adebayo, 2023). The exact origin of fluted pumpkin is debated, but a strong consensus identifies it as indigenous to West Africa. Nwonualaand Akani (2022) report that it is widely believed that wild populations have been largely replaced by cultivated forms, making it a true domesticate of the region. Fluted pumpkin is a vigorous climber, able to reach lengths of over 20 meters in branched tendrils. It is dioecious, meaning individual plants are either male or female. Female plants are typically more robust, with larger leaves and longer vegetative periods, making them more desirable for leaf harvest (Obiagwu and Madukwe, 2021). The large, fluted pods are a distinctive feature, measuring up to 70 cm long and containing 40-110 flat, oily seeds. A significant challenge in its cultivation is the recalcitrant (desiccation-sensitive) nature of its seeds, which lose viability rapidly if not planted soon after extraction from the pod, posing a constraint on seed storage and distribution (Eze *et al.*, 2020).

Fluted pumpkin is adaptable but thrives in deep, well-drained, loamy soils rich in organic matter, with a slightly acidic to neutral pH (5.5-6.5). It requires a warm, humid climate with annual rainfall between 1,000mm and 2,500mm. Although moderately drought-tolerant, consistent soil moisture is crucial for high leaf yield, and irrigation can enable year-round production (Akinrotimi *et al*., 2021). Cultivation is primarily from seeds, sown on mounds, ridges, or beds. Close spacing is used for intensive leaf production, while wider spacing with staking is preferred for fruit and seed development. Smallholder farmers often intercrop it with staples like yam yams and cassava, where it serves a dual purpose as a food source and a soil cover for weed suppression (Okon *et al*., 2022).

The economic and nutritional importance of fluted pumpkin cannot be overstated. The leaves are a rich source of protein, vitamins (A, C, and E), minerals (iron, calcium, magnesium), and antioxidants. Recent analyses confirm that the leaves contain significant amounts of iron and folate, making them a potent dietary tool in combating anaemia, a prevalent public health issue (Airaodion *et al*., 2020). The seeds are exceptionally nutritious, containing up to 30% protein and 50-60% high-quality oil, rich in essential fatty acids. This oil has potential applications in the food and cosmetic industries (Olaniran *et al*., 2023).

Beyond its nutritional value, fluted pumpkin holds profound medicinal importance in ethnobotanical practices. Extracts from the leaves and seeds have demonstrated anti-anemic, anti-inflammatory, anti-diabetic, and hepatoprotective properties in scientific studies, validating their traditional uses (Ejike *et al*., 2021). The plant also contributes to rural livelihoods; it is a significant income source, particularly for women who often dominate its marketing. Its cultivation in home gardens enhances household dietary diversity and provides a safety net against food insecurity (Nwachukwu and Otekunrin, 2024). Despite its importance, the commercial production of fluted pumpkin remains suboptimal. The sector is dominated by resource-poor smallholder farmers who face numerous challenges. In addition, and notably, inherently low soil fertility, particularly in the heavily weathered soils of the Niger Delta, and the high cost and limited access to inorganic fertilizers (Chukwuka and Uka, 2022). Furthermore, the recalcitrant nature of seeds and a lack of improved, high-yielding cultivars constrain productivity.

These challenges create a significant gap between domestic supply and the soaring demand driven by rapid urbanization and population growth. Consequently, prices often become prohibitive, especially during the off-season, forcing consumers to seek less nutritious alternatives (Adewumi and Adebayo, 2023). This scenario underscores the urgent need for research into sustainable agronomic practices that can boost yield and make cultivation more profitable and resilient.
A promising strategy to overcome production constraints lies in the integrated use of organic soil amendments and improved planting material. The frequent and often inefficient use of mineral fertilizers is not only expensive but also associated with environmental pollution, such as soil acidification and water eutrophication. In contrast, organic manures like poultry manure offer a sustainable alternative. Poultry manure is rich in nitrogen, phosphorus, potassium, and micronutrients. Its application improves soil structure, enhances water-holding capacity, and promotes beneficial microbial activity, leading to sustained nutrient release (Ojo *et al*., 2023). Studies on other indigenous vegetables have

consistently shown that poultry manure application significantly improves vegetative growth, leaf yield, and overall plant health. Simultaneously, the selection of high-quality planting material is a critical factor often overlooked by traditional farmers. Seed size is a key physiological attribute that can influence germination vigour, seedling establishment, and subsequent crop performance. Larger seeds typically contain greater food reserves, which can support the young seedling until it can photosynthesize independently. While some studies on crops like cowpea and maize have confirmed a positive correlation between seed size and seedling vigour, research specific to fluted pumpkin has yielded conflicting results, indicating a knowledge gap that needs to be addressed (Nwonuala and Akani, 2022).

There is a clear, synergistic opportunity to investigate the combined effects of poultry manure application and seed size selection on the productivity of fluted pumpkin. Understanding this interaction can provide a low-cost, accessible, and sustainable protocol for smallholder farmers to enhance their yields. By optimizing these two factors, farmers can potentially reduce their reliance on chemical inputs, improve germination rates, and achieve more robust plant growth for both leaf and seed production.

Therefore, this study was designed to generate knowledge to bridge the existing production gap. The study therefore determined the effect of different application rates of poultry manure and the size of seeds on the growth and yield of fluted pumpkin *(Telfairia occidentalis).*

Materials and method

Description of the Study Area and Experimental Procedures

The experiment was conducted during the 2020 early cropping season at the University of Uyo Teaching and Research Farm, Use-Offot, Uyo, Akwa Ibom State, Nigeria. Uyo lies within the humid tropical rainforest zone of southern Nigeria, between latitudes 5.18°-5.28°N and longitudes 7.26°-7.57°E, at an elevation of approximately 38 m above sea level. The region experiences wet and dry seasons, with mean annual rainfall ranging between 268.8 and 270.1 mm, mean monthly relative humidity of about 80%, and mean monthly temperature of 26.8-27.0°C. The site, previously fallowed for one year to restore fertility, had been used for growing cassava, maize, fluted pumpkin, yams, and garden egg. Experimental design and field layout followed a 3 × 4 factorial arrangement in Randomized Complete Block Design (RCBD), of three seed size categories; viz small (<14 g), medium (14-20 g), and large (>20 g) and four poultry manure (PM) levels: 0, 5, 10, and 15 t/ha. This yielded 12 treatment combinations replicated three times, giving 36 plots in total. Each plot measured 3.0 m × 2.5 m, separated by 1 m paths, with a total experimental area of 850 m². Poultry manure was incorporated two weeks before planting. Soil and manure analysis were carried out using composite soil samples collected at 0-15 cm and 15-30 cm depths for physical and chemical analysis. Parameters determined included pH (1:2.5 soil-water suspension), total nitrogen (Micro-Kjeldahl), available phosphorus (Bray P-1), exchangeable cations (Ca, Mg, K, Na), and particle size distribution (hydrometer method). The soil was classified as sandy loam. Poultry manure samples were oven-dried at 60-80°C, sieved through a 2 mm mesh, and analysed for N, P, K, Ca, Mg, Zn, Fe, Cu, and Mn. Seeds were sourced from Afaha market (Ibesikpo Asutan LGA, Akwa Ibom State, Nigeria), air-cured for two days, and planted on July 18, 2020, at 4-5 cm with 80 × 60 cm spacing, two seeds per hole. Major weeds included *Ipomea involucrata, Axonopus compressus*, and *Chromolaena odorata,* and these were manually controlled at 5 and 11 weeks after planting (WAP). Chlorpyrifos (1 mL per 4 L of water) was used for the control of pest infestations by termites, grasshoppers, and caterpillars. Data was collected from four central plants per plot tagged for weekly observations at 3, 6, 9, and 12 WAP. Growth parameters measured included vine length, number of leaves and tendrils, and foliar yield. Yield components recorded were the number of pods per plot, the length of pods, pod girth, and pod yield. Data were analysed for Analysis of Variance (ANOVA), and post-hoc test using Fisher's Least Significant Difference (FLSD) at 5% probability level (Gomez & Gomez, 1984).

