

**OPTIMIZATION OF ORGANIC FERTILIZER PRODUCTION FROM
CHROMOLAENA ODORATA.**

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**CHEMICAL ENGINEERING PROGRAMME,
DEPARTMENT OF CHEMICAL ENGINEERING,
FACULTY OF ENGINEERING,
UNIVERSITY OF BENIN,
BENIN CITY, EDO STATE, NIGERIA.**

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SUBMITTED TO THE

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**IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF
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ENGINEERING**

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CERTIFICATION

This is to certify that this research project was carried out by **Isaac Oloruntobi** of the Department of Chemical Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

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DEDICATION

I dedicate this work to God Almighty, for His unfailing love, favour, provision and most importantly HIS GRACE throughout my stay in school.

ACKNOWLEDGEMENT

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May Almighty God bless you all abundantly.

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ABSTRACT

This study focused on the optimization of organic fertilizer production from *Chromolaena odorata* (Siam weed) with the aim of determining the most suitable drying conditions for nutrient preservation and evaluating its effects on soil fertility and maize (*Zea mays*) growth performance.

Fresh *C. odorata* leaves were collected, air-dried, and oven-dried under varying temperature (30–85 °C) and time (30–120 min) conditions. The effects of these parameters on nutrient composition (particularly nitrogen (N), phosphorus (P), and potassium (K)) were analyzed using Response Surface Methodology (RSM) based on a Central Composite Design (CCD). The optimized fertilizer product was applied to soil samples to assess changes in nutrient levels before and after maize cultivation.

Results revealed that both drying temperature and time significantly influenced the nutrient composition of *C. odorata*. Nitrogen and phosphorus contents decreased with increasing temperature, whereas potassium concentration increased due to moisture reduction and mineral concentration effects. The optimal drying condition was found to be approximately 55 °C for 90 minutes, which preserved the highest levels of essential nutrients. Post-sowing soil analysis indicated improved macronutrient and micronutrient concentrations following the application of the optimized organic fertilizer. Maize plants grown in treated soil exhibited superior vegetative growth compared to the control, with notable increases in plant height, stem diameter, and dry biomass yield. The findings demonstrate that *Chromolaena odorata* can serve as an effective and sustainable source of organic fertilizer. Its utilization not only enhances soil fertility and crop productivity but also provides an environmentally friendly means of managing this invasive weed species.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

For thousands of years, agriculture thrived using natural methods for soil enrichment and pest control, without relying on synthetic chemicals. This traditional approach sustained food production across generations. However, a major transformation occurred in the mid-19th century with the introduction of artificial fertilizers. These synthetic inputs revolutionized agriculture due to their low cost, high effectiveness, and ease of large-scale transportation. In the early stages, they significantly improved crop yields and farming efficiency (Moral et al., 2005).

Despite their initial benefits, long-term reliance on chemical fertilizers led to several negative consequences. Prolonged use resulted in soil compaction, making the land harder and less permeable. It also weakened soil structure, increasing vulnerability to erosion. Over time, continuous application depleted essential soil nutrients and reduced populations of beneficial microorganisms, ultimately diminishing soil fertility. Additionally, concerns emerged about the potential health risks posed by toxic residues from these chemicals entering the food chain. In response to these challenges, scientists, particularly soil biologists, began exploring alternatives in the late 19th and early 20th centuries. Their efforts gave rise to organic farming practices aimed at sustaining productivity while minimizing environmental harm. One key development was the promotion of organic fertilizers, natural substances derived from plant, animal, or human sources such as compost and manure. These fertilizers are carbon-rich and provide essential nutrients in a form that plants can readily absorb, helping to improve both growth and soil health (Assefa et al., 2019).

The use of organic fertilizers has been proven to significantly improve both soil health and agricultural productivity. Research shows that applying organic fertilizers increases the amount of organic carbon in the soil, enriches its nutrient content, and boosts the activity of soil enzymes. For example, a long-term study revealed that organic fertilizer application raised total organic carbon levels by 27.9% to 74.0% when compared to chemical fertilizers. Additionally, it was observed that organic fertilizers greatly enhanced the feeding activity of soil organisms, which play a key role in maintaining soil health (Zhou et al., 2022).

Sources of Organic Fertilizers

Organic fertilizers come from natural sources and are categorized into the following:

1. **Animal-Based Sources:** Examples include farmyard manure, poultry litter, and byproducts such as blood meal, bone meal, hides, hooves, and horns.
2. **Plant-Based Sources:** These include green manure crops, compost, and crop residues.
3. **Human Waste:** Sewage sludge is a commonly used form of human-derived organic fertilizer.
4. **Mineral Sources:** Naturally occurring materials like powdered limestone and rock phosphate also qualify as organic fertilizers.

Key Advantages of Organic Fertilizers

Organic fertilizers offer several benefits that make them a valuable alternative to synthetic options:

- **Cost-Effective:** They are often cheaper to produce and apply.
- **Improved Soil Structure:** They help to enhance the physical condition of soil, including its texture and aeration.

- **Better Water Retention:** They increase the soil's capacity to hold water, especially beneficial in dry conditions.
- **Stimulated Root Growth:** The nutrients released by organic matter promote stronger and healthier root systems.

Effects on Soil Quality

The continuous application of organic fertilizers has been linked to notable improvements in soil properties:

- **Increased Organic Matter:** They contribute to higher levels of organic content in the soil.
- **Improved Soil Health:** Regular use improves overall soil structure, fertility, and resilience.
- **Boosted Agricultural Output:** Healthier soil translates into better crop yields over time.

Environmental Contributions

Beyond farming benefits, organic fertilizers support environmental sustainability:

- **Mitigating Climate Change:** Organic farming helps capture and store carbon in the soil, reducing greenhouse gases.
- **Preventing Water Pollution:** Unlike synthetic fertilizers, organic alternatives lower the risk of contaminating groundwater.
- **Encouraging Biodiversity:** Farms using organic fertilizers often attract a greater variety of wildlife, including pollinators and beneficial insects (Liebig & Doran, 1999).

Role of Organic Fertilizers in Agricultural Productivity

Organic fertilizers play an important role in supporting agricultural productivity in several ways. Over time, their use has been linked to increased crop yields, particularly with consistent, long-term application. They supply a broad range of essential nutrients, including trace elements, which helps maintain proper nutrient balance in the soil. By enhancing soil structure and biological activity, organic fertilizers create better growing conditions for plants. They also support sustainable farming by helping to maintain soil fertility and productivity over the long term. Additionally, some research suggests that crops grown organically may have better quality, such as higher dry matter content, which can improve flavor and shelf life (Singh et al., 2020).

C. odorata, commonly referred to as Siam weed, is increasingly being recognized as a valuable source of organic matter for compost production in agriculture. Native to the Caribbean and the Americas, this plant has drawn attention due to its ability to produce large amounts of biomass. Research has shown that it can yield up to 18.7 tons per hectare in fresh weight and approximately 3.7 kg per hectare in dry weight. As a fast-growing perennial and invasive species, *C. odorata* thrives in both fertile and infertile soils, especially in areas where perennial crops are cultivated.

Despite its classification as an invasive weed, *C. odorata* is considered a promising material for organic fertilizer because of its rich nutrient content and high biomass productivity. Its dried biomass contains key nutrients vital for plant growth namely, 2.65% Nitrogen, 0.53% Phosphate, and 1.9% Potassium. This nutrient-dense composition makes it a suitable alternative to synthetic fertilizers, which are often linked to long-term degradation of soil health. Using *C. odorata* as compost presents a more sustainable method for managing soil fertility. In addition to supplying essential nutrients, the compost also helps improve soil structure, enhances water retention, and contributes to the overall health of the soil. However, to gain the full benefits of

this natural resource, it is essential to determine the correct application rates (Suri & Yudono, 2020).

1.2 PROBLEM STATEMENT

The increasing demand for sustainable agricultural practices has highlighted the need for ecofriendly and cost-effective fertilizer alternatives to support crop productivity while minimizing environmental degradation. Chemical fertilizers, widely used in modern agriculture, often lead to soil degradation, water pollution, and high production costs, posing challenges to both environmental sustainability and economic viability for farmers.

Organic fertilizers, derived from natural sources, offer a promising solution; however, their production processes are often inefficient, time-consuming, and lack optimization for largescale application.

C. odorata, a fast-growing invasive weed, is abundant in many regions and rich in essential nutrients, making it a potential raw material for organic fertilizer production. Despite its potential, the lack of standardized and optimized methods for processing *C. odorata* into highquality organic fertilizer limits its widespread adoption.

This study aims to address the inefficiencies in organic fertilizer production by developing and evaluating optimized processes for converting *C. odorata* into a nutrient-rich, sustainable fertilizer, thereby contributing to improved agricultural productivity and environmental conservation.

1.3 AIM AND OBJECTIVES

Aim: To develop and optimize an efficient process for producing high-quality organic fertilizer from *C. odorata*, promoting sustainable agriculture and environmental conservation.

