



ASSESSMENT OF YIELD PER UNIT GLOBAL WARMING POTENTIAL (GWP) OF CONTROLLED ENVIRONMENTAL AGRICULTURE (CEA) AND FIELD-BASED CHILLI PEPPER PRODUCTION IN NORTHWESTERN, NIGERIA

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ABSTRACT

This study evaluates the performance metrics of chilli pepper production using Controlled Environment Agriculture (CEA), rainfed field, and irrigated field methods in Likoro, Kudan LGA of Kaduna State. We use life cycle inventory (LCI) methods to estimate total fixed and variable costs, yield, saleable product, price, total revenue, gain from investment, return on investment (ROI), and global warming potential (GWP). CEA incurs the highest total cost of production at ₦4,222,893/ha but yields significantly more (72,000 kg/ha/year) compared to rainfed (900 kg/ha/year) and irrigated fields (4,500 kg/ha/year). The saleable product for CEA is 68,400 kg/ha/year, while rainfed and irrigated fields produce 360 kg/ha/year and 3,825 kg/ha/year, respectively. The total revenue generated by CEA is ₦47,880,000, with a gain from investment of ₦47,457,711, and an impressive ROI of 1,124%. In contrast, rainfed fields produce a total revenue of ₦360,000, with a gain from investment of ₦309,105, and an ROI of 61%. Irrigated fields generate a total revenue of ₦1,530,000, with a gain from investment of ₦1,361,596, and an ROI of 81%. The GWP is lowest for CEA at 0.03 CO₂eq/kg, whereas rainfed and irrigated fields have higher GWP values of 445.26 CO₂eq/kg and 42.21 CO₂eq/kg, respectively. The findings highlight CEA offers a sustainable alternative to traditional field-based methods, with higher ROI(1,124%) and lower greenhouse gas emissions (0.03 CO₂eq/kg). This highlights CEA's efficiency and sustainability, making it an attractive option for environmentally conscious and economically viable farmers.

Keywords: Yield, Saleable, Price, Return, Investment, Global

INTRODUCTION

In 2023, agricultural processes, including crop and livestock production, contributed approximately 11% of total global anthropogenic greenhouse gas (GHG) emissions. The agriculture sector remains the largest anthropogenic source of methane (CH₄) and nitrous oxide (N₂O) emissions, accounting for 50% and 60% of global emissions, respectively (Statista, 2024). Projections indicate that, under a business-as-usual scenario, GHG emissions from traditional farming practices, land-use changes such as deforestation, and pre- and post-production processes in Asia, Africa, and Latin America will increase by 37%, 32%, and 21%, respectively, by 2050 (Adegbeye *et al.*, 2020). Notably, nitrous oxide (N₂O) emissions primarily result from fertilizer use (FAOSTAT, 2022), and both methane (CH₄) and N₂O are potent greenhouse gases (GHGs) with a Global Warming Potential (GWP) far greater than that of carbon dioxide (CO₂) (Statista, 2024).

The significance of GWP metrics in assessing the environmental impact of agricultural practices is evident. The Sixth Assessment Report (2021) by the Intergovernmental Panel on Climate Change (IPCC) defines GWP as a metric that quantifies the relative impact of different greenhouse gases on global warming over a specified time horizon, typically 100 years. GWP is expressed in terms of the equivalent amount of CO₂ that would produce the same warming effect. This metric is crucial for comparing the environmental impact of various agricultural practices and identifying opportunities to mitigate GHG emissions (Abdela *et al.*, 2024). For instance, the 2017 Climate Change Vulnerability Index (CCVI) is a GWP metric that highlights the vulnerability of certain regions to climate change. In the case of Nigeria, the CCVI classifies the country as a high-risk region, indicating its significant vulnerability to climate change (Department of Climate Change, Federal Ministry of Environment (FME), Nigeria, 2021). The CCVI's classification of Nigeria as a high-risk



region is particularly concerning, given the country's reliance on agriculture that include chilli pepper production.

Field-based chilli pepper production, primarily carried out in the northern regions of Nigeria, is one of the most profitable agricultural ventures among low-income farmers (Daily Trust, 2023). These farmers may not have sufficient capital to invest in crops that demand significant financial input. Chilli peppers require lower inputs such as fertilizer, pesticides, and labor, which are less costly compared to other vegetables like tomatoes, cucumber, cabbage, and pineapple that require more investment and attention. Additionally, the application of fertilizers and pesticides can be delayed for several weeks if necessary, providing flexibility even when funds to purchase these inputs are not immediately available at the time of planting.