Results and Discussion

The baseline physico-chemical characteristics of the experimental soil are presented in Table 1. The soil was classified as sandy loam, with a high sand fraction (75.60%) and lower silt (10.40%) and clay (14.00%) contents. This textural class typically promotes good drainage and aeration (Brady and Weil, 2008), which is beneficial for root development and prevents water-logging. However, such soils are also known for their moderate to low inherent nutrient-holding

capacity, making them susceptible to nutrient leaching. The soil was slightly alkaline (pH 8.00 in H_2O), a condition that can influence the availability of essential micronutrients. The electrical conductivity was low (5.80 DS/m), indicating that salinity was not a constraint to plant growth. Notably, the soil exhibited moderately high levels of organic carbon (4.05%), total nitrogen (2.86%), and available phosphorus (45.33 mg/kg). This suggests a pre-existing moderate fertility status. The exchangeable bases were dominated by calcium (4.80 cmol/kg) and magnesium (1.40 cmol/kg), while potassium (0.17 cmol/kg) was relatively low. The combination of a sandy loam texture and a potentially low potassium level underscore the likelihood that the soil would be responsive to organic amendments, such as poultry manure, which can improve cation exchange capacity and supplement essential nutrients.

The application of poultry manure (PM) significantly (P ? 0.05) enhanced all measured growth attributes of *Telfairia occidentalis* at six weeks after planting (Table 2). Vine length, number of leaves, number of tendrils, and foliar yield exhibited a consistent, positive response to increasing PM rates. The application of 15 t/ha PM resulted in the most pronounced growth, producing the longest vines (91.06 cm), the highest number of leaves (36.45), and the greatest foliar yield (10.13 kg). This represents a substantial improvement over the control, clearly demonstrating the role of PM in mitigating the limitations of the sandy loam soil. The growth promotion observed can be attributed to the synergistic effects of PM. Poultry manure is a rich source of organic matter and nutrients, particularly nitrogen, which is crucial for vigorous vegetative growth and chlorophyll synthesis (Adekiya *et al*., 2020). Its application improves soil structure, enhances microbial activity, and facilitates a slow, sustained release of nutrients, thereby matching the crop's demand and reducing losses through leaching-a critical factor in sandy soils.

Concerning seed size, large seeds produced significantly taller vines (81.48 cm), more leaves (37.61), and higher foliar yield (12.13 kg) compared to medium and small seeds. This is consistent with the principle that larger seeds possess greater food reserves, providing more energy and resources for seedling emergence and early establishment (Milberg et al., 2000). A key finding from this study is the non-significant (NS) interaction between poultry manure and seed size (PM × S) for all growth parameters. This indicates that the effects of PM application and seed size were independent and additive. In other words, the positive effect of using large seeds was consistent across all manure rates, and conversely, the benefit of applying PM was evident regardless of the seed size used. This suggests that the advantage conferred by larger seed reserves is not diminished by nutrient availability from manure, and both factors can be managed separately to optimize growth.

The positive effects of PM application extended to the yield components of T. occidentalis (Table 3). Pod number, pod length, pod girth, and total pod yield all increased significantly with higher rates of PM application. The highest pod yield (13.15 t/ha), along with the longest (69.09 cm) and widest pods (59.08 cm), was recorded at the 15 t/ha PM rate, while the control plots yielded the lowest (5.88 t/ha). This robust response underscores the importance of adequate nutrition, particularly during the reproductive and pod-filling stages. The nutrient-rich environment provided by the high PM rate likely supported better flower formation, fruit set, and photosynthate allocation to the developing pods.
In contrast to the clear effects on vegetative growth, seed size had only a slight and non-significant influence on yield components. Although plots with large seeds recorded a marginally higher pod yield (13.60 t/ha), the differences were not statistically significant. This indicates that while seed size is a critical factor for initial vegetative vigour, its influence on ultimate yield may be superseded by post-emergence agronomic practices, particularly nutrient management, as the plant develops.

Again, the interaction between PM and seed size (PM × S) was not significant for any yield parameter. This reinforces the conclusion that the rate of poultry manure application is a far more dominant factor determining the yield of T. occidentalis than the size of the seed planted. The absence of interaction simplifies agronomic recommendations, as the benefits of optimal manure application can be realized irrespective of the seed size category used by farmers.

Summary and Conclusion

In summary, the results of this study demonstrate that the application of poultry manure is a highly effective strategy for enhancing both the growth and yield of *Telfairia occidentalis* cultivated on a sandy loam soil. The significant improvements in vegetative growth and pod yield with increasing PM rates up to 15 t/ha highlight the role of organic amendment in improving soil fertility and plant nutrition. While large seeds provided an advantage for early seedling

growth, this effect was independent of manure application and did not translate into a significant yield advantage. The consistent lack of significant interaction between the two factors indicates that their effects are additive. Therefore, under the described soil and climatic conditions, the application of 15 t/ha poultry manure is recommended as the optimal practice for maximizing the productivity of *T. occidentalis.*

Table 1: Soil physical and chemical properties of the experimental site before planting and poultry manure

Soil Parameter	**Soil depth**	**Poultry**	**Value(%)**
	0-15	**manure**	
pH($H_2$0)1:2	5.2	pH ($H_2$0) 1:1	8.0
	5.8	pH ($CaCl_2$)	6.2
EC (DS/M)	0.065		
Organic Matter (g/kg)	1.09	Total P	0.94
Total N (g/kg)	2.90	Nitrogen	2.86
Available P (mg kg^{-1})	45	Calcium	6
Exchangeable		Magnesium	1.88
Bases(cmol/kg)			
Ca	4.8	Potassium	0.5
Mg	1.4	Sodium	0.1
Na	0.1	Organic carbon	4.05
K	0.2	C/N Ratio	4:2
Acidity	2.8		
ECEC	9.3		
Base Saturation	69.79		
Particle Size			
Analysis (g/kg)			
Sand	756.00		
Silt	104.00		
Clay	140.00		
Textural Class	Sandy		
	Loamy		

Table 2: Effects of poultry manure (PM) and seed size on growth attributes of Telfairia occidentalis at 6 weeks after planting

Treatment	Vine length (cm)	Number of leaves	Number of tendrils	Foliar yield (kg)
Seed size				
Small	65.56	32.96	3.51	8.75
Medium	79.83	36.23	3.80	10.76
Large	81.48	37.61	3.95	12.13
LSD (P≤0.05)	2.38	1.67	NS	1.33
Poultry Manure				
0	46.42	20.19	2.18	3.01
5	60.14	32.27	3.08	5.78
10	74.80	35.81	3.28	9.16
15	91.06	36.45	3.63	10.12
LSD (P⩽0.05)	17.33	4.21	1.11	3.02
PM x S	NS	NS	NS	NS

NS: Not significant

Table 3: Effects of poultry manure (PM) and seed size on number of pods per plant, length of pod (cm), girth of pod(cm), and yield(t/ha) of Telfairia occidentalis

Treatment	Number of pods/plots	Length of pods (cm)	Girth of pod (cm)	Pod yield (t ha-^{1})
Seed size				
Small	5.25	64.71	56.86	12.75
Medium	5.40	68.84	58.12	13.33
Large	5.50	70.70	58.45	13.60
LSD (P⩽0.05)	NS	NS	NS	NS
Poultry Manure				
0	4.11	45.51	43.31	5.88
5	5.12	60.33	51.40	8.35
10	5.18	65.19	55.40	12.30
15	5.89	69.09	59.08	13.15
LSD (P⩽0.05)	NS	6.62	4.21	2.72
PM x S	NS	NS	NS	NS