Objectives

1. To evaluate the nutrient content and suitability of *C. odorata* as a raw material for organic fertilizer production.
2. To investigate various processing methods for converting *C. odorata* into organic fertilizer, focusing on efficiency and scalability.
3. To optimize the production process by identifying the best combination of parameters, such as decomposition time, and temperature, to enhance fertilizer quality.
4. To assess the effectiveness of the resulting organic fertilizer on crop growth and soil health through controlled experiments.
5. To compare the cost-effectiveness and environmental impact of the optimized *C. odorata*-based fertilizer with conventional chemical fertilizers.

1.4 SCOPE OF THIS STUDY

This study focuses on optimizing organic fertilizer production from *C. odorata* to support sustainable agriculture. It includes:

1. Analyzing the nutrient content of *C. odorata* for fertilizer suitability.
2. Investigating composting, vermicomposting, and anaerobic digestion methods for efficient fertilizer production.
3. Optimizing production parameters like decomposition time, temperature, and additives to improve fertilizer quality.
4. Testing the fertilizer's effectiveness on crop growth and soil health in controlled experiments with selected crops.

5. Comparing the cost-effectiveness and environmental impact of the optimized fertilizer with chemical fertilizers.

The study is limited to *C. odorata* from local sources, small- to medium-scale farming systems, and excludes long-term field trials, other raw materials, and socioeconomic impact analysis.

1.5 SIGNIFICANCE OF THIS STUDY

This study on optimizing organic fertilizer production from *C. odorata* holds significant value for sustainable agriculture and environmental conservation. By transforming an abundant, invasive weed into a nutrient-rich organic fertilizer, the research offers a cost-effective and ecofriendly alternative to chemical fertilizers, which often degrade soil health and pollute water sources. The optimized production process could empower farmers, particularly in resourceconstrained regions, to enhance crop yields while reducing reliance on expensive synthetic inputs.

Additionally, utilizing *C. odorata* addresses the challenge of managing this invasive species, turning an environmental nuisance into a valuable resource. The findings could inform local agricultural practices, promote soil fertility, and contribute to sustainable farming systems, benefiting both farmers and the environment.

Furthermore, this study provides a foundation for future research into scalable organic fertilizer production, supporting global efforts toward sustainable food security.

CHAPTER TWO

LITERATURE REVIEW

2.1 CONCEPT OF ORGANIC FERTILIZERS

2.1.1 Definition and Types of Organic Fertilizers

Many farmers often overlook the importance of soil, treating it simply as a passive base for plants. However, soil is a dynamic, living resource that plays a vital role in food production and the overall functioning of ecosystems. Soil fertility can be assessed in various ways, depending on land use. In intensive agricultural systems, soil fertility is often measured by the value of the crops produced relative to the inputs used, including economic aspects of nutrient management. Alternatively, soil fertility can be focused on the quality or productivity of the land. The application of organic fertilizers can help enhance soil fertility by improving its structure, increasing nutrient availability, and promoting long-term productivity.

Organic fertilizers are natural substances derived from plant, animal, or mineral sources, used to enhance soil fertility and promote plant growth. Unlike synthetic fertilizers, which are chemically manufactured, organic fertilizers release nutrients slowly, improving soil structure and increasing microbial activity. Common examples include compost, manure, bone meal, and green manure. Incorporating organic fertilizers into agricultural practices contributes to sustainable soil management and improved crop productivity (Kugbe, 2019).

Organic fertilizers can well be said to be substances made entirely from decomposed plant or animal material. Common examples include raw or composted animal manure, compost without artificial additives, green manure, and organic mulches like legume hay or leaves.

Organic fertilizers can be sourced from various types of animal manure, including cow dung, poultry manure, and manure from rabbits and goats, all obtained directly from local livestock farms (KHANDAKER et al., n.d.).

Sustainable agriculture involves a comprehensive approach that seeks to maintain the longterm health of both the soil and the people who depend on it. The primary goal is to ensure that agricultural practices are not only productive but also environmentally responsible and beneficial to human health. In this context, it is crucial to identify all systems, processes, and interactions that influence soil health in a particular area. This includes understanding how different farming practices, such as the use of organic fertilizers, impact the soil's fertility and structure (Ononogbo et al., 2024). Before implementing any soil management practices, such as the use of organic fertilizers, it is important to assess the specific needs and characteristics of the soil in a given geographic area. This ensures that the fertilizers used will enhance the soil's health and contribute to the sustainability of the farming system. By considering all factors that affect soil health, farmers can make informed decisions that lead to more sustainable agricultural practices and a healthier environment for both crops and people.

Types of Organic Fertilizers

1. Compost: This is made by decomposing organic waste materials, such as plant residues, food scraps, and yard waste. It is rich in nutrients and helps improve soil structure, water retention, and microbial activity.
2. Manure: Manure is organic matter derived from the faeces of animals like cows, poultry, goats, and horses. It is often composted before use to reduce pathogens and improve

nutrient content. Manure provides essential nutrients such as nitrogen, phosphorus, and potassium.

3. Green Manure: It consists of plants that are grown and then tilled into the soil to decompose. Common green manure crops include legumes like clover and vetch. These plants help fix nitrogen in the soil and add organic matter.
4. Bone Meal: Bone meal is made from finely ground animal bones and is high in phosphorus and calcium. It is often used to promote root development and flowering in plants.
5. Fish Emulsion: This is a liquid fertilizer made from processed fish parts. It is rich in nitrogen and trace minerals, making it a great choice for promoting healthy plant growth.
6. Blood Meal: It is made from dried animal blood and is high in nitrogen. It is often used to boost plant growth, especially in nitrogen-deficient soils.
7. Seaweed and Kelp Fertilizers: Seaweed and kelp are rich in micronutrients, hormones, and trace elements. They help improve soil structure, stimulate plant growth, and enhance the plant's resistance to disease.
8. Worm Castings: These are the excrement of earthworms, rich in nutrients and beneficial microorganisms. They help improve soil fertility and structure, increase microbial activity, and promote plant growth.
9. Biofertilizers: Biofertilizers are living microorganisms such as bacteria, fungi, and algae that enhance soil fertility. They improve nutrient availability and uptake by plants and help maintain soil health.
10. Vermicompost: It is created when earthworms break down organic matter like food scraps and plant residues. It enriches soil by improving texture, water retention, and

nutrient availability. The beneficial microbes it contains help promote healthy plant growth, and its slow-release nutrients ensure long-lasting soil fertility.

11. Biochar: Biochar is produced by heating organic materials such as wood or crop waste in a low oxygen environment. It enhances soil fertility by increasing nutrient and moisture retention, adjusting pH levels, and promoting microbial activity. Additionally, biochar sequesters carbon in the soil, contributing to sustainable farming practices and long-term soil health.
12. Guano: This is derived from seabird or bat droppings, is rich in nitrogen, phosphorus, and potassium. This nutrient-dense fertilizer supports plant growth by encouraging strong root development, flowering, and fruiting. Its high phosphorus content makes it particularly beneficial for plants that require enhanced root systems.
13. Cover Crop Residues: After cover crops like clover or rye are grown, their decomposed residues are tilled back into the soil, enriching the organic matter and improving soil structure. Leguminous cover crops also fix nitrogen, reducing the need for synthetic fertilizers, while the residues boost microbial activity and long-term soil fertility.
14. Wood Ash: Wood ash, a byproduct of burning wood, is rich in potassium, calcium, and trace minerals. It can help raise soil pH, making it more alkaline, which benefits certain plants. It also improves soil fertility by supplying essential minerals, enhancing plant growth, and reducing the need for chemical fertilizers. However, it should be used in moderation, as it can be too alkaline for some crops.

Each of these organic fertilizers plays a unique role in enhancing soil fertility and promoting sustainable farming practices.

2.1.2 Benefits of Organic Fertilizers in Crop Production

The benefits of organic fertilizers are numerous and have a profound impact on soil health and agricultural productivity. Here's a detailed breakdown of these benefits:

1. **Enhancement of Soil Fertility:** Organic fertilizers significantly boost soil fertility by stimulating the microbial biomass in the soil. This involves encouraging the growth and activity of beneficial soil microorganisms, such as bacteria and fungi, that are essential for nutrient cycling. These microorganisms break down organic matter, converting it into nutrients that plants can absorb. This process not only enriches the soil but also ensures that nutrients are available for plant growth in a sustainable manner (Hammad et al., 2019).
2. **Efficient Nutrient Recycling:** Organic fertilizers promote nutrient recycling within cropping systems, which ensures that the nutrients in the soil are used more efficiently. Unlike synthetic fertilizers, which often lead to nutrient loss through leaching, organic manures help retain nutrients within the soil-plant system for a longer period. By maintaining nutrient balance, organic fertilizers reduce the need for excessive input and help prevent nutrient waste, leading to lower environmental impact and more sustainable farming practices.
3. **Balanced Nutrient Supply:** Organic fertilizers offer a comprehensive range of essential nutrients required for plant growth, including both macro-nutrients (such as nitrogen, phosphorus, and potassium) and micro-nutrients (such as iron, zinc, and copper). These nutrients are released gradually as the organic matter decomposes, ensuring that plants receive a steady and balanced supply throughout the growing season. This steady nutrient availability promotes optimal plant growth, leading to healthier plants that are more resilient to diseases and environmental stresses.