A successfully grown chilli pepper plant can be harvested more than 10 times before it stops producing. This provides multiple opportunities to recover and exceed initial investments. Even if the first or second harvests are not highly profitable, subsequent harvests can still yield substantial income. Each plant can be harvested numerous times in a single season, making it a reliable source of revenue. Farmers rarely return from the market with unsold chilli peppers. Moreover, if market conditions are unfavorable, farmers can dry the peppers to prevent spoilage and sell them later at a higher price, as dried chilli peppers are highly valued (Foraminifera, 2018).

Conventional chilli pepper production methods, primarily relies on traditional farming methods, encompassing both rainfed and irrigated systems, that pose significant environmental concerns. Rainfed systems are particularly vulnerable to climate variability, while irrigated systems require significant water and energy inputs (Cornell University, 2025). Despite these challenges, field-based chilli pepper production remains a common practice due to its lower initial costs and accessibility for low-income small-scale farmers (Daily Trust, 2023).

The two most critical environmental variables for growing plants, including chilli peppers, are temperature and light. In Controlled Environment Agriculture (CEA), both parameters must be uniformly controlled across different locations and consistently maintained from day to day (Roland Berger, 2023; Cornell University, 2025). Achieving this consistency requires the use of supplemental lighting. CEA has the potential to regulate temperature and light effectively, resulting in high yields with minimal environmental impact. This makes CEA a promising solution for sustainable agriculture.

CEA is a technology-based approach to food production that optimizes growing conditions within an enclosed structure, such as a greenhouse or vertical farm. CEA systems aim to provide protection from external environmental factors and maintain optimal conditions for crop growth throughout the year. These systems utilize advanced techniques such as hydroponics, aeroponics, and aquaponics to enhance resource efficiency and crop yield ((Roland Berger, 2023; Cornell University, 2025).

Current understanding of GHG emissions in Sub-Saharan Africa (SSA) is particularly limited when compared to the potential the continent has as both a GHG sink and a source (Adegbeye *et al.*, 2020; Ntinyari & Gweyi-Onyango, 2021; Abdela *et al.*, 2024). Limited data and information on agricultural production in Africa make it difficult to quantify the contribution that the continent could make towards global mitigation of GHG emissions. With the increasing concerns about global warming and its consequent effects on climate change, there is need for sustainable agricultural practices. It is essential to evaluate the environmental impact of different production systems. This study aims to assess the yield per unit GWP of CEA and field-based chilli pepper production systems in Northwestern Nigeria.

METHODOLOGY

This study employs a life cycle assessment (LCA) approach to evaluate the Yield per unit land area and Greenhouse gas emissions (GHG), expressed as global warming potential (GWP) between CEA and Chilli pepper production systems in the Kudan Local Government Area (LGA) of Kaduna State, Nigeria. Three production systems were analyzed: two field-based (rainfed and irrigated “Fadama”/“Lam-bu”), and Poly-tunnel. A functional unit of product was defined as one kilogram of saleable unprocessed product (i.e., kg of rainfed local red bell pepper (*Capsicum annuum*))



"Tatase", irrigated Scotch Bonnet Pepper (*Capsicum chinense*), or "Atarodo", and Piquante F1 cultivated in a poly-tunnel).

Data on energy consumption, greenhouse gas emissions, and crop yields are collected from both systems. The GWP per unit yield is calculated by dividing the total GWP by the crop yield for each system. This allows for a direct comparison of the environmental efficiency of CEA and field-based production.

Study Area

The study area, Kudan Local Government Area (LGA) of Kaduna State, is situated at latitude 11°16'23"N and longitude 7°47'56"E. It spans 400 square kilometers and has an average temperature of 32°C (Weather Spark, 2024). The LGA experiences two distinct seasons: the dry season and the rainy season.

Farmers in the study site predominantly cultivate open-pollinated pepper varieties due to their lower cost. However, these seeds often result in lower yields and may lack the same level of pest and disease resistance as hybrid seeds (Veggie Concept, 2021). The local bell pepper (*Capsicum annuum*) "Tatase" is widely grown under rainfed conditions, achieving high yields with annual rainfall between 250 mm to 1000 mm.