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The Role of Biochar in Agricultural Production; Soil Fertility and Water Quality Improvement: An Overview

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Abstract
A review of the roles of biochar in agricultural production highlights its relevancein combining water treatment and soil enhancement, which ultimately leads to higher crop yield and carbon sequestration over time. The demandfor biochar as a soil amendment, its efficacy inimproving water quality for sustainable agriculture, and addressing the negative effects of climate change cannot be undermined. Biochar is a porous, largely carbon-based material produced through pyrolysis, a thermochemical process that occurs in the absence or low oxygen. The biomass used for biochar could be obtained from plant and animal residue or waste. Biochar performance is dependent on the type of feedstock and the pyrolysis conditions employed during its production.
The global demand for biochar is rising for various uses, including fertilizer materials, as itameliorates nutrient deficiency in nutrient-depletedsoil because of continuous cropping, excessive synthetic fertilizer application, and other human activities. Biochar, an environmentally friendly soil conditioners, is suggested for large-scale held application due to its numerous benefits, which are adsorbent for removal of contaminant/inorganic pollutants from water, purifying water, carbon sequestration, soil fertility improvement, nutrient release and uptake, soil water retention, crop yield improvement, and enhances fertilizer use efficiency thereby reducing greenhouse gas emissions as a results of its unique characteristics like high surface area and pore volume.
This review focuses on the potential of biochar as an agricultural amendment that enhances water quality, soil fertility, and crop productivity, in addition to serving as a growth medium and composting material. Composting of biochar produced from various organic sources can ensure the stability of the soil, restoration of marginalized soil, and reduce carbon emissions associated with agriculture. In conclusion, this review revealed that biochar can also serve as media for growing vegetables in a screen house, which enhances the growth of high-value food crops, especially fruits and vegetables, to meet the increasing global demand for food by humans.

Keywords: Biochar, Soil Fertility, Water Quality, Crop Productivity, Carbon Sequestration

Résumé
Une analyse du rôle du biochar dans la production agricole met en lumière son importance pour le traitement de l'eau et l'amélioration des sols, ce qui permetd'accroître les rendementsagricoles et la séquestration du carbone à long terme. L'intérêt du biochar commeamendement du sol, son efficacité pour améliorer la qualité de l'eau et favoriserune agriculture durable, ainsiquesacapacité à atténuer les effetsnéfastes du changementclimatique, sontindéniables. Le biochar est un matériau poreux, principalement composé de carbone, produit par pyrolyse, un procédé thermochimique qui se déroule en l'absence ou en faible quantité d'oxygène. La biomasse utilisée pour sa production peut provenir de résidus ou de déchets végétaux et animaux. Les performances du biochar dépendent du type de matière première et des

conditions de pyrolyse mises en œuvre lors de sa production.La demande mondiale de biochar est en hausse pour diverses applications, notamment comme engrais. Il permet en effet de pallier les carences en nutriments des sols appauvris par la monoculture intensive, l'utilisation excessive d'engrais de synthèse et d'autres activités humaines. Le biochar, un amendement de sol écologique, est recommandé pour une application à grande échelle en raison de ses nombreux avantages : adsorption des contaminants et polluants inorganiques présents dans l'eau, purification de l'eau, séquestration du carbone, amélioration de la fertilité des sols, libération et absorption des nutriments, rétention d'eau, amélioration des rendements agricoles et optimisation de l'efficacité des engrais. Grâce à ses caractéristiques uniques, telles qu'une surface spécifique et un volume poreux élevés, il contribue à réduire les émissions de gaz à effet de serre.Cette étude se concentre sur le potentiel du biochar comme amendement agricole. Il améliore la qualité de l'eau, la fertilité des sols et la productivité des cultures, tout en servant de substrat de culture et de matériau de compostage. Le compostage du biochar issu de diverses sources organiques peut garantir la stabilité des sols, la restauration des sols marginalisés et la réduction des émissions de carbone liées à l'agriculture.En conclusion, cette étude révèle que le biochar peut également servir de substrat pour la culture de légumes sous serre, favorisant ainsi la croissance de cultures vivrières à haute valeur ajoutée, notamment les fruits et légumes, afin de répondre à la demande alimentaire mondiale croissante.

Mots-clés: Biochar, fertilité des sols, qualité de l'eau, productivité des cultures, séquestration du carbone

Introduction

Rapid global population growth has increased demand for grains and other food materials, thereby placing growing pressure on agricultural systems worldwide. This makes farmers use uncontrolled synthetic fertilizers and chemical inputs to increase crop production (Rathore *et al*., 2021). The consequences may include soil compaction, reduced soil fertility, air and water pollution, and greenhouse gas emissions (Tripathi *et al*., 2020). The utilization of agricultural waste to produce biochar could solve the disposal and management of agricultural waste. Biochar is a carbon-rich material obtained by heating biomass in the absence of air (Panwar et al., 2020). The type and composition of the feedstock, particle size, reaction temperature, heating rate, and reactor parameters all affect the efficiency of biochar formation from biomass. Unique physical and chemical characteristics of biochar, like large surface area, high pore volume, high cation exchange capacity, and functional groups, make it suitable for a wide range of applications (Leng *et al*., 2021). The applications of biochar impact soil characteristics, soil texture, and greenhouse gas emission control (Sri Shalin et al., 2020). Multiple nutrient inadequacies related to severe soil nutrient deficiency have emerged as the most significant global constraint to agriculture's long-term productivity (Singh *et al*., 2022).

Biochar is known to achieve several sustainability goals, including C sequestration, soil and plant growth improvements, and energy production (Marris 2006). Biochar production yields several beneficial co-products like hydrogen,bio-oil, syngas, process heat, and liquid smoke via the pyrolysis process, while the implication of small stoves for food processing in developing countries could help to reduce respiratory diseases and decrease the pressure on forests (Barrow 2011, Mankasingh *et al*., 2011).

Recently, biochar has been used as an additive for composting and soil remediation to control greenhouse gases and NH3, humidification, and to inactivate heavy and organic pollutants. The incorporation of compost and biochar as soil amendments is affordable and long-lasting, with a positive impact on soil enhancement and the growth of plants (Guo et al., 2020).

Descriptions and Characteristics of Biochar

Biochar is known to have a low bulk density due to its porous structure, leading to a high specific surface area ranging from 50 - 900 m^2 g-1 (Schimmelpfennig and Glaser, 2012), and a high-water retention capacity (Glaser *et al*., 2002). From a chemical point of view, the most striking feature of biochar is its polycondensed aromatic structure (Glaser *et al*., 1998) caused by dehydration during thermochemical conversion (Schimmelpfennig and Glaser, 2012), leading to its black colour. This structure is also responsible for its relative recalcitrance compared to other organic matter in the environment. In addition, basic ash compartments lead to a high pH value. Several studies show that the quality of the feedstock and production conditions, such as pyrolytic temperature and time, have a significant influence on the

quantity, quality, and elemental compositions of the biochar (Dume et al., 2015). Therefore, the selection of suitable feedstock and optimum pyrolytic protocol is crucial for biochar producers to produce a designer biochar amendment that is made to improve a specific nutrient deficiency in soil in agriculture. Low temperature biochar has high volatile matter content, but lower fixed carbon and ash contents than the high temperature biochar (Bourke et al., 2007).