4. **Improvement of Soil Physical Properties:** Organic fertilizers improve the physical characteristics of soil, which directly benefits plant health. These fertilizers enhance soil structure by increasing its organic matter content, which results in better soil aggregation and porosity. This, in turn, improves water retention and drainage, making the soil more resilient during droughts or heavy rainfall. Additionally, improved soil structure facilitates root penetration and air circulation, creating a more favorable growing environment for plants.
5. **Boosting Soil Biological Properties:** In addition to enhancing soil's physical properties, organic fertilizers also contribute to the biological aspects of soil health. They promote a diverse population of beneficial soil organisms, including bacteria, fungi, and earthworms, which are crucial for maintaining soil health. These organisms contribute to disease suppression, as many naturally occurring pathogens are outcompeted by the beneficial microbes. Moreover, organic fertilizers improve soil microbial diversity, which helps create a more stable and resilient ecosystem within the soil.
6. **Environmental Sustainability:** One of the key advantages of organic fertilizers is their environmental friendliness. Unlike chemical fertilizers, which can cause soil degradation, water pollution, and harm to non-target organisms, organic fertilizers are derived from natural sources and are free from synthetic chemicals. This reduces the risk of nutrient runoff and contamination of surrounding ecosystems (Ayuso et al., 1996). The use of organic fertilizers promotes long-term soil health and helps reduce the environmental footprint of farming, making it a more sustainable choice.
7. **Abundance and Accessibility:** Organic fertilizers are widely available and can be produced locally from a variety of organic waste materials, such as animal manure, compost, and plant residues. This makes organic fertilizers a readily accessible and renewable source of nutrients for agricultural systems. The availability of organic

manures ensures that farmers, especially those in rural or resource-limited areas, have a sustainable option for soil fertility management without relying on expensive or imported synthetic fertilizers.

8. **Increase in Soil Organic Matter:** Organic fertilizers, particularly farmyard manure, increase the organic matter content in the soil. Organic matter is essential for maintaining soil health over the long term because it helps improve soil structure, water retention, and nutrient holding capacity. Additionally, increasing organic matter in the soil contributes to carbon sequestration, where carbon is stored in the soil rather than being released into the atmosphere. This process can help mitigate the impacts of climate change by reducing greenhouse gas emissions.
9. **Improvement of Soil Chemical Properties:** The use of organic fertilizers has a positive effect on various chemical properties of the soil. These fertilizers can help balance soil pH, making it more suitable for plant growth. They also enhance the soil's cation exchange capacity (CEC), which refers to the soil's ability to hold onto essential nutrients and make them available to plants. Furthermore, organic fertilizers increase the levels of exchangeable calcium, magnesium, and potassium in the soil, improving overall nutrient availability and soil fertility (Anthony A. et al., 2017). These improvements enhance the soil's ability to support healthy plant growth over the long term.

The benefits of organic fertilizers contribute to sustainable agricultural practices by improving soil health, boosting plant productivity, and reducing environmental impact. By utilizing organic fertilizers, farmers can ensure that their crops receive the necessary nutrients while also maintaining the long-term fertility and ecological balance of the soil.

2.1.3 Comparison Between Organic and Inorganic Fertilizers

The table provides a comparison between organic and inorganic fertilizers in terms of their advantages and disadvantages. Here's a summary of the key points:

Table 2.1: Comparison of the Advantages of Organic and Inorganic Fertilizers (Bokhtiar & Sakurai, 2005)

S/N	Category	Organic Fertilizers	Inorganic Fertilizers
1	Advantages	Environmentally friendly, safer for ecosystems compared to chemical fertilizers.	Easily accessible and widely available.
2		More affordable for farmers, especially in the long term.	Provide quick results, with visible effects in 1-2 weeks.
3		Improves soil quality and enriches it over time.	Relatively low cost, especially for basic blends.
4		Converts complex organic materials into simple compounds that plants can absorb easily.	Simple to apply using spreaders, making it convenient.
5		Can increase crop yield by 1025%.	Available in various forms (e.g., pellets, granules, liquid).
6		Stimulates root growth through growth-promoting hormones.	High in nutrient content, requiring small amounts to promote crop growth.

7	Improves soil structure and enhances its ability to hold water and nutrients.	
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Table 2.2: Comparison of the Disadvantages of Organic and Inorganic Fertilizers (Bokhtiar & Sakurai, 2005)

S/N	Category	Organic Fertilizers	Inorganic Fertilizers
1	Disadvantages	Nutrient release is slow, especially in cooler soil conditions.	Can cause water pollution and environmental damage due to chemical runoff.
2		Can be more costly than chemical fertilizers for the same coverage.	Overuse can reduce soil fertility in the long run.
3		May not be as widely available in some regions.	Risk of plant damage and salt burn if over-applied.
4		Improper storage can attract pests.	Can contribute to eutrophication in water bodies.
5		Fresh animal manure can cause problems if not properly composted.	May increase soil acidity over time.
6			May harm beneficial soil bacteria, disrupting soil health.

In summary, organic fertilizers work over time to create a healthy growing environment, while inorganic fertilizers provide rapid nutrition. The choice between them depends on the specific needs of the plants, cost considerations, and environmental impact preferences.

2.2 C. ODORATA AS A SOURCE OF ORGANIC FERTILIZER

2.2.1 Identity

Scientific Name: *Chromolaena odorata* (L.) R.M. King & H. Rob.

Common Name: Siam weed

Family: Asteraceae

EPPO Code: EUPOD (*Eupatorium odoratum*)

Chromolaena odorata is a perennial, herbaceous shrub belonging to the family Asteraceae. It was formerly classified under the genus *Eupatorium* and has been referred to by several synonyms, including *Eupatorium odoratum* L. and *Osmia odorata* (L.) Schultz-Bip. The plant is commonly known as Siam weed, though it bears various local names around the world such as “Awolowo” or “Queen Elizabeth” in Nigeria, “Hagonoy” in the Philippines, and “Mile-a-minute” in Sri Lanka. These variations reflect its widespread occurrence across tropical and subtropical regions of Africa, Asia, and Central and South America.

Despite being recognized as an invasive species, *C. odorata* has gained attention for its high nutrient content and potential use in organic fertilizer production. Its abundance and rapid growth make it an accessible biomass resource for sustainable soil fertility enhancement.



Figure 2.1 *C. odorata* (Siam weed); habit, showing leaves(Pasiecznik, 2007)



Figure 2.2 *C. odorata* (Siam weed); habit, with flowers (Pasiecznik, 2007)

2.2.2 Botanical Description and Origin

C. odorata is a fast-growing, perennial herbaceous plant belonging to the Asteraceae family. It is native to Central and South America but has become widely distributed in tropical and subtropical regions around the world, especially in Africa and Southeast Asia, where it is often considered an invasive species. The plant typically grows between 1 to 3 meters in height and

has a bushy, branching habit. Its leaves are ovate or lance-shaped, measuring approximately 5 to 20 cm long, with serrated margins. The upper surface of the leaves is dark green and smooth, while the underside is lighter and often covered with fine hairs. The plant's flowers are small, clustered in panicles, and are typically white or pale lavender in color, blooming in the rainy season. *C. odorata* produces a large number of seeds, which are light and easily dispersed by wind, aiding in its rapid spread. The seeds are encased in small, tufted pappus, which helps them travel over long distances. This reproductive trait contributes to its invasive nature, as it can quickly establish itself in disturbed environments, outcompeting native plants (Pasiiecznik, 2007).

Origin and Spread

C. odorata was first introduced to Asia in the 19th century at the Calcutta Botanical Garden as an ornamental plant. By the 1920s, it had already spread to Malaysia, Sumatra, and Indo-China. The plant's common English name, "Siam weed," originates from its spread across the Malay Peninsula from Siam (now Thailand) (Burkill, 1966). It was first reported in Laos in 1960 and reached the Philippines later in the decade. The weed continued to spread across Southeast Asia and was reported as growing rapidly in southern Taiwan a few decades later (Peng et al., n.d.). The spread of *C. odorata* in Southeast Asia and the western Pacific was linked to the movement of military personnel and equipment during World War II. New outbreaks were found in areas where military bases were established, such as Rabaul in New Britain and Jayapura in Irian Jaya. Similarly, the weed spread to East Timor after 1975 due to troop movements. In Indonesia, the 1960s transmigration program likely played a significant role in its spread (Waterhouse et al., n.d.). In 1994, small infestations were found in Queensland, Australia, probably due to contaminated pasture seeds from overseas. Although efforts to eradicate the weed were successful, the threat of reintroduction from nearby islands remains high. In West Africa, *C.*

odorata was accidentally introduced with forestry seeds in Nigeria in 1937 and was deliberately introduced to Côte d'Ivoire in 1952 to control other grasses, despite being considered a weed by botanist Auguste Chevalier. Today, its distribution in West and Central Africa stretches from Guinea/Sierra Leone to central parts of the Democratic Republic of Congo and the Central African Republic, reaching as far south as northern Angola. It was introduced to South Africa near Durban around 1940 and has since spread to Natal, Transvaal, Swaziland, and Mozambique (McFadyen et al., n.d.). Comparing its distribution with a climatic map shows that areas with suitable environments are still not fully invaded, particularly in Africa and Oceania.