Pepper farming is unsuitable for very cold environments, and excessive heat can cause flower abortion and leaf defoliation. Ideal growing conditions include daytime temperatures of 18 to 27 °C, nighttime temperatures of 15 to 18 °C, and soil pH of 5.5 to 6.5 (Institute for Agricultural Research (IAR, 2021). The best months to harvest and sell peppers in Nigeria are from April to July, with prices increasing by 100-200% due to scarcity (Veggie Concept, 2021). Peppers are sold in bags, with prices ranging from ₦4,000 to ₦20,000 for a 10 to 20 kg bag in the open market.

Farmers typically raise pepper seeds in nursery beds or ridges before transplanting to the main field. They provide shade for seedlings using palm fronds, leaves, or shade nets, treat nursery soil with pesticides, and add well-cured manure for fertility. Some farmers plant peppers in December to take advantage of high prices from May to July and fewer fungal diseases. The relative humidity is around 16%, and the average wind speed is approximately 10 km/h (IAR, Meteorological Unit, 2021).

Scotch Bonnet pepper (*Capsicum chinense*), known as "Atarodo," is a popular variety grown with irrigation. It is small, intensely hot, and has a distinct fruity flavor, maturing from green to various colors. Habanero pepper "Rodo," a close cousin, is also intensely hot and used in spicy dishes. Habanero plants can last over 12 months, fruiting after 3 months of transplanting and harvested for 6-8 months with good practices. Despite lower yields than sweet peppers, irrigated habanero pepper farmers report yields exceeding 40 tonnes per hectare. However, Nigeria still imports peppers despite these production levels (Veggie Concept, 2021).

Pepper farmers in Nigeria who utilize greenhouses, including poly-tunnels, achieve significantly higher yields compared to those cultivating in open fields. High-quality hybrid pepper seeds, such as Piquante F1, Avenir F1, and Supe Habanero F1, are recommended for cultivation. The Piquante F1 hybrid, widely used in Northern Nigeria, is preferred for its high heat level, strong aroma, excellent flavor, and large fruit size. It starts green when unripe and turns bright red when mature.

Nigeria's tropical climate can negatively impact pepper yield due to high humidity and temperature, which can cause flower abortion in Piquante F1 hybrids. Operators successfully grow Piquante F1 in a non-automated poly-tunnel measuring 79 feet by 20 feet (147 m²), accommodating around 588 plants. The tunnel maintains temperatures between 20°C to 35°C, light intensity of 75-330 $\mu\text{mol m}^{-2} \text{s}^{-1}$, relative humidity of 50-70%, and wind speed around 10 km/h. The soil is sandy loamy, well-draining, with a pH of 5.5 to 6.5, enriched with organic matter. Plants are spaced 18-24 inches apart, with seedlings transplanted after 6-8 weeks. The peppers mature in 75-80 days, with yields of 60-120 kg/m² per season, allowing for 4-5 harvests per year.

The life cycle assessment (LCA) methodology of ISO 14044, adapted by Perrin *et al.* (2017), tracks inputs and outputs within the production system. Drip irrigation maintains consistently moist soil, organic mulch conserves moisture, and balanced fertilizers promote fruit development.

Pests are monitored and controlled organically or chemically. Piquante F1 is resistant to bacterial leaf spot and powdery mildew. During cold weather, 1000 ppm CO₂ is recommended, and in



summer, 400 ppm CO₂ is beneficial. Horizontal air movement at 1 m/s distributes moisture and CO₂, enhancing productivity and energy conservation.

To assess the environmental impact of pepper production, background data on energy, material, fertilizer, and pesticide production were benchmarked against the Ecoinvent database version 2.2 and the Athena Sustainable Materials Institute. This analysis enabled the calculation of seasonal, farm-level emissions of greenhouse gases (GHG), methane, and nitrous oxide, with transportation logistics excluded from the assessment.

Calculation of Economic and Environmental Indicators

Production Costs

Primary data collected from 125 chili pepper producers during the 2022/2023 dry and rainy seasons formed the basis for calculating production costs in field-based systems, including rainfed and irrigated ("Fadama"/"Lam-bu") methods. Revenue calculations were based on yield and output price. Interestingly, some farmers perceive open-field pepper farming as requiring fewer inputs, with manure being the primary input.