Biochar Production Method

A variety of thermal conversion processes can be used to prepare biochar (Deal et al., 2012). Pyrolysis systems employed to process unused and excess crop and agroforestry residues for biochar production can be categorized into four types: (i) slow pyrolysis, (ii) fast pyrolysis, (iii) flash pyrolysis, and (iv) gasification. Slow pyrolysis performed under lower temperature (<400-500°C) and with long contact times often results in a high yield of biochar (35%) (Meyer and Quicker, 2011). Faster pyrolysis or gasification operates at higher temperatures (<800°C) and gives a high yield of combustible gases in relation to the solid biochar (12%) (Laird et al., 2009). The most employed method is slow pyrolysis. This process involves direct thermochemical decomposition (exothermic reaction) to transform low-density residue matrix into a biochar at a temperature range of 450-500?C under low-toxic or anoxic conditions in a closed reactor (Gul et al., 2015). Biochar can be produced at scales ranging from large industrial facilities down to the individual farm and even at the domestic level through a distributed network of small facilities that are located close to the crop residue source.

Biochar Production Process

Biochar production from agricultural residue starts with biomass feeding into the combustion chamber in the absence of air. There are mainly five production stages: drying, conditioning, torrefaction, exothermic pyrolysis, and endothermic pyrolysis at different temperatures. As the temperature rose to 150-180 °C, the biomass conditioning process began, releasing carbon dioxide. The biomass breakdown starts during the torrefaction phase at 180-250 °C, producing carbon dioxide and carbon monoxide. When an exothermic reaction begins at about 250-400 °C, it produces a significant quantity of heat, and condensable vapours such as water, acetic acid, methanol, acetone, etc., and tar are the prevailing products when the temperature rises to 400 °C. When the temperature rises above 450 °C, it is possible to convert biomass to biochar. The biochar production process is practically completed, but biochar contains considerable amounts of tar. To avoid this further, increase the temperature up to 500°C to complete the carbonization stage (Panwar et al., 2020)

Effects and Contribution of Biochar Application to Soil and Crop Yield

Many studies and reviews have pointed out the potential advantages of biochar application as a soil amendment (Sohi et al., 2010), having benefits beyond carbon sequestration. The benefits are: improvement of soil physical properties that benefit crops (Ajayi and Horn, 2016), improved retention and availability of soil nutrients (Dume *et al*., 2016), improved biological activity, by providing metabolizable organic carbon substrates (Hersztek *et al*., 2016) and consequently higher crop yields and societal advantages through mitigation of climate change by carbon sequestration (Zhang *et al*., 2017). Biochar production and application to soil enhances the rate of soil carbon sequestration through a shift from the short-term bio-atmospheric carbon cycle to the long-term geological carbon cycle (Lehmann *et al*., 2011)

I. Effects of Biochar Application on Soil Fertility

Biochar efficiently sequesters adequate amounts of carbon in soil over time, thus increasing soil fertility and crop productivity, thereby mitigating climate change because of deforestation, urbanization, and industrialization (Semida *et al*., 2019). Various parameters, such as feedstock type, pyrolysis chamber temperature, soil type, and biotic interactions, were discovered to influence the efficiency of biochar application in agricultural soil. Biochar has the capacity to absorb carbon and reduce greenhouse gas emissions in the soil (Ashiq *et al*., 2020).

Tanure *et al*. (2019) applied the biochar to a maize crop with two particle sizes (2.0?0.5 and<0.5 mm) at six doses (0, 5, 10, 20, 40, and 60 g/kg) under two soil moisture conditions in a greenhouse environment. It was found that biochar boosted the photosynthesis process, stomata conductance, moisture retention, pore ratio, reduced bulk density, and fertility when added to soil (Tanure *et al*., 2019). Biochar enhances soil pH and lowers the exchangeable acidity because of its high magnesium and calcium content (Kannan *et al*., 2021)
Cation exchange capacity (CEC) is essential for soil quality, and adding biochar to the soil increases CEC. A

higher CEC of soil indicates a high capability for nitrogen fixation, which is crucial for plant growth. Biochar can affect soil microbes in terms of pH, pore structure, surface area, sorption behaviour, and nutrient content (Zhang *et al*., 2021). According to recent studies, biochar's growth-promoting effects on soil microbes have been verified.

Biochar can also improve plant nutrition and yield since it is the source of nutrient elements such as nitrogen (N), phosphorus (P), potassium (K), and other trace elements (Purakayastha *et al*., 2019). In an ecological farming system, biochar increased crop yield by 25% in tropical soils. Mensah and Frimpong (2018) reported that biochar addition in two soil types of significantly increased biomass and yield of maize. Moreover, adding biochar to soil, with or without chemical fertilizer, has been reported to supply sufficient macro- and micro-nutrients to plants (Piash *et al*., 2021).

II. Effect of Biochar Application on Crop Productivity

Several researchers have reported that biochar applications to soils have shown positive responses for net primary crop production, grain yield, and dry matter. The rice yield was increased between 8.5% -10.7% when the application rate of rice straw biochar was about 4.5 t/ha (Liu *et al*., 2016). Furthermore, applying the same biochar in greenhouses at the rates of 10, 25, and 50 t/ha increased the rice and wheat yields by 12% and 17%, respectively (Wang *et al*., 2012).

III. Climate Change Mitigation

Biochar has the potential to reduce the negative effects of climate change because the inherent fixed carbon in raw biomass that would otherwise degrade to greenhouse gases is sequestered in soil for years. Recently, the use of surplus organic matter to create biochar has yielded promising results in the sequestration of carbon. Lehmann *et al*. (2006) estimated that a potential global carbon sequestration of 0.16 Gt yr-1 can be obtained from biochar production from forestry and agricultural wastes. In India, biochar from residues of maize, castor, cotton, and pigeon pea can sequester about 4.6 Mt of total carbon annually in soil, making it a carbon sequestering process (Venkatesh *et al*., 2015). Several studies have reported on environmental benefits of biochar incorporation which will reduce emission of non-CO2 greenhouse gases by soil (Zwieten *et al*., 2010) that could be due to inhibition of either stage of nitrification and/ or inhibition of denitrification, or promotion of the reduction of N2O; increases CH4 uptake from soil and long-term carbon sequestration in soil (Srinivasa *et al*., 2013).

IV. Effect of Biochar Application to Soil Microbial Activity

Biochar serves as a suitable habitat for a large and diverse group of soil microorganisms (Bacteria, Fungi, Algae, Protozoa,etc.) A higher retention of microorganisms in biochar-amended soils may be responsible for greater activity and diversity due to a high surface area, as well as surface hydrophobicity of both the microorganisms and biochar. Carbonized biomass, such as rice husk charcoal or wood ash,has been a valuable material as a soil amendment. The optimal biochar combining fertilizer and carbon storage function in soils would activate the microbial community, leading to nutrient release (Venkatesh *et al*., 2018). Applied biochar may provide habitats for the growth of soil-dwelling microorganisms (Tong *et al*., 2014) and protect them against natural enemies.

V. Nutrient use efficiency

Biochar significantly increases the efficiency and reduces the need for synthetic fertilizer application to the soil with sustainable crop yields. The incorporation of biochar into soil alters important soil chemical qualities, such as soil pH increasing towards neutral values, and typically increases soil cation exchange capacity. Glaser *et al*. (2002) observed an increasing trend of bioavailable P and base cations in biochar-applied soils. Biochar application boosts the soil fertility and improves soil quality by raising soil pH, increasing moisture retention capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity, and retaining nutrients in soil (Lehmann *et al*., 2006). For agronomic purposes, biochar applied with N fertilizer helps to counter the potentially unavailable biochar N (Steiner *et al*., 2008).

VI. Application of Biochar as Growing Media

Conventional farming has a few disadvantages, including high water and land requirements, high use of pesticides, soil degradation, and nutrient runoff (Reganold and Wachter, 2016). When comparing hydroponics to conventional agriculture, the former is preferred because of its ability to sustainably meet future food demands. When comparing vertical farming to conventional agriculture, the former is preferred because of its ability to sustainably meet future food demands as a result ofthe increasing human population.