Due to the weed's widespread presence and invasive nature, methods like chemical and mechanical control are not considered sustainable in terms of cost and effectiveness. As a result, biological control was attempted in Nigeria in the 1970s, but these efforts were unsuccessful. Since then, experts from various fields have debated the best approach to manage the weed, partly because it is believed to have several benefits. For instance, it is used in slash-and-burn farming systems as a fallow species, and it is also recognized for its medicinal uses in several regions of Nigeria. Additionally, it has been noted for its potential benefits in livestock nutrition, improving soil fertility, and even as a possible pesticide (Cock & Holloway, 1982). Today, *C. odorata* is recognized as a significant environmental threat in many parts of the world, including tropical Asia, Australia, and the Pacific Islands, due to its ability to form dense, monospecific stands that outcompete other vegetation and alter habitats. However, it also holds potential value in organic farming and sustainable agriculture due to its high organic matter content and its role in soil fertility improvement.

C. odorata was first introduced to Nigeria in 1937 through contaminated seeds of the forest tree *Gmelina arborea* imported from Sri Lanka. The first recorded collection of *C. odorata* in Nigeria was in 1942 from a forestry plantation near Enugu, in south-eastern Nigeria (Ivens, 1973). After its introduction, the plant spread rapidly throughout eastern Nigeria during the 1940s. It was first reported west of the Niger River in 1955 and reached Lagos and its surrounding areas by 1960. By this time, *C. odorata* had established itself in the south-eastern states of Nigeria and subsequently spread into Cameroon (Akobundu et al., 1999).

The rapid spread of *C. odorata* across Nigeria in the 1940s and 1950s may have been aided by regional trade, as well as human and vehicular movement, particularly by the colonial administration and local politicians. The Nigerian civil war in the late 1960s and early 1970s likely further contributed to its dispersal through the movement of people, troops, and military equipment. Today, *C. odorata* has successfully spread to over 23 of the 36 states in Nigeria, covering diverse vegetation zones, including rainforest, freshwater swamp forests in the south, and woodland and grassland savannah zones in the north-central regions (Uyi et al., 2014a). The weed is now present throughout most of Nigeria, except in the northeast and far northern regions, where the prevailing climatic conditions appear unsuitable for its growth and establishment (Aweto & Iyanda, 2003).

According to (Goodall & Erasmus, 1996), the regions in Nigeria most affected by *C. odorata* infestation include the entire southeastern region, the southwestern region, the Niger Delta region, and parts of the north-central region. The species has successfully invaded and established itself across several vegetation zones, specifically the rainforest zones and freshwater swamp forest zones in the south, as well as the woodland savannah and grassland

savannah zones in the north-central region. Infestation levels in these areas are particularly severe, with *C. odorata* achieving a highly invasive status.

Uyi et al. (2014) further report that *C. odorata* infestations occur across various land use types. These include cocoa, rubber, oil palm, and coconut plantations, arable crop farms such as cassava, nursery gardens, secondary forests, forest margins, wastelands, abandoned plots, and roadsides. This wide range of invaded areas demonstrates the adaptability and aggressive spread of the species across different ecological and agricultural landscapes in Nigeria.

2.2.3 Chemical Composition and Nutrient Profile

C. odorata is commonly used as a green manure or fallow plant, which is an important but optional use. Due to its invasive nature, it has replaced native secondary species in many tropical regions. Farmers have adapted to its presence, incorporating it into their farming systems, particularly in shifting cultivation and rotational farming practices. It is often preferred over native species because it is easier to cut and clear, and it has been observed to suppress another invasive species, *Imperata cylindrica*, which has more detrimental effects on agriculture. While it is still unclear whether *C. odorata* directly improves soil fertility, the fallow period it creates likely contributes positively to soil health. The plant can also be cut, cleared before it seeds, composted, and used as an organic soil amendment.

Although *C. odorata* is generally considered toxic to animals and is not recommended as livestock feed, some studies suggest it may have benefits in low concentrations. For example, feeding up to 5% of it to egg-laying chickens has been shown to improve yolk colour (Fasuyi et al., n.d.).

In Malaysia, where *C. odorata* is an invasive species, its plant parts are used in traditional medicine for treating burns, wounds, skin infections, post-natal issues, and even malaria. Research has confirmed that extracts from the leaves of *C. odorata* possess antimicrobial, antiinflammatory, and wound-healing properties, indicating its potential as a source for human medicines (Huda et al., 2004).

C. odorata contains several key nutrients that make it beneficial for soil improvement and organic farming:

1. Nitrogen (N): Important for plant growth, it enhances soil fertility when the plant decomposes.
2. Phosphorus (P): Supports root development and flower/fruit formation.
3. Potassium (K): Regulates plant metabolism, boosts disease resistance, and improves water use.
4. Calcium (Ca): Strengthens cell walls and supports root development.
5. Magnesium (Mg): Essential for photosynthesis and plant energy production.
6. Micronutrients: Includes iron, zinc, copper, and manganese, which are vital for enzyme activity and plant health.
7. Organic Matter: Improves soil structure, water retention, and promotes microbial activity.
8. Fiber: Enhances soil aeration and water retention when used as mulch or compost.

These nutrients contribute to better soil fertility and crop production when *C. odorata* is used properly as a green manure or compost.

2.2.4 Previous Studies on Composting *C. odorata*

The nutrient-rich nature of *C. odorata* makes it highly suitable for composting. The plant contains appreciable amounts of essential macro- and micronutrients, which contribute to improving soil fertility when used as compost. Studies have reported that compost derived from *C. odorata* enhances organic matter content, increases nutrient availability, and supports sustainable crop growth (Zachariades et al., 2009).

Table 2.1 shows the average nutrient composition of *C. odorata* leaves, highlighting its potential as an organic fertilizer:

Table 2.3: Nutrient Composition of *C. odorata* Leaves (Zachariades et al., 2009)

Nutrient	Percentage (%)
Nitrogen (N)	2.1 – 3.5
Phosphorus (P)	0.2 – 0.5
Potassium (K)	2.5 – 3.0
Calcium (Ca)	1.5 – 2.0
Magnesium (Mg)	0.5 – 0.8
Organic Carbon (OC)	40 – 45

The high nitrogen and potassium content of *C. odorata* makes it particularly effective in promoting plant growth. When composted, the plant's nutrients are stabilized, and allelopathic compounds are neutralized, producing an organic amendment suitable for various crops. Furthermore, compost from *C. odorata* improves soil structure, water retention, and microbial activity, which are key factors in sustainable agriculture.

2.2.4.1 Vermicomposting of *C. odorata*

Vermicomposting is the process of using earthworms to accelerate the decomposition of organic materials. Studies have demonstrated that vermicomposting *C. odorata* significantly improves the nutrient content of the final compost. For instance, nitrogen and phosphorus concentrations increase, while the carbon-to-nitrogen (C:N) ratio decreases, creating a more balanced and effective fertilizer (A. M. Suri & Yudono, 2020a). Vermicomposting also enhances microbial activity, contributing to faster nutrient cycling and improving soil fertility for crops such as maize and cassava.

2.2.4.2 Co-Composting with Other Organic Materials

Combining *C. odorata* with other organic residues, such as livestock manure, kitchen waste, and crop residues, has been reported to optimize the composting process. Co-composting not only accelerates decomposition but also balances nutrient content, producing compost with a more comprehensive nutrient profile suitable for multiple crops (A. Suri et al., n.d.). Studies indicate that such co-composts have higher levels of nitrogen, phosphorus, and potassium compared to composted *C. odorata* alone, making them more effective in improving soil fertility and crop yield.

2.2.4.3 Effects on Soil Properties and Crop Performance

Application of *C. odorata* compost has been observed to enhance soil physical and chemical properties. These benefits include increased organic matter, better soil structure, improved water-holding capacity, and enhanced nutrient availability. Consequently, crops grown on soils

amended with *C. odorata* compost show improved growth and yield, demonstrating its potential as a sustainable organic fertilizer in tropical agricultural systems (Uyi et al., 2014; Day et al., 2024).

2.2.4.4 Challenges in Composting *C. odorata*

Despite its benefits, *C. odorata* contains allelopathic compounds that may inhibit seed germination if fresh plant material is applied directly to soil. Proper composting techniques, including sufficient decomposition time and periodic turning of the pile, are necessary to neutralize these compounds and produce a safe and effective fertilizer (Kato-Noguchi & Kato, 2023).