Total production costs encompass both variable and fixed expenses, including seeds, herbicides, manure, fertilizer, tools, and labor. A comparative analysis of Controlled Environment Agriculture (CEA), Rainfed, and Irrigated methods revealed significant differences in fixed, variable, and total costs per hectare.

CEA incurred the highest fixed costs, totalling ₦2,012,250, mainly due to investments in poly-tunnel structures and advanced irrigation systems, making it the most capital-intensive method. In contrast, Rainfed and Irrigated systems had substantially lower fixed costs, at ₦77,250 and ₦794,750, respectively, reflecting simpler infrastructure requirements.

Variable costs further highlighted the economic differences between the methods. CEA had variable costs of ₦595,987, with four production seasons annually, while Rainfed and Irrigated systems had variable costs of ₦431,700 and ₦646,065, respectively. These costs were driven by diverse input needs, such as seeds, fertilizers, and labor.

Consequently, the total production cost per hectare for CEA stood at ₦4,222,893, which, despite its high initial costs, benefited from high yield efficiency. The varying costs underscored the trade-offs between investment and productivity in different agricultural practices.

Energy costs accounted for over one-third of total expenses for CEA operations, representing a primary cost difference from rainfed and irrigated field operations. Electric pumps in chili pepper production consumed around 300 kWh per season, costing approximately ₦38.53 per kWh (Nigerian Price, 2024). Inconsistent electricity supply in Nigeria led to the use of alternative energy sources like gasoline, diesel, or solar power. Diesel engine pumps in open fields consumed about 360 to 391.2 liters per hectare per season. Poly-tunnel energy usage was 7.512 liters per m² per season, costing ₦1,185 per liter annually (Table 1).

Global Warming Potential (GWP)

We used Tier 1 default methods and emission factors (EFs) from the 2006 IPCC guidelines (2007) to estimate emissions from nitrogen fertilizer inputs on managed soils. This included direct and indirect nitrous oxide (N₂O) emissions, which were converted to CO₂ equivalents using Global Warming Potentials (GWPs) from the Sixth Assessment Report (2021) by the Intergovernmental Panel on Climate Change (IPCC). For a 100-year horizon, we applied GWPs of 273 for N₂O, 27 for CH₄, 0.014 for NH₃ and 0.001 for NO₃. Emission factors were 4% for NPK fertilizer and NH₃, 20% for manure, and 25% for urea. GWP values for pesticides, nitrate leaching, potassium nitrate, and humate were assumed negligible.



Table 1: Cost per Hectare for CEA, Rainfed and Irrigated Chilli Pepper Production

Production Inputs		Units of Quantity	CEA	Rainfed Field				Irrigated Field			
Fixed Production Inputs			Price/unit	Quantity Used	Cost/ hectare (Naira(₦)/ha)	Price/unit	Quantity Used	Cost/ hectare (Naira(₦)/ha)	Price/unit	Quantity Used	Cost/ hectare (Naira(₦)/ha)
Drip Irrigation System											0
Borehole/Well and other componets	Unit/s	1935000	1	1935000				717500	1	717500	
Poly-tunnel Structure	Unit/s	520251	1	520251							0
Small farm tools											0
Garden Trowel	Piece/s	2500	1	2500	2500	1	2500	2500	1	2500	
Hand Fork	Piece/s	2500	1	2500	2500	1	2500	2500	1	2500	
Seedling Trays 1 set (10-20 trays)	Set	7500	1	7500	7500	1	7500	7500	1	7500	
Watering Can	Piece/s	2250	1	2250	2250	1	2250	2250	1	2250	
Gloves	Pair	1500	1	1500	1500	1	1500	1500	1	1500	
Stakes	Unit/s	1000	15	15000	1000	15	15000	1000	15	15000	
Weed Hoe	Unit/s	3000	1	3000	3000	1	3000	3000	1	3000	
Spray Bottle	1 bottle	1500	1	1500	1500	1	1500	1500	1	1500	
Soil Tester	1 Piece/s	7500	1	7500	7500	1	7500	7500	1	7500	
Basket	1 Piece/s	1500	2	3000	1500	2	3000	1500	2	3000	
Pruners	1 Piece/s	4000	2	8000	4000	2	8000	4000	2	8000	
Twine or String	1 roll	1500	1	1500	1500	1	1500	1500	1	1500	
Mulch	1 bag	12500	1	12500	12500	1	12500	12500	1	12500	
Compost Bin:	1 Piece/s	7500	1	7500	7500	1	7500	7500	1	7500	
Labels or Markers 1 pack (20-50 labels)	1 Pack/s	1500	1	1500	1500	1	1500	1500	1	1500	
Total Fixed Cost		₦/ha		2532501			77250				794750
Variable Production Inputs											
Electricity for Irrigation Pump	Naira/ KWH	39	300	11559	39	300	11700	39	300	11700	