Many researchers suggest that biochar has similar physicochemical characteristics to other growing media (such as peat and coir) and enhances high-value crop production. (Barrett *et al*., 2016). There is a constant search for new materials with more suitable properties for plant growth. The use of biochar to replace peat (Tian *et al*., 2012) and vermiculite substrate in growing media improves nutrient retention and is also disease and drought resistant. In addition, Dunlop *et al*. (2015) suggested that biochar be used as a medium for hydroponic systems, enhancing high-value food crops' growth.

Conclusions

In recent years, more attention has been drawn to the use of biochar in agricultural production based on scientific evidence that points to the effectiveness of biochar as useful material for reclamation of degraded agricultural soil and mitigating greenhouse gas emissions, the use of biochar has emerged as an environmentally friendly strategy, biochar has the capacity to provide solution to agricultural issues such as land degradation due to acidity, salinity, and nutrient depletion. However, the agricultural advantages of biochar are solely dependent on using specific biochar at the optimal field application rate under suitable soil types and parameters. Biochar can improve soil as a growing medium to meet the ever-increasing food demand and generate additional income by improving crop productivity and providing other revenue opportunities, leading to economic and agricultural benefits.

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Response of Common Beans *(Phaseolus Vulgaris L.)* to Organic Fertilizers in a Maize - Beans Intercropping System in Farmers' Fields of Western Kenya.

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Abstract
Soil degradation resulting in unhealthy soils is negatively affecting food production and crop yields in western Kenya. Agroecologically based crop production practices, such as using organic fertilizers, provide a means for enhancing the soil fertility and improving crop yields of such degraded soils. A study, codesigned and managed by farmers, was conducted in the farmers' fields to evaluate the response of intercropped common beans (Phaseolus vulgaris L.) to organic fertilizers. The experiments were set up in four farmers' fields in different locations in Vihiga and Kakamega Counties using a local beans variety (Haraka mtoka) intercropped with maize (Zea mays L.). Four treatments, three organic fertilizers, namely, bokashi, biostimulant, and compost, and a control (zero) where no fertilizer was added, were replicated three times and arranged in a randomized complete block design. Crop growth (plant height, number of leaves, and leaf size) and yield of beans were determined. The growth and yield of beans were significantly affected by organic fertilizers and experimental sites. Organic fertilizers generally resulted in better growth and yield of beans with average increments in beans yield ranging from 58% to 153% compared to unfertilized plots. We conclude that organic fertilizers enhanced the growth and yield of beans, but overall soil health conditions moderated their effects. Superior soil conditions associated with long-term use of organic fertilizer resulted in better growth and yield at Ekwanda, while inferior soil attributes caused the poorer performance at Ebunangwe. Organic fertilizers may buffer soil fertility such that even without their addition in the current season, beans crop can sufficiently grow and produce a good yield, as noted for Ekwanda.

Key words: *(Phaseolus vulgaris L)*; Organic fertilizers; Maize-Beans intercropping, Western Kenya

Résumé
La dégradation des sols, qui les rend impropres à la culture, affectenégativement la production alimentaire et les rendementsagricoles dans l'ouest du Kenya. Les pratiques agricoles agroécologiques, telles que l'utilisation d'engrais organiques, permettent d'améliorer la fertilité des sols dégradés et d'accroître les rendements. Une étude, conçue et gérée conjointement par les agriculteurs, a été menée sur leurs parcelles afin d'évaluer la réponse du haricot commun (Phaseolus vulgaris L.) cultivé en association avec des engrais organiques. Les essais ont été mis en place sur quatre parcelles agricoles situées dans différentes localités des comtés de Vihiga et de Kakamega, avec une variété locale de haricot (Haraka mtoka) cultivée en association avec du maïs (Zea mays L.). Quatre traitements, trois engrais organiques (bokashi, biostimulant et compost) et un témoin (sans engrais), ont été appliqués, répétés trois fois selon un dispositif en blocs aléatoires complets. La croissance des cultures (hauteur des plants, nombre et taille des feuilles) et le rendement du haricot ont été mesurés. La croissance et le rendement des haricots ont été significativement influencés par les engrais organiques et les sites expérimentaux. Les engrais organiques ont généralement permis une meilleure croissance et un meilleur rendement, les performances les plus élevées et les rendements les plus faibles étant observés à Ekwanda et Ebunangwe. Nous concluons que les engrais organiques ont amélioré la croissance et le rendement des haricots, mais que l'état général du sol a modéré leurs effets. À Ekwanda, les conditions pédologiques optimales, associées à une utilisation prolongée d'engrais organiques, ont permis une meilleure croissance et un meilleur rendement, tandis qu'à Ebunangwe, les caractéristiques pédologiques inférieures ont entraîné des performances moindres. Les engrais organiques semblent maintenir la fertilité du sol, permettant ainsi aux cultures de haricots de se développer et de produire un bon rendement, même sans leur apport durant la saison en cours, comme observé à Ekwanda.

Mots-clés : Haricots (Phaseolus vulgaris L.) ; Champs agricoles ;Engraisorganiques ; Ouest du Kenya

Introduction

The common beans *(Phaseolus vulgaris L.)* are among the most important grain legumes and is cultivated in over 34 million hectares of land globally (FAO, 2023). It is nutritionally rich being a major source of quality protein of up to 23.5% (high in the essential amino acids of leucine, phenylalanine, and lysine), complex carbohydrates at 59 - 66%, group B vitamins, minerals (including calcium, potassium, phosphorus, magnesium, iron and zinc) giving 4% ash, dietary fibre (4.05%) and phenolics (Neupane *et al*., 2024; Vidak *et al*., 2023). Beans also play significant environmental roles through biological N-fixation that enhances soil fertility and by controlling pests and diseases under multiple cropping systems with minimal use of synthetic fertilizers and pesticides(Vidak *et al*., 2023).

In Kenya, common beans is fundamental to the local diet, serving as the primary source of protein, particularly to the low-income populations who cannot afford costly animal proteins. Its high lysine, which is generally low in maize, cassava, and rice, the main staple cereals in Kenya, makes beans a great complement to these cereals in the country and partly justifies the common practice of intercropping beans with maize nationally. Beans are also a major source of income for the Kenyan farmers from local markets as well as export markets, especially as French beans.

Land and particularly soil degradation is however, limiting the yields of crops, including beans in Kenya. Kirui et al. (2021) reported western Kenya as a hot spot for land degradation in the country, resulting in crop yield reductions as high as 75% (Ajwera *et al*., 2024). The leading aspects of soil degradation, especially among the smallholder farmers in western Kenya, is nutrient mining associated with continuous cultivation and nutrient losses caused by erosion, leaching, and the removal of crop residues from crop fields (Ajwera *et al*., 2024). There is a need, therefore, for curtailing further soil degradation and rehabilitating the degraded soils.

Agroecological crop production systems, such as the application of organic fertilizers, are potential means to check soil degradation and improve the productivity of the soils in western Kenya. When obtained from the farm (crop residues and animal wastes), organic fertilizers facilitate on-farm recycling with relatively low fertilization costs compared to synthetic fertilizers. Besides nutrient addition to soils, application of organic fertilizers also enhances physical, chemical, and biological soil properties, including soil porosity, soil permeability to water, and soil nutrient-holding capacity (Abdulraheem *et al*., 2023; Avery, 2021). Organic fertilizers increase soil organic matter (SOM) that feeds soil microbes, retains soil nutrients and water, and binds soil particles to form stable aggregates (Li *et al*., 2017) thus improving soil structure. In addition, organic fertilizers slowly release nutrients to plants a process that may restrict their leaching losses(Panday *et al*., 2024).