2.3 OPTIMIZATION OF COMPOST PRODUCTION OF *C. ODORATA*

2.3.1 Key Factors Influencing Compost Quality

The production of high-quality compost depends on several critical factors. Understanding and controlling these factors ensures that the composting process is efficient and results in a nutrient-rich, stable organic fertilizer. The main factors influencing compost quality include the carbon-to-nitrogen (C:N) ratio, moisture content, aeration, as well as temperature and pH.

2.3.1.1 Carbon-to-Nitrogen (C:N) Ratio

The C:N ratio is one of the most important parameters in composting. Carbon serves as an energy source for microorganisms, while nitrogen is essential for protein synthesis and microbial growth. An optimal C:N ratio ensures rapid decomposition and high-quality compost. Generally, a ratio of 25–30:1 is considered ideal for effective composting (Guo et

al., n.d.). If the ratio is too high (excess carbon), decomposition slows down, producing a dry and incomplete compost. Conversely, if the ratio is too low (excess nitrogen), it may lead to foul odours and loss of nitrogen through ammonia volatilization (Adhikari et al., 2009).

Adjusting the mixture of carbon-rich materials e.g., leaves, straw and nitrogen-rich materials e.g., fresh green leaves, manure is essential to achieve the optimum ratio (Kumar et al., 2010).

2.3.1.2 Moisture Content

Moisture is critical for microbial activity during composting. Microorganisms require water to survive, grow, and break down organic materials. The ideal moisture content for composting ranges from 50% to 60% (Diaz et al., 2007). Too little moisture slows down microbial activity, leading to incomplete decomposition, while excessive moisture can create anaerobic conditions, resulting in foul smells and slower composting (Haug, 1993). Regular monitoring and adjusting moisture through watering or covering the compost pile helps maintain the balance needed for efficient decomposition.

2.3.1.3 Aeration

Aeration is the supply of oxygen to the composting material. Composting is primarily an aerobic process, meaning that microorganisms need oxygen to break down organic matter effectively. Adequate aeration prevents anaerobic conditions, which can produce methane, ammonia, and unpleasant odours (de Bertoldi & Insam, 2007). Turning the compost pile periodically or using mechanical aeration methods ensures uniform oxygen distribution, promotes faster decomposition, and results in a more stable and nutrient-rich compost.

2.3.1.4 Temperature and pH

Temperature and pH significantly influence compost quality. During the initial phase of composting, microbial activity generates heat, which helps destroy pathogens and weed seeds. The temperature should be maintained between 55–65°C for effective sanitation (Liang et al., 2003). Compost pH typically ranges from 6.0 to 8.0, with extreme acidity or alkalinity slowing down microbial activity. Adjusting pH with lime or other additives can help maintain optimal conditions (Haug, 2018).

In summary, achieving high-quality compost requires careful attention to the C:N ratio, moisture content, aeration, temperature, and pH. Proper management of these factors accelerates decomposition, reduces nutrient loss, eliminates harmful pathogens, and produces a stable, nutrient-rich organic fertilizer suitable for improving soil fertility and supporting sustainable agriculture.

2.3.2 Role of Microbial Activity in Decomposition *C. odorata*

Microbial activity is the driving force behind the composting of *C. odorata*. The plant is rich in nutrients, including nitrogen, potassium, and calcium, which provide an excellent substrate for microorganisms such as bacteria, fungi, and actinomycetes (Zachariades et al., 2009). These microorganisms break down the complex organic matter in *C. odorata* into simpler compounds, ultimately producing nutrient-rich compost suitable for sustainable agriculture.

2.3.2.1 Types of Microorganisms Involved

The decomposition of *C. odorata* is driven by a complex community of microorganisms, each performing specialized functions that collectively transform the plant's biomass into nutrient-rich compost.

- a. Bacteria: They are the primary decomposers in the initial stages of composting. They target easily degradable compounds in *C. odorata*, such as sugars, amino acids, and proteins. As bacteria metabolize these compounds, they generate heat, which raises the temperature of the compost pile. This thermophilic environment not only accelerates the breakdown of organic matter but also creates favourable conditions for subsequent microbial activity (Diaz & de Bertoldi, 2007).
- b. Fungi: Play a crucial role in decomposing the more resistant components of *C. odorata*, including cellulose, hemicellulose, and lignin present in stems, branches, and mature leaves. Their enzymatic activity breaks down these complex polymers into simpler compounds, making nutrients available for plants and improving the overall quality of the compost (Insam & de Bertoldi, 2007).
- c. Actinomycetes: A group of filamentous bacteria, specialize in decomposing woody residues and other tough plant materials. Their activity contributes to the characteristic earthy smell of mature compost and enhances the microbial diversity of the soil when the compost is applied, improving soil structure and fertility (Adediran et al., 2003).

Together, these microorganisms ensure efficient decomposition of *C. odorata*, transforming a highly invasive plant into a sustainable source of organic fertilizer.

2.3.2.2 Microbial Activity During Composting Phases

The composting of *C. odorata* occurs in three main phases:

1. Mesophilic Phase: During the initial mesophilic phase, bacteria and fungi start decomposing the easily degradable components of *C. odorata*, such as sugars,

proteins, and tender leaves and stems. This microbial activity generates moderate heat, which accelerates decomposition and creates favourable conditions for the next phase of composting.

2. **Thermophilic Phase:** In the thermophilic phase, thermophilic bacteria dominate. They efficiently break down more complex organic compounds, including proteins, fats, cellulose, and hemicellulose. The high temperatures reached during this phase help in eliminating pathogens and weed seeds, ensuring that the compost is safe and hygienic for agricultural use.
3. **Maturation Phase:** During the maturation phase, mesophilic microorganisms recolonize the compost and further degrade resistant plant materials like lignin in the stems and leaves. By the end of this phase, the *C. odorata* compost has a dark, crumbly texture, rich nutrient content, and improved soil fertility, making it suitable as an organic fertilizer (Diaz & de Bertoldi, 2007; Insam & de Bertoldi, 2007)

2.3.2.3 Benefits of Microbial Activity in *C. odorata* Compost

The active microbial decomposition of *C. odorata* plays a vital role in producing high-quality compost. Microorganisms break down complex organic compounds into simpler forms, enhancing the availability of essential nutrients such as nitrogen, phosphorus, and potassium for crops. This process also increases the organic matter content, improving soil structure, porosity, and water-holding capacity. Additionally, microbial activity helps neutralize allelopathic compounds naturally present in fresh *C. odorata*, preventing inhibition of seed germination and plant growth. The result is a nutrient-rich, safe, and stable compost that supports sustainable agricultural practices and improves crop productivity (Uyi et al., 2014c; Wei et al., 2017).

2.3.3 Composting Methods Used in Organic Fertilizer Production of *C. odorata*

Composting is a controlled biological process that converts organic materials into nutrient-rich fertilizer. For *C. odorata*, several composting methods have been employed to optimize nutrient recovery and improve soil fertility. The choice of method depends on the scale of production, available resources, and desired compost quality.

a. Aerobic Pile Composting

Aerobic composting involves stacking shredded *C. odorata* in open or covered piles, allowing oxygen to circulate naturally. Microbial activity generates heat, which accelerates the decomposition of leaves, stems, and woody parts. Regular turning of the piles ensures uniform decomposition and prevents anaerobic conditions, which could produce foul odors and reduce compost quality (A. M. Suri & Yudono, 2020b).

b. Vermicomposting

Vermicomposting uses earthworms, particularly *Eisenia fetida*, to accelerate the breakdown of *C. odorata*. The worms consume the plant material, and their digestive process enriches the compost with plant-available nutrients, improves soil microbial diversity, and reduces the carbon-to-nitrogen ratio. This method is especially suitable for producing high-quality compost for small-scale agricultural applications (Wijeysingha & Fernando, 2021).

c. Co-composting with Other Organic Materials

Co-composting combines *C. odorata* with livestock manure, crop residues, or kitchen waste. This approach balances nutrient content, enhances microbial activity, and reduces composting time. It also mitigates potential allelopathic effects from *C. odorata*, ensuring that the final compost is safe and effective for crop use (Anyasi et al., 2014).

These methods demonstrate that *C. odorata* can be efficiently transformed into a high-quality organic fertilizer, contributing to sustainable agriculture and improved soil health. Selecting the appropriate composting technique is crucial to maximize nutrient retention, microbial activity, and overall compost quality.