Diesel Fuel for Irrigation Pump	Naira/Litre	1185.00	7.51	8902	1185.00	0	0	1185.00	375.6	445086
Seeds (Piquante Red F1 Habanero)	1 kg bag	20500	5	102500	6000	5	30000	6000	5	30000
Fertilizers										
NPK	1 kg bag	6000	15	90000	6000	0	0	6000	7.5	45000
Chicken Manure	1 kg bag	20	36.75	735	20	2500	50000	20	2500	50000
Calcium Magnesium (CalMag)	1 kg bag	10000	3	30000	10000	0	0	10000	1.5	15000
Potassium Humate	1 kg bag	5000	1	5000	5000	0	0	5000	0.5	2500
Pesticides										
Pesticides	1 litre	2000	7.5	15000	2000	15	30000	2000	7.5	15000
Nematicides	1 litre	2000	2.5	5000	2000	5	10000	2000	2.5	5000
Insecticide	1 litre	2000	7.5	15000	2000	15	30000	2000	7.5	15000
Fungicide	1 litre	2000	7.5	15000	2000	15	30000	2000	7.5	15000
300m by 1.5m Plastic mulch	square meter	95	147	13965	95	0	0	95	0	0
Labor and Installation	Man-day	80	3000	240000	80	3000	240000	80	3000	240000
Total Variable Cost	₦/ha			2210643			431700			889286
Total Cost of Production	₦/ha			4743144			508950			1684036

Note: Data Source: Authors' calculations.

^a In Controlled Environment Agriculture (CEA) production, each season requires new sets of variable inputs, including seeds, fertilizers, pesticides, and other consumables, to ensure optimal growing conditions and productivity. We assumed 4 harvests of Piquante F1 chili peppers in a year. ^b Pepper crops experience significant losses due to climate change: up to 60% during the rainy season and 10-20% during the dry season. However, using Controlled Environment Agriculture (CEA) techniques like poly-tunnel cultivation reduces losses to around 5%, ensuring stable and higher yields.



For pepper cultivation, 1-4 tonnes of chicken manure per hectare is recommended, as it's nutrient-rich and has lower greenhouse gas emissions compared to other manures. However, only well-cured manure should be used to avoid introducing pests like aphids, mites, thrips, pod borers, and root grubs, which can significantly damage pepper plants. Weeds can also reduce yields by up to 98%.

Analyzing the Global Warming Potential (GWP) of different chilli pepper production systems reveals significant variations. Open-field production, encompassing both rainfed and irrigated methods, exhibits substantially higher GWP values compared to poly-tunnel production. Specifically, the Local red bell pepper (*Capsicum annuum*) "Tatase," produced under rainfed conditions has a total GWP of 146,857.51 kg CO₂-eq per hectare, resulting in a GWP of 407.94 kg CO₂-eq per kilogram of saleable product.

In contrast, the Scotch Bonnet Pepper ("Atarodo") produced under irrigated conditions has a slightly higher total GWP of 147,996.20 kg CO₂-eq per hectare, but a significantly lower GWP of 38.69 kg CO₂-eq per kilogram of saleable product.

Poly-tunnel production, utilizing the Piquante Red F1 Habanero hot pepper ("Atarodo"), demonstrates a remarkably lower total GWP of 2,060.81 kg CO₂-eq per 147m². This translates to a negligible GWP of 0.03 kg CO₂-eq per kilogram of saleable product. These findings highlight the environmental benefits of poly-tunnel production systems, which offer a more sustainable alternative to traditional open-field methods (Table 2).