The slow nutrient release by organic fertilizers, as well as low and variable nutrient contents, can be limitations to crop production (Panday *et al*., 2024). The low nutrient content of organic fertilizers dictates that large quantities of bulky organic fertilizers are required to meet the crop nutrient needs, acquisition and handling of which may be costly if sourced away from the farm. The variability in nutrient content makes accurate application difficult, while the slow release of nutrients risks causing nutrient deficiency, particularly at peak nutrient demands, consequently reducing yield (Panday *et al*., 2024). The type, amount, and timing of application of organic fertilizers are therefore bound to influence soil nutrient availability and crop yield (Larkin, 2020) with possible different effects of different fertilizers. Furthermore, nutrient release from organic fertilizers is largely via the microbial decomposition of the organic material, releasing simpler nutrients readily available to plants, a process that is affected by the soil conditions and soil microbial activities. This makes it important to establish the effects of the various organic fertilizers on crops at specific sites and under specific cropping systems. A study was therefore codesigned and managed by smallholder farmers to evaluate the response of common beans to three organic fertilizers in a common beans-maize intercropping system on four farmers' fields for two seasons (March to May and August to October) of 2025

MATERIALS AND METHODS

Study sites

The experiment was set up in four farmers' fields, two in Kakamega County (Emakunda and Emalindi villages), and two in Vihiga County (Ebunangwe and Ekwanda villages). The Kakamega sites, have an average annual temperature of 21 °C and a bimodally distributed rainfall averaging 1800-2200mm annually. Emalindi is at 0º13'13.44" N and 34º61'65.68" E, and an altitude of 1481m above sea level. The soils are well-drained red-loamy soils. Emakunda is at 0º13'24.45" N and 34º63' 89.24" E and an altitude of 1500 m above sea level. The soils are reddish-brown sandy clay luvisols.

Ekwanda and Ebunangwe, in Vihiga County, have a mean annual temperature of 23 °C, with bimodally distributed rainfall averaging 1500-2000mm annually. Ebunangwe is located at 0º0'44.8" N and 34º34'15.1" E, at an altitude of 1554m above sea level and characterized by sandy clay reddish-brown luvisols soil. Ekwanda is at 0º5'32.9" and 34º40'6.7" E, at an altitude of 1498m above sea level with reddish-brown clayey soils.

Organic-fertilizer preparation

Bokashi

Bokashi, a nutrient-rich soil fertilizer made by fermenting organic matter, was prepared in layers. Each layer consisted of about 40kg of dry chopped crop residue mixed with the same quantities of topsoil and decomposed manure (in the ratio of 1:1:1). To this mixture, a litre of yeast/molasses/tap water mixture was added. The yeast /molasses/ water mixture was made by suspending100g of yeast in a mixture of 2 litres of molasses and 5 litres of tap water. Thereafter, about 9kg each of wheat bran and charcoal dust, 3 kg of wood ash, 0.35 kg of sand, and 30 g of crushed bones were added to complete the layer. The layer was allowed to settle for 24 hours before the pile was turned twice daily for the first 3 days and then once daily for the subsequent11 days to thoroughly mix the ingredients. The fertilizer was ready for use by day 14. A sack of 6 kg of the ready bokashi fertilizer was then soaked in a 20-liter bucket of water for 10 days, being shaken twice daily to obtain the liquified extract for foliar application.

Bio-stimulant

Solid bio-stimulant fertilizer balls were prepared from fresh cow dung, topsoil, beans flour, molasses, and water. For every 25 kg of fresh dung, about 2.5 kg of topsoil, 0.5 kg of beans flour, and 1liter of molasses were added. These were then mixed, and water added as the mixture was moulded into balls of uniform texture and size (fistful). The balls were then dried in the shade while being turned daily till they were well dried and ready for use. For its foliar spray (liquid bio-stimulant fertilizer), 10kg of the freshly prepared mixture was put in a sack before being moulded into balls and then hung in a container with 40litres of water. The sack was shaken at least twice daily while stirring the water it was immersed in for a period of five days for the resultant extract to be ready for use.

Compost

Compost fertilizer was made by decomposing organic materials. Wood chippings (sawdust), green crop residue, dry crop residue, and animal manure were mixed in the ratio of 3:2:1:1 by weight and then piled in an enclosed, well-ventilated area in the order of wood chippings at the bottom, then animal manure, green crop residue, and finally dry crop residue at the top. Topsoil, enough to form a thin layer on top of the pile, was added, and some water sprinkled to make the pile moist but not wet. The layering was repeated in a vertical arrangement until the pile was about 1M high, after which it was covered with banana leaves and allowed to settle for a week. Thereafter, the pile was regularly turned to mix the ingredients therein at a 3-day interval in the first two weeks while moistening. The turning interval was then reduced to once a week for the subsequent four weeks. The fertilizer was ready for use when all its constituent materials were fully broken down, and it was now crumbly.

Its liquid form for foliar application was obtained from vermicompost. At an elevated composting structure, animal manure was added, then red worms *(Eisenia fetida)* were introduced, and then biodegradable kitchen refuse was added.

The structure was then covered to create a dark environment for the ideal operation of the worms. The liquid extract was collected into a container placed beneath the structure. The worms were continuously fed by adding kitchen refuse as liquid vermicompost was being collected.

Crop establishment and management

A local variety of common beans *(Phaseolus vulgaris L.)*, "Haraka mtoka," was intercropped with a local composite maize *(Zea mays L.)* variety. The crops were planted between 19th and 22nd March 2025 (onset of the long rains) and from 18th to 23rd August 2025 (onset of the short rains). The experimental plots measured 3m x2m with the maize planted at a spacing of 80cm x 25cm. Two rows of beans spaced at 40cm x 10cm were planted between two rows of maize, with the rows of beans at 20 cm from the rows of maize.

The organic fertilizers were applied at planting at basal rates (about 100g per hill for bokashi and compost, and one fistful ball for bio-stimulant) and later as foliar feeds to the point of runoff at five weeks after planting (5WAP). For foliar application, the liquid extracts of bokashi, bio-stimulant, and vermicompost were diluted at 1:15 (extract: water).

Experimental Design and Treatments

The experiment consisted of four treatments (organic fertilizers): (i) bokashi, (ii) compost, (iii) bio-stimulant, and (iv) zero (a control without fertilizers). At each site, the experimental units were arranged in a randomized complete block design with three replicates.

Measured parameters

Soil and organic fertilizer analysis.

The baseline status of the soils in the fields and the organic fertilizers applied were analysed for chemical properties and textural classification (for soil). Soils were sampled in a zigzag manner across the plots to a depth of 30cm. From each site, a composite soil sample was prepared and subjected to chemical and textural analyses. Organic fertilizers were prepared in bulk at a central place, and representative samples of each was chemically analysed for pH, EC, and the major macro nutrients.

Plant growth and yields

At the start of the season and before the commencement of data collection, four common beans plants in the net plots (two centre rows) were randomly selected and tagged for data collection. All data were collected only from the tagged plants. Plant height, number of leaves, and size of leaves were measured at an interval of 2 weeks from the 2nd week after planting (2WAP).The length of the central leaflet of the recently produced fully expanded trifoliate leaf of beans plants was measured and used to estimate the leaf size of the trifoliate leaf using the equation of Pohlmann et al. (2021):

LA=1.092L^1.946

Where LA is the leaf area; L is the length of the central leaflet of the trifoliate leaf. The beans were harvested at physiological maturity (after the 8th week after planting), and the grains were dried to a moisture content of 14% before being weighed to obtain the yield.

Data Analysis

The data for plant height, number of leaves, leaf size, and yield per plot were subjected to analysis of variance (ANOVA) and significant means separated using Fisher's least significant difference (LSD) using SAS software (SAS Institute Inc., 2004).