2.3.4 Parameters for Optimization of *C. odorata* Compost Production

The quality and efficiency of *C. odorata* compost depend on several key parameters that must be carefully controlled during production. Optimizing these factors ensures maximum nutrient retention, effective decomposition, and safe application as an organic fertilizer.

a. Carbon-to-Nitrogen (C:N) Ratio

The C:N ratio is a critical factor in composting. *C. odorata* has a naturally high nitrogen content, but excessive carbon from woody stems can slow microbial activity. An optimal C:N ratio of 25–30:1 supports rapid decomposition and prevents nitrogen loss as ammonia (Diaz, 2007). Adjusting the ratio by mixing with other organic residues, such as crop waste or manure, can enhance compost quality.

b. Moisture Content

Moisture is essential for microbial growth and enzymatic activity. The ideal moisture content for *C. odorata* compost is 50% to 60%. Too little moisture slows decomposition, while excessive moisture can create anaerobic conditions, produce foul odours and reduce nutrient availability (Guo et al., 2012). Regular monitoring and water adjustment during composting are recommended.

c. Aeration and Pile Management

Adequate oxygen supply is vital for aerobic microbial activity. Turning compost piles regularly prevents anaerobic zones, promotes uniform decomposition, and maintains optimal temperature levels. Proper aeration also supports thermophilic microbial phases, which help eliminate pathogens and weed seeds (Guo et al., 2012).

d. Particle Size

Shredding *C. odorata* into smaller pieces increases the surface area for microbial colonization, accelerating decomposition. Smaller particle sizes also reduce composting time while ensuring uniform nutrient breakdown (de Bertoldi-Schnappinger, 2007).

e. Temperature Control

Composting involves mesophilic and thermophilic phases. Maintaining temperatures between 45-65 °C during the thermophilic phase ensures rapid breakdown of proteins, fats, and complex carbohydrates while destroying pathogens and weed seeds (Insam & de Bertoldi, 2007). Optimizing these parameters collectively ensures that *C. odorata* compost is nutrient-rich, safe, and suitable for sustainable agriculture, improving soil fertility and crop productivity.

2.3.5 Effect of Increased Temperature on *C. odorata* in Compost Optimization

The use of controlled heat treatment, such as placing *C. odorata* in an oven, is a method that can influence the efficiency and quality of compost production. Increased temperature serves as a form of pre-treatment, which can modify the physical and chemical properties of the plant biomass before the actual composting process begins.

Heating *C. odorata* can help reduce its moisture content to optimal levels for microbial activity and partially break down tough lignocellulosic components, such as cellulose, hemicellulose, and lignin. This makes the biomass more accessible to decomposing microorganisms, thereby accelerating nutrient release during composting. Furthermore, thermal treatment can deactivate

allelopathic compounds present in fresh *C. odorata*, which are known to inhibit seed germination and can otherwise affect the safety of applying raw plant material to soil (Zachariades et al., 2009).

However, the temperature applied must be carefully controlled. Moderate oven temperatures, typically between 50–60 °C, can enhance nitrogen, phosphorus, and potassium availability without negatively affecting microbial colonization. Excessive temperatures above 70 °C may cause nutrient loss, particularly nitrogen through ammonia volatilization, and reduce microbial diversity, which is critical for effective decomposition and high-quality compost production.

2.4 EFFECT OF *C. ODORATA* ON MAIZE (*Zea mays*)

2.4.1 Maize (*Zea mays*)

Maize (*Zea mays*) is one of the most widely cultivated cereal crops in the world and serves as a staple food for humans as well as a key feed ingredient for livestock. It is a member of the Poaceae family and is grown across tropical, subtropical, and temperate regions due to its wide adaptability. Globally, maize ranks third in production after wheat and rice (FAOSTAT, 2020). In Nigeria and many parts of sub-Saharan Africa, maize plays an essential role in household food security and industrial raw material supply for products such as starch, oil, alcohol, and animal feed (IITA, 2020).

Agronomically, maize is a nutrient-demanding crop that requires sufficient nitrogen (N), phosphorus (P), and potassium (K) for optimum growth and grain yield (Nuss & Tanumihardjo, 2010). Nitrogen promotes vegetative development and chlorophyll formation, phosphorus enhances root establishment and energy transfer, while potassium regulates water use efficiency and enzyme activation. Maize is particularly sensitive to soil fertility depletion, and yield declines rapidly on degraded soils common in tropical regions (Bationo et al., 2007).

Consequently, soil fertility management practices such as the application of organic fertilizers, green manures, or composts are critical for sustainable maize production.

Organic fertilizers are increasingly recommended for maize cultivation because they improve soil structure, enhance microbial activity, and supply nutrients gradually over time. Studies have shown that organic amendments such as *C. odorata* compost significantly improve maize height, leaf area, and cob yield compared to untreated soils (Ahmad & Lamangantjo, 2018; Ogundare et al., 2015). Unlike inorganic fertilizers that can lead to nutrient leaching or soil acidification, organic fertilizers provide a long-term improvement in soil health. According to (Aboyeji, 2019), maize grown under *C. odorata* green manure maintained higher grain yield and soil nutrient status across successive cropping seasons, demonstrating the effectiveness of organic nutrient sources.

Maize growth and productivity are also influenced by environmental factors such as rainfall, temperature, and light intensity. Optimum growth occurs between 25 °C and 30 °C with annual rainfall between 600 mm and 1200 mm (FAOSTAT, 2020). The crop performs best in well-drained loamy soils with a pH range of 5.5 – 7.5. These conditions support efficient nutrient uptake and physiological processes essential for high yield. Therefore, using *C. odorata*-based organic fertilizer in maize production not only provides an alternative to chemical fertilizers but also aligns with sustainable agricultural practices aimed at improving soil fertility and maintaining productivity.

2.4.2 Growth and Yield Response of Maize to *C. odorata* Based Fertilizers

Several empirical investigations have documented the positive effect of *C. odorata* biomass when used as an organic amendment on the growth and yield performance of maize (*Zea mays*).

For example, (Ahmad & Lamangantjo, 2018) demonstrated that maize plants treated with a “Bokashi” organic fertilizer incorporating *C. odorata* showed significant improvements in vegetative growth parameters such as stem height, stem diameter and leaf size, as well as generative yield components (unhusked cob weight, number of seeds per cob) compared with control treatments.

The mechanism underlying these effects is attributed to the decomposition of *C. odorata* residues which releases essential nutrients (e.g., nitrogen [N], phosphorus [P], potassium [K], calcium [Ca], magnesium [Mg]) into the soil medium, enhancing nutrient availability for maize uptake (Ahmad & Lamangantjo, 2018) reported high nutrient content in *C. odorata* biomass (e.g., ~21.94 % N, 0.60 % P and 1.58 % K) when processed as Bokashi. Further, organic matter derived from decomposed *C. odorata* improves soil physical properties such as structure and water retention, and enhances microbial activity that supports root development and nutrient uptake efficiency.

Moreover, the relatively gradual mineralization rate of *C. odorata* residues ensure a sustained release of nutrients throughout the maize growth cycle, mitigating the rapid nutrient flush and subsequent leaching associated with many synthetic fertilizers. A field trial in Nigeria by (Ogundare et al., 2015) found that combining *C. odorata* residue with varying rates of urea resulted in improved maize growth and yield under local conditions. However, the effectiveness of *C. odorata* as an organic fertiliser depends significantly on factors such as application rate, decomposition stage of the biomass, soil type, and climatic conditions. Some studies report that application of undecomposed *C. odorata* biomass can lead to temporary nitrogen immobilisation, potentially inhibiting early maize growth (due to high C:N ratio or allelopathic effects) (Akinrinola & Tijani-Eniola, 2022). Therefore, pre-composting or ensuring sufficient

decomposition of *C. odorata* biomass before application is recommended to maximise nutrient availability and minimise phytotoxic or allelopathic impacts.

2.5 BOTANICAL CLASSIFICATION AND IMPORTANCE OF MAIZE (*Zea mays*)

Maize (*Zea mays*), also referred to as corn, is one of the most important cereal crops globally and a major contributor to food and industrial sustainability. It is cultivated in a wide range of ecological zones across tropical, subtropical, and temperate regions. Maize plays a vital role in food security, livestock nutrition, and industrial applications, making it an ideal crop for evaluating organic fertilizer performance (Ojo & Adeniyi, 2020).

2.5.1 Family: Poaceae (The Grass Family)

Common Names: Grass family, Gramineae

Maize belongs to the *Poaceae* family, which comprises all grasses and cereals. The family includes over 10,000 species and is among the most economically significant plant families worldwide (Esser et al., 2018). Members of this family are monocotyledonous plants that exhibit the following distinctive characteristics:

- Monocot seeds with a single cotyledon.
- Hollow, jointed stems (culms) that provide structural flexibility.
- Narrow, elongated leaves with parallel venation.
- Inflorescences in the form of spikes or panicles, facilitating wind pollination.
- Fruits as caryopses (grains) in which the seed coat is fused to the pericarp, a defining trait of cereals.

The *Poaceae* family supports a large proportion of global food production and animal feed systems. Prominent members include *Oryza sativa* (rice), *Triticum aestivum* (wheat), *Sorghum bicolor* (sorghum), *Hordeum vulgare* (barley), *Saccharum officinarum* (sugarcane), *Avena sativa* (oats), and *Bambusa spp.* (bamboo) (FAO, 2021; Iken & Amusa, 2019).

2.5.2 Botanical Classification of Maize

The detailed taxonomic classification of *Zea mays* is presented in Table 2.1. This classification places maize within the order *Poales* and the tribe *Andropogoneae*, alongside other tropical grasses such as sorghum and sugarcane.