Table 2: Total Global Warming Potential (GWP) for Open Field (Rainfed and Irrigated) and Poly-tunnel Chilli Pepper Production

Growing System	Species of Chilli Pepper	Total GWP (kg CO ₂ -eq)	Saleable Product	GWP/kg Product
Open Field (Rainfed 1 hectare)	Local red bell pepper (<i>Capsicum annuum</i>) "Tatase"	146857.51	360	407.94
Open Field (Irrigated 1 hectare)	Scotch Bonnet Pepper (<i>Capsicum chinense</i>) "Atarodo"	147996.20	3825	38.69
Poly (147m ²) -tunnel	Piquante Red F1 Habanero hot pepper "Atarodo"	2060.81	68,400	0.03

Note: Data Source: Authors' calculations

RESULTS AND DISCUSSION

Preliminary results indicate that CEA systems have a significantly lower GWP per unit yield compared to field-based systems. The optimized growing conditions and advanced technologies used in CEA result in higher yields and lower greenhouse gas emissions per kilogram of chilli peppers produced. The best months to harvest and sell peppers in Nigeria are from April to July, with prices increasing by 100-200% due to scarcity (Veggie Concept, 2021). The price per kilogram of peppers in the open market ranges from N400 to N1000. Depreciation was estimated using the straight-line method. A 10% allowance or salvage value was taken from the assets' initial cost and then divided by the assets expected economic life of 1 year, to determine the depreciation (Finance Strategists, 2025). For the repayment, principal and interest are to be repayable in seven years with a moratorium for the first year on interest and for 2 years on principal (TNAU AGRICTECH Portal, 2013).

In contrast, field-based systems, particularly rainfed methods, exhibit higher GWP due to lower yields and greater susceptibility to climatic variations. Irrigated field systems, while more productive than rainfed methods, still have a higher GWP per unit yield compared to CEA due to the energy-intensive nature of irrigation.



A comprehensive analysis of three agricultural production methods - Controlled Environment Agriculture (CEA), Rainfed Field, and Irrigated Field - was conducted to assess their economic and environmental sustainability. The functional unit of product was defined as one kilogram of saleable unprocessed product.

Return on Investment (ROI) is a crucial metric for evaluating investment success, measuring returns relative to investments. While it has limitations overlooking the time value of money, risk factors, and non-financial benefits, ROI remains a vital tool for businesses and investors, enabling informed decision-making, resource allocation, and profitability assessment (Finance Strategists, 2025).

The CEA (Table 3), despite having the highest total cost of production at ₦4,222,893 per hectare, achieves significantly higher yields and revenues. CEA yields 72,000 kg/ha/year and generates a total revenue of ₦47,880,000, resulting in an impressive gain from investment of ₦47,457,711. This translates to a remarkable return on investment (ROI) of 1,124% and a low global warming potential (GWP) of 0.03 CO₂eq/kg.

In contrast, the Rainfed Field method has the lowest total cost of production at ₦508,950 per hectare but yields the lowest results. The yield is 900 kg/ha/year, generating a total revenue of ₦360,000 and a gain from investment of ₦309,105. Rainfed production systems predominantly rely on open-pollinated seeds, which offer a cost-effective option, priced as low as ₦30,000 per hectare. However, these seeds often compromise on disease resistance and yield potential compared to hybrid seeds. Additionally, rainfed farmers typically adopt a synchronized planting and harvesting approach, resulting in market saturation and subsequent price declines. From an economic and environmental perspective, rainfed production yields a modest return on investment (ROI) of 61% and a notably high GWP of 445.26 CO₂eq/kg.

While the demand for peppers remains relatively steady throughout the year, the supply experiences a significant decline from April to August due to the limited cultivation period in the northern region of Nigeria. During this time, farmers rely on irrigation systems due to inadequate water supply from January to April.

In terms of production costs, the Irrigated Field method falls in the middle, with a total cost of ₦1,684,036 per hectare. This method yields moderate results, including a yield of 4,500 kg/ha/year and a total revenue of ₦1,530,000. The gain from investment is ₦1,361,596, resulting in a return on investment (ROI) of 81% and a global warming potential (GWP) of 42.21 CO₂eq/kg.