Results

Soil characteristics and the organic fertilizers:

Soil properties differed significantly across the sites. Whereas the other experimental sites had clay-textural soils,

Ebunangwe, had sandy clay loam texture (Table 1). The pH of the soils at the study sites were highly to slightly acidic, with the lowest pH (4.91 - highly acidic) in Emakunda and the highest (5.91 - slightly acidic) in Ekwanda. Ekwanda exhibited better soil fertility as reflected in higher cation exchange capacity (CEC), organic matter, and exchangeable bases than Ebunangwe. Regarding history of using of organic fertilizers, Ebunangwe site was largely using organic fertilizers and agroecology-related cropping practices for the first time whereas, Ekwanda site had used organic fertilizers for over four years. Emakunda and Emalindi sites were categorized as intermediate between Ebunangwe and Ekwanda in terms of using organic fertilizers. Among the organic fertilizers, bokashi had a lower pH (close to neutral) and carbon to nitrogen ratio (C:N). The biostimulant had relatively higher pH (more alkaline), electrical conductivity (EC), percent carbon, and percent potassium than the others.

Plant height, number of leaves, and leaf size

Plant height and number of leaves increased gradually across the study sites and organic fertilizers from week 2 to week 8 (Fig. 1, 2). The plant heights in Ebunangwe, Emalindi, and Emakunda insignificantly differed between weeks 2 and 4 but significantly differed between weeks 4 and 6. On the contrary, plant heights at weeks 2, 4, and 6 were significantly different in Ekwanda. In all the sites and across the organic fertilizers applied, the increment in height from week 6 to 8 was insignificant. The number of leaves, however, declined insignificantly in Ebunangwe and Emalindi but significantly in Ekwanda between week 6 and week 8.

Apart from Ekwanda where the leaf size tended to increase from week 2 through to week 8, in the other sites, leaf size decreased from week 2 to week 4, then increased from week 4 to week 6 before declining from week 6 to week 8 (Fig. 3). The size of leaves at weeks 2 and 4 were significantly lower than those at week 6 in Ebunangwe, Emalindi and Emakunda across all the organic fertilizers. Ebunangwe had the lowest leaf sizes in weeks 2 and 4, which were significantly lower than those in the other sites. Ekwanda had significantly higher leaf size in week 4 than the other sites, which was comparable to the highest leaf sizes (week 6) in the other sites. Leaf size peaked at week 6 for all sites and all organic fertilizers.

The plots without organic fertilizers (zero) had significantly shorter plants at week 8 and lower leaf size than those with organic fertilizers in Ebunangwe and Emakunda, and lower than the Bokashi plot in Emalindi. Organic fertilizer application did not significantly affect plant height and size of leaves in Ekwanda, nor did it affectthe number of leaves across the sites.

Yield of beans

Across the sites, organic fertilizers significantly increased the yield of beans compared to zero plots (Fig. 4). The increment in beans yields due to organic fertilizers averaged 58%, 85%, 107% and 153% at Ekwanda, Ebunangwe, Emalindi, and Emakunda sites, respectively.. The zero plot at Ekwanda had significantly higher yields than the zero plots at all the other sites and higher than all the organic fertilizers at Ebunangwe. On the overall, Ebunangwe had a lower yield per plot of beans, which was significantly lower than that of Ekwanda.

Discussion

The four study sites showed clear differences in soil physical and chemical properties (Table 1). Ebunangwe, a sandy clay loam soil with a short agroecological management history, had the lowest organic matter content, CEC, and exchangeable base levels, indicating limited nutrient- and water-holding capacity. Its moderately acidic soil reaction is likely to exacerbate nutrient leaching and reduce overall fertility. Ekwanda, a clay soil with a long agroecological history, exhibited the highest CEC, relatively higher pH, and substantially greater concentrations of exchangeable Ca, Mg, and K. These properties indicate a more buffered and fertile soil with greater capacity to retain nutrients. Emalindi and Emakunda, both clay soils with intermediate agroecological management histories, had higher organic matter and total nitrogen contents than Ebunangwe but lower available phosphorus. Emakunda was the most acidic site, a condition likely to further constrain phosphorus availability. These site differences highlight the importance of site-specific soil fertility management.

The three organic fertilizers exhibited distinct chemical characteristics (Table 2) with important implications for soil fertility management. Bokashi, characterized by a near-neutral pH, low EC, and low C:N ratio, is likely to provide rapid nutrient mineralization and early crop nutrition. The bio-stimulant showed high alkalinity, salinity, carbon content, and potassium concentration, indicating strong soil-amending potential but also a higher risk of salinity and nutrient imbalance if improperly applied. Compost exhibited moderate pH, low salinity, higher nitrogen content, and a wide C:N ratio, suggesting a primary role in long-term soil organic matter accumulation and gradual nutrient release.

Table1: Soil characteristics of the experimental sites at the beginning of the study

Site	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	T/Class	Agroecological history	pH (H_2O)	CEC (cmol/kg)	OM (g/kg)	C (g/kg)	N (g/kg)	P (mg/kg)	K (cmol/kg)	Ca(cmol/kg)	Mg (cmol/kg)
Ebunangwe	669	118	213	S/Clay loam	New	5.2	4.9	18.5	10.3	0.9	10	0.1	1.5	0.8
Ekwanda	249	238	513	Clay	Old	5.9	13.2	26.7	15.5	1.4	16	0.3	7.9	1.9
Emalindi	389	118	493	Clay	Intermediate	5.3	10.6	37.4	21.7	1.8	2	0.2	4.0	1.8
Emakunda	329	178	493	Clay	Intermediate	4.9	8.8	37.7	21.9	1.8	5	0.2	2.6	1.0

Table 2: Chemical properties of the organic fertilizers used in the study.

Organic fertilizer	pH 1:2 (H_2O)	EC(ms/cm)	OC (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	C:N
Bokashi	7.8	3.45	11.30	1.17	0.16	0.82	0.71	0.27	9:60
Bio stimulant	9.3	15.50	34.60	1.50	0.26	2.33	0.80	0.33	19:10
Compost	8.5	3.85	13.10	2.16	0.13	0.15	0.70	0.29	21:70

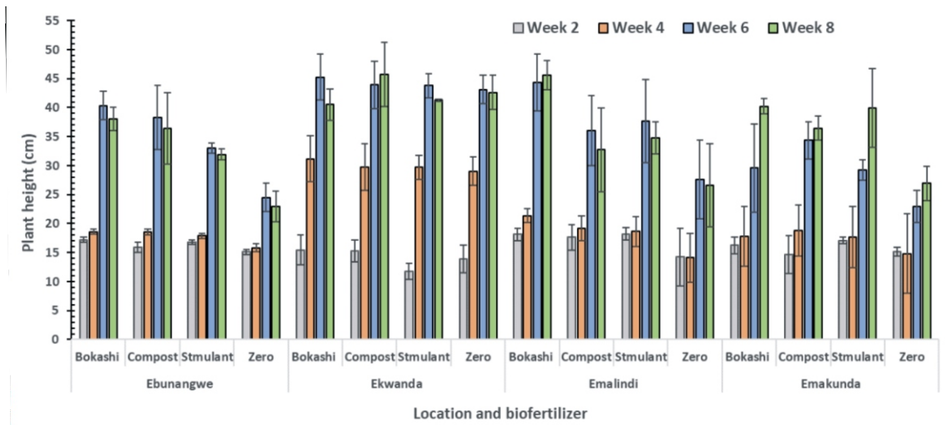

Fig:1. Plant height (cm) across the study sites for the different organic fertilizers from week 2 to week 8.