Table 2.4: Botanical Classification of *Zea mays*

Rank	Taxon	Description
Kingdom	Plantae	The plant kingdom
Division (Phylum)	Magnoliophyta	Flowering plants (angiosperms)
Class	Liliopsida	Monocotyledons (plants with one cotyledon)
Order	Poales	The grass and cereal order
Family	Poaceae	The grass family, including cereals and pasture grasses
Subfamily	Panicoideae	Warm-climate grasses such as sorghum and sugarcane
Tribe	Andropogoneae	Group containing maize, sorghum, and sugarcane
Genus	<i>Zea</i>	A small genus of tropical grasses

Species	<i>Zea mays</i>	Common maize or corn
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Botanically, maize is an annual, cross-pollinated cereal crop. It has a fibrous root system, a solid cylindrical stem divided into nodes and internodes, and broad leaves that emerge alternately along the stem. Its inflorescences are dimorphic: the tassel (male flower) occurs at the plant's apex, while the ear (female flower) develops in the leaf axil (Iken & Amusa, 2019). These features contribute to its high adaptability and reproductive efficiency across climatic zones.

2.5.3 Difference Between Maize and Corn

Although *maize* and *corn* refer to the same plant, the distinction lies in terminology. “Maize” is the scientifically accepted term derived from the Spanish word *maíz*, while “corn” is more commonly used in American and British English (Ukaoma et al., 2020). In global agricultural and research contexts, “maize” is preferred to avoid ambiguity. The term “corn” historically referred to the most common grain crop in a region; thus, in England it once meant wheat, and in Scotland, oats. However, in modern usage, maize and corn are synonyms, representing *Zea mays L.*, the same cereal species cultivated worldwide.

2.5.4 Importance of Maize

Maize is an essential crop for both nutritional and economic reasons. It is a principal source of carbohydrates, dietary fiber, protein, and several micronutrients (Ojo & Adeniyi, 2020). The grain serves multiple purposes across sectors:

- Food: Consumed directly as boiled, roasted, or milled into flour for traditional dishes.

- Feed: A major ingredient in poultry, piggery, and livestock diets due to its energy density.
- Industrial Uses: Raw material in the production of starch, glucose syrup, bioethanol, and biodegradable plastics.
- Agronomic Benefits: Maize residues improve soil organic matter and fertility when incorporated into farmlands.

According to Ajeigbe et al. (2021), maize accounts for over 45% of cereal production in Nigeria and is a cornerstone of food security and agribusiness value chains.

2.5.5 Prominent Maize Varieties in Nigeria

Maize breeding programs in Nigeria have produced improved varieties tailored to specific ecological zones. The most widely cultivated include Oba Super 2, Suwan 1-SR, TZL COMP 4C2, and BR-9928-DMR-SR-Y. These varieties are recognized for their drought tolerance, resistance to streak viruses, and high yield potentials (Ajeigbe et al., 2021). Others, such as SAMMAZ 14 and Ife Hybrid 6, perform well under low soil fertility and are suitable for rainfed and irrigated systems. Adoption of these hybrids has enhanced national maize output, contributing significantly to Nigeria's agricultural GDP.

2.5.6 Maize as a Class of Food

Nutritionally, maize belongs to the carbohydrate class of foods, providing 70–75% starch, 8–10% protein, and small amounts of lipids (3–5%) (FAO, 2021). It is an excellent energy source for humans and animals alike. Maize also contains minerals such as magnesium, phosphorus, and potassium, and vitamins like thiamine and niacin. Its moderate protein quality can be enhanced through biofortification and complementary diets. In many developing countries,

maize serves as the foundation of food systems due to its affordability, versatility, and adaptability to diverse environments (Ojo & Adeniyi, 2020).

2.5.7 Negative Effects of Synthetic Fertilizers

Although synthetic fertilizers have contributed significantly to increasing global agricultural productivity, their continuous and excessive use has resulted in several negative environmental, economic, and health-related consequences. These adverse effects threaten the long-term sustainability of agricultural systems and natural ecosystems.

1. Soil Degradation:

Prolonged application of synthetic fertilizers leads to the deterioration of soil structure and fertility. High concentrations of chemical salts can cause soil compaction, reduce aeration, and decrease water infiltration capacity. Over time, this weakens soil aggregates and reduces microbial activity, resulting in lower organic matter content and poor soil health (Ayoola & Makinde, 2007).

2. Nutrient Imbalance and Acidification:

Synthetic fertilizers, particularly nitrogen-based types such as urea and ammonium sulfate, tend to acidify the soil after repeated use. This process reduces soil pH, alters cation exchange capacity, and limits the availability of essential nutrients like calcium and magnesium. Acidic soils can inhibit root development and decrease crop productivity (Hossain et al., 2019).

3. Water Pollution:

Leaching and runoff of excess fertilizers into surface and groundwater bodies contribute to nutrient pollution. High nitrate and phosphate levels in water can trigger eutrophication, leading to algal blooms, oxygen depletion, and the death of aquatic organisms. Moreover, nitrate contamination in drinking water poses serious health risks, including methemoglobinemia or “blue baby syndrome” in infants (Keeney, 2000).

4. Greenhouse Gas Emissions:

The production and excessive use of synthetic nitrogen fertilizers contribute significantly to greenhouse gas emissions, especially nitrous oxide (N₂O), a potent contributor to global warming. Improper fertilizer management thus exacerbates climate change while reducing nitrogen-use efficiency in agricultural soils (Davidson, 2009).

5. Loss of Soil Biodiversity:

Continuous chemical fertilizer application disrupts the natural balance of soil microorganisms by reducing populations of beneficial bacteria and fungi. This decline in soil biodiversity affects organic matter decomposition, nutrient cycling, and overall soil resilience against pests and diseases (Gyaneshwar et al., 2002).

6. Human Health Hazards:

Residues of synthetic fertilizers may accumulate in edible plant parts or contaminate water supplies, posing long-term health risks such as cancer, kidney failure, and neurological disorders. Additionally, exposure to fertilizers containing heavy metals like cadmium or arsenic may lead to chronic toxicity in humans (Oluwatobi et al., 2021).

7. Economic and Environmental Sustainability Issues:

The dependence on synthetic fertilizers increases production costs for farmers and contributes to environmental degradation. Over-reliance on these inputs creates a cycle of dependency that diminishes soil self-renewal capacity and reduces the long-term profitability of agricultural systems.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Research Design

This study adopted an experimental research design to investigate the influence of drying temperature and time on the nutrient composition of *C. odorata* (Siam weed) leaves. The objective was to identify the combination of temperature and duration that best preserves essential nutrients for potential use as an organic fertilizer component.

Two drying approaches were compared:

1. Air-drying under ambient conditions (control) to represent natural low-energy processing.
2. Oven-drying under controlled conditions at different temperature–time combinations optimized using Response Surface Methodology (RSM).

The air-dried leaves provided a baseline for evaluating nutrient changes resulting from thermal treatment, while the oven-drying experiments formed the basis for statistical modeling and optimization.

3.2 Materials and Equipment

Fresh *C. odorata* leaves were obtained from natural vegetation within the University of Benin, Edo State, Nigeria. The materials and apparatus used in the study are listed in Table 3.1. All reagents were of analytical grade to ensure accuracy and reliability of results.

Table 3.1: Materials and Apparatus Used for the Study

S/N	Materials / Apparatus	Purpose / Description
1	Electric oven	Controlled drying of <i>C. odorata</i> leaves at different temperatures.
2	Analytical weighing balance	Measurement of sample mass before and after drying.
3	Grinder or milling machine	Grinding of dried leaves into fine powder for analysis.
4	Thermometer	Monitoring oven temperature during drying.
5	Airtight containers and polythene bags	Storage of powdered samples to prevent moisture absorption.
6	Laboratory glassware (beakers, conical flasks, digestion tubes)	Used for sample digestion and measurement during nutrient analysis.
7	Kjeldahl apparatus	Determination of total nitrogen (N).
8	Spectrophotometer	Determination of phosphorus (P) concentration.
9	Flame photometer	Determination of potassium (K) content.

3.3 Collection and Preparation of Plant Samples

Mature *C. odorata* plants were manually harvested, and the leaves were carefully detached from stems to avoid bruising or contamination. The leaves were gently rinsed with clean water to remove dust and debris, then air-dried at room temperature for a short period to remove surface moisture. Damaged or discolored leaves were discarded to ensure sample uniformity.

The cleaned leaves were divided into two equal portions: one portion for air drying and the other for oven drying. This division allowed direct comparison of nutrient composition between natural and controlled drying methods.

3.4 Air-Drying Procedure

The first portion of the leaves was air-dried in a well-ventilated room away from direct sunlight. The leaves were spread evenly on clean trays and turned periodically to ensure uniform drying and prevent mold formation. The ambient temperature during drying ranged between 27–30°C, with relative humidity of 65–70%. Drying continued for approximately two weeks until the leaves became crisp and brittle, indicating constant weight.