Nigeria's organized markets, such as supermarkets, hotels, and eateries, provide a lucrative opportunity for pepper sales, offering higher prices than traditional open markets. Targeting these buyers is a viable strategy for farmers. Additionally, Nigeria's rapidly growing population increases the demand for chilli peppers, ensuring a steady market for producers. Utilizing Controlled Environment Agriculture (CEA) allows for year-round pepper cultivation, providing farmers with a stable and profitable market for their produce. This method offers significant benefits, including a remarkable 1,124% return on investment (ROI) and a negligible global warming potential (GWP) of 0.03 CO₂eq/kg.

In conclusion, CEA stands out as the most attractive option for sustainable agriculture, boasting the highest returns and lowest environmental impact. In contrast, Rainfed Field production yields limited returns and has a substantial environmental footprint. Meanwhile, Irrigated Field production offers moderate returns and environmental impact. These findings underscore the importance of balancing economic and environmental considerations when selecting agricultural production methods.



Table 3: Performance Metric of 1 kg of Rainfed, Irrigated and Poly -tunnel Chilli Pepper Production Likoro, Kudan LGA of Kaduna State

Parameters	Units	CEA	Rainfed Field	Irrigated Field
Total Fixed Cost	₦/ha	2,012,250	77,250	794,750
Total Variable Cost	₦/ha	2,210,643	431,700	889,286
Total Cost of Production	₦/ha	4,222,893	508,950	1,684,036
Salvage Value at 10%	₦/ha	422,289	50,895	168,404
Depreciation Expense:	₦/ha	3,800,604	458,055	1,515,632
Adjusted Total Cost	₦/ha	422,289	50,895	168,404
Yield	kg/ha/year	72,000 ^a	900 ^a	4,500 ^a
Saleable Product	kg/ha/year	68,400 ^b	360 ^b	3,825 ^b
Price	₦/kg	700	1000	400
Total Revenue (TR)	₦	47,880,000	360000	1,530,000
Gain from Investment	₦	47,457,711	309,105	1,361,596
ROI	%	1,124	61	81
GWP	CO ₂ eq/kg	0.03	445.26	42.21

Note: Data Source: Authors' calculations. ^a We assumed 4 harvests of Piquante F1 chili peppers in a year. ^b Pepper crops experience significant losses due to climate change: up to 60% during the rainy season and 10-20% during the dry season. However, using Controlled Environment Agriculture (CEA) techniques like poly-tunnel cultivation reduces losses to around 5%, ensuring stable and higher yields.

Implications

The findings of this study have significant implications for Nigeria's agricultural sector. Economically, adopting Controlled Environment Agriculture (CEA) can enhance profitability for farmers by increasing yields and providing better price control. This improvement can lead to greater food security by ensuring a stable food supply and reducing the risk of shortages and price fluctuations. Furthermore, the implementation of CEA and other intensive agricultural practices can create employment opportunities in rural areas, thereby improving livelihoods for farmers and their communities.

From an environmental standpoint, the study underscores the potential of CEA to lower greenhouse gas emissions and foster sustainable agriculture. With a reduced global warming potential compared to traditional farming methods, CEA can contribute to climate change mitigation efforts. Additionally, the irrigation systems used in CEA can minimize water waste and optimize water usage, promoting water conservation.

The social implications of the study are equally important. Enhancing the livelihoods of farmers and rural communities can positively impact poverty reduction and food security. Moreover, the controlled environment of CEA can decrease the risk of contamination, ensuring a safer food supply for consumers. The increased production of peppers can also improve access to nutritious food, especially in urban areas.

In terms of policy implications, the study suggests that governments can play a vital role in promoting sustainable agriculture practices like CEA. This can be achieved through incentives such as subsidies or tax breaks to encourage farmers to adopt CEA. Additionally, governments can invest in irrigation infrastructure to support farmers, particularly in regions with limited water resources. Lastly, the development of agricultural insurance programs can help protect farmers from crop failures and price fluctuations, promoting stability and security in the agricultural sector.



CONCLUSION AND RECOMMENDATION

The assessment of yield per unit GWP highlights the environmental benefits of CEA systems for chilli pepper production in Northwestern Nigeria. CEA offers a sustainable alternative to traditional field-based methods, with higher ROI(1,124%) and lower greenhouse gas emissions (0.03 CO₂eq/kg). Policymakers and stakeholders should consider promoting the adoption of CEA technologies to enhance agricultural productivity and mitigate the environmental impact of chilli pepper production. Further research is needed to explore the economic feasibility and scalability of CEA systems in the region.

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