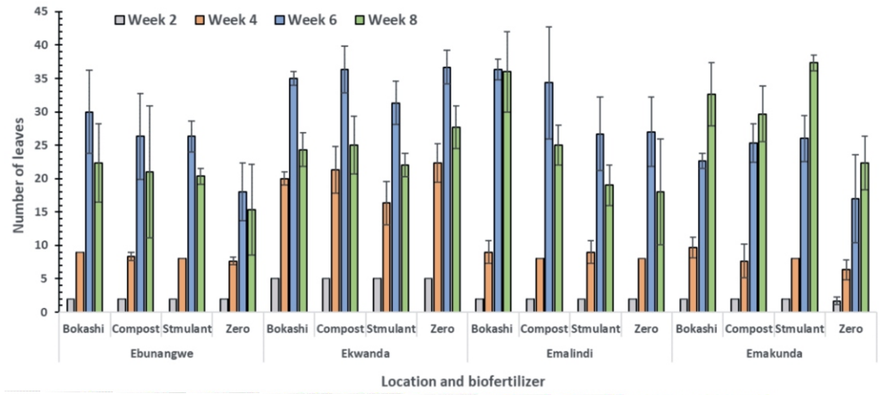

Fig.2: Number of leaves across the study sites andorganic fertilizers from week 2 to week 8.

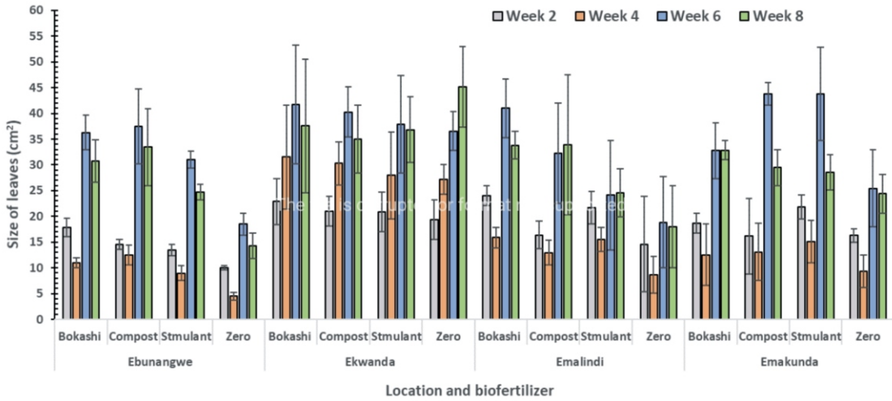

Fig. 3: Size of leaves across the study sites andorganic fertilizers from week 2 to week 8.

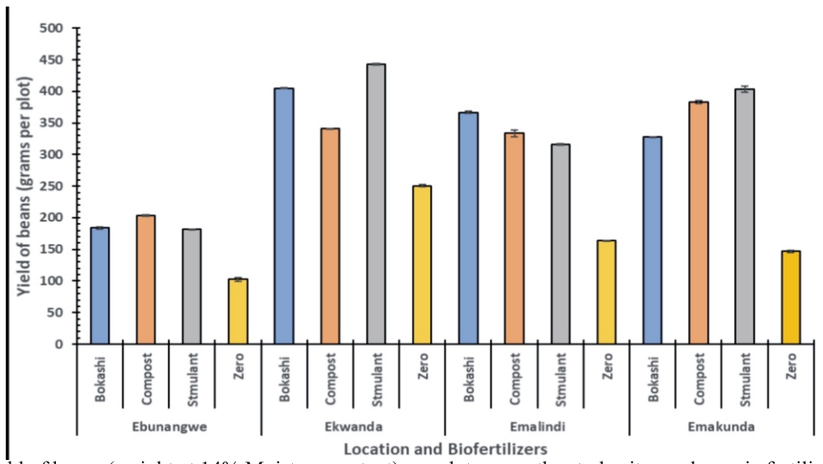

Fig. 4: Yield of beans (weight at 14% Moisture content) per plot across the study sites andorganic fertilizers.

Plant height, number of leaves, and leaf size gradually increased from week 2 to week 8, with rather limited increments between weeks 2 and 4 at Ebunangwe, Emalindi, and Emakunda (Fig. 1, 2, 3). However, in Ekwanda, the plant height and number of leaves increased significantly over the weeks. Plant height, number of leaves, and leaf sizes at week 4 in Ekwanda were much higher than those of the other sites and comparable to those at week 6 of these other sites. This points to better crop performance in Ekwanda than the other sites, which is also evident from the higher yield of beans. We attribute the higher crop growth and yield at Ekwanda to its superior chemical properties (Table 1), resulting from prolonged application of organic fertilizers, and the poor growth and yield of beans at Ebunangwe to its limited nutrients and water-holding capacity.

Organic fertilizers are known to slowly release nutrients to crop plants (Panday *et al*., 2024; Vasileva *et al*., 2025)through microbial decomposition, resulting in possible nutrient limitations and consequently reduced development, especially at the early stages of the crops (Vasileva *et al*., 2025). Such suppression of development is bound to be more pronounced in crops growing under limited nutrients due to low amounts of nutrients released or a mismatch between the nutrients released and those demanded by the crops. This could account for the poorer initial growth of beans in Ebunangwe, Emalindi and Emakunda. The generally poor soil health at Ebunangwe, as reflected in its sandiness, low organic matter and CEC, and low macro nutrients, including N, P, and K was possibly responsible for its lower crop performance at the initial crop stages and ultimately lower yield per plot relative to Ekwanda.

To the contrary, beans at the Ekwanda site attained higher and nearly maximum plant height, leaf number, and leaf sizes by the 4th week compared to the other sites. By attaining higher leaf sizes and numbers by week 4, the crops at the Ekwanda site possibly had a longer duration of greater photosynthesis, leading to more food made in the lifespan of the crop that consequently accounted for the observed higher yields. In beans, longer leaf area duration that extends the photosynthetic period is known to be more related to higher overall yields than the maximum leaf area achieved (Trindade *et al*., 2010).

In areas that have accumulated organic matter from long-term applications of organic fertilizers, such as the Ekwanda site, continuous decomposition of organic matter releases and retains nutrients in the soil (Bot & Benites, 2005) thus ensuring a sufficient supply of nutrients to crop plants even when no fertilizers are currently applied. Indeed, even the unfertilized plots at Ekwanda had comparable and better growth and yield of beans than fertilized plots at the other sites. The superior performance of the Ekwanda site relative to the other sites reflects the cumulative benefits of long-term organic matter accumulation, which enhances nutrient retention and buffering capacity.

Organic fertilizers generally increased plant height, number of leaves, and leaf sizes compared to the plots where no fertilizer was added in Ebunangwe and Emakunda (Fig. 1, 2, 3) and yield per plot across all the sites (Fig. 4). This is attributed to the ability of organic fertilizers to not only provide nutrients (Abdulraheem *et al*., 2023; Avery, 2021) but to also improve soil structure especially of degraded soils and consequently enhance soil nutrients and water retention (Abdulraheem *et al*., 2023; Larkin, 2020; Li *et al*., 2017) thus supporting the growth and yield of crops. This is consistent to previously reported increase in growth and yields of beans due to organic fertilizers(Ali *et al*., 2023).However, responses to organic fertilizers were moderated by baseline soil fertility, emphasizing the need for site-specific nutrient management strategies in agroecological systems.

Conclusion

Organic fertilizers enhanced the growth and yield of beans in the maize-beans intercropping systems under smallholder conditions in western Kenya. The magnitude of the response was strongly influenced by site-specific soil properties and history of use of organic fertilizers. Sites with relatively long history of use of organic fertilizers and that had higher organic matter and CEC exhibited greater and more stable productivity, including in unfertilized plots, indicating soil fertility buffering effects. These findings underscore the importance of sustained soil organic matter restoration and context-specific organic nutrient strategies for improving resilience and productivity of smallholder agroeco systems.

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