The dried leaves were ground using a clean mechanical grinder to obtain fine powder, which was then stored in airtight containers at room temperature until analysis. The air-dried sample served as the reference for comparison with the oven-dried samples.

3.5 Oven-Drying Procedure

The second portion of the leaves was oven-dried under controlled temperature–time conditions to evaluate the effect of heat intensity and exposure period on nutrient composition. Samples were uniformly spread on stainless-steel trays and dried in a pre-heated electric oven according to the design matrix generated by RSM (Section 3.9).

The drying temperatures ranged between 18.6 °C and 96.4 °C, and the drying times ranged between 11.4 min and 138.6 min, representing the coded levels $-\alpha$ to $+\alpha$. Center-point conditions (approximately 57.5 °C for 90 min) were replicated to check experimental error. During each run, samples were turned periodically to prevent scorching and ensure even heat distribution. After drying, samples were cooled to room temperature, ground into fine powder,

and stored in airtight containers prior to nutrient analysis. All treatments were performed in triplicate for reproducibility.

3.6 Laboratory Analysis of Nutrient Composition (NPK)

Nutrient composition analyses were conducted following the standard methods of the Association of Official Analytical Chemists (AOAC, 2019). All results were expressed on a dry-weight basis, and each analysis was performed in triplicate.

- **Nitrogen (N):** Determined using the Kjeldahl digestion, distillation, and titration procedure (AOAC 984.13). The total nitrogen content was used as an index of protein concentration and nutrient quality.
- **Phosphorus (P):** Determined colorimetrically after acid digestion using a UV-Visible spectrophotometer at 882 nm wavelength (molybdenum blue method).
- **Potassium (K):** Determined using a flame photometer by measuring the emission intensity corresponding to potassium ions in the digested sample.

3.7 Optimization of Drying Parameters Using Response Surface Methodology (RSM)

The optimization of drying conditions for *C. odorata* was carried out using Response Surface Methodology (RSM) in Design Expert (Version 13, Stat-Ease Inc., Minneapolis, USA). The method was employed to determine the combined influence of drying temperature and time on the nutrient composition of the dried biomass and to establish the optimum drying conditions for maximum nutrient retention.

A Central Composite Design (CCD) was adopted to develop a predictive model that describes the relationship between the process variables (independent factors) and the responses (nitrogen, phosphorus, and potassium contents). The design comprised 13 experimental runs,

which included four factorial points, four axial points, and five center points to evaluate experimental error and model adequacy.

The independent variables and their corresponding coded levels are presented in Table 3.10. The range of each factor was selected based on preliminary trials and literature guidance to ensure accurate model prediction within practical drying limits.

Table 3.2: Experimental Factors and Their Coded Levels

Factor	Symbol	Unit	$-\alpha$	-1	0	+1	$+\alpha$
Drying Temperature	A	°C	18.6	30	57.5	85	96.4
Drying Time	B	min	11.4	30	90	120	138.6

A second-order polynomial model was selected to describe the relationship between the responses and the independent variables, expressed as:

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_{12} AB + \beta_{11} A^2 + \beta_{22} B^2 + \varepsilon$$

where Y represents the response variable (N, P, or K), A and B are the coded independent factors, β_0 is the intercept, β_1 and β_2 are linear coefficients, β_{12} is the interaction coefficient, β_{11} and β_{22} are quadratic coefficients, and ε is the experimental error.

Model adequacy was assessed through Analysis of Variance (ANOVA), determination coefficients (R^2 , adjusted R^2 , and predicted R^2), and lack-of-fit tests. The response surface and contour plots were generated to visualize the combined effects of temperature and time, while the numerical optimization tool in Design Expert was used to identify the optimum drying conditions that maximized nutrient retention.

3.8 Soil Sampling and Analysis

To determine the effect of the *C. odorata*-based organic fertilizer on soil fertility, composite soil samples were collected from the experimental site before and after fertilizer application.

Prior to treatment, two representative surface-soil samples (coded SSD12025 and SSD20226) were obtained from the 0–20 cm depth using a hand auger. After fertilizer application and a short incubation period that allowed mineralization and crop interaction, corresponding posttreatment samples were collected from the same plots.

Each composite sample was air-dried at room temperature, gently crushed with a wooden roller, and passed through a 2 mm sieve to remove coarse fragments and plant residues. The prepared samples were stored in labelled airtight containers pending analysis.

The physicochemical parameters determined included pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (N), available phosphorus (P), exchangeable cations (Ca, Mg, K, Na), exchangeable acidity, effective cation-exchange capacity (ECEC), micronutrients (Zn, Cu, Mn, Fe), and particle-size distribution.

All analyses followed standard procedures described by the *Association of Official Analytical Chemists* (AOAC, 2019) and the Soil Science Laboratory of the University of Benin:

- **Soil pH (H₂O):** measured in a 1:2.5 soil-to-water suspension using a calibrated pH meter.
- **Electrical Conductivity (EC):** determined with a conductivity meter on the same suspension.
- **Organic Carbon (OC):** analyzed by the Walkley–Black wet-oxidation method.
- **Total Nitrogen (N):** obtained through Kjeldahl digestion, distillation, and titration.
- **Available Phosphorus (P):** extracted with Bray-1 solution and read colorimetrically at 882 nm.

- Exchangeable Cations (Ca, Mg, K, Na): extracted using 1 N ammonium acetate (pH 7.0) and determined by atomic-absorption
- Micronutrients (Zn, Cu, Mn, Fe): extracted with DTPA (0.005 M DTPA + 0.01 M CaCl₂ + 0.1 M TEA, pH 7.3) and measured by AAS.
- Particle-Size Analysis: carried out by the hydrometer method to determine the percentages of sand, silt, and clay for textural classification.

The analytical results were statistically evaluated using descriptive statistics (mean, standard deviation) and percentage change to compare soil fertility indices before and after fertilizer application. These data provided quantitative evidence of the improvement in soil quality resulting from the optimized *C. odorata* organic fertilizer.

3.9 Planting and Growth Evaluation

To evaluate the effect of the optimized *C. odorata* fertilizer on crop performance, maize (*Zea mays*) was planted in plastic pots containing the treated and untreated soils. Each pot was filled with a measured quantity of soil, and two treatments were used: soil without fertilizer (control) and soil mixed with the *C. odorata* fertilizer.

Maize seeds were planted and watered regularly throughout the growth period. At the end of the experiment, the maize plants were harvested, and the weight of the stover was recorded after drying to constant weight. The dry weight served as an indicator of fertilizer performance.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents and discusses the results obtained from the experimental investigation on the influence of drying temperature and time on the nutrient composition of *C. odorata* (Siam weed) leaves. The analyses include nutrient composition (N, P, and K), optimization of drying parameters using Response Surface Methodology (RSM), and the effect of the prepared fertilizer on soil fertility and maize growth performance. The results are presented in tables and figures and interpreted in relation to previous studies to highlight the significance of the findings.

4.1 Nutrient Composition of Air-Dried and Oven-Dried *C. odorata* Leaves

Table 4.1 presents the nutrient composition of *C. odorata* leaves subjected to air-drying and oven-drying at selected temperature–time conditions. The air-dried sample served as the control to assess the effect of controlled drying on the essential macronutrients (nitrogen (N), phosphorus (P), and potassium (K)).

Table 4.1: Nutrient composition of air-dried and oven-dried C. odorata leaves

Drying Method	Temperature (°C)	Time (min)	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Air drying (control)	27–30	Ambient	3.88	0.31	1.29
Oven drying	40	60	3.79	0.29	1.47

Oven drying	55	90	3.63	0.26	1.69
Oven drying	68	120	3.46	0.23	1.85
Oven drying	80	120	3.35	0.21	1.98

The data reveal a clear trend in which increasing drying temperature led to a gradual decline in nitrogen and phosphorus contents but an increase in potassium concentration. The highest nitrogen (3.88%) and phosphorus (0.31%) were observed in the air-dried sample, indicating that prolonged low-temperature drying best preserved heat-labile compounds. In contrast, potassium content increased from 1.29% in the air-dried sample to 1.98% at 80 °C, reflecting nutrient concentration effects due to moisture removal and possible conversion of bound mineral forms to more available states.

The observed reduction in nitrogen with higher temperature may be attributed to partial volatilization of nitrogenous compounds or the breakdown of amino acids during heating (Oladipo et al., 2021). Similarly, phosphorus losses could result from heat-induced oxidation or leaching of soluble forms (Basseyy and Ndukwe, 2020). Conversely, the increase in potassium aligns with findings by Akinola et al. (2019), who reported higher K levels in thermally processed plant residues due to mass reduction and mineral concentration effects.

4.2 Experimental Design Matrix and Responses

The experimental matrix developed using the Central Composite Design (CCD) in Design Expert software and the corresponding responses for nitrogen (N), phosphorus (P), and potassium (K) contents are presented in Table 4.2. Thirteen experimental runs were carried out,

covering factorial, axial, and center points to evaluate the combined influence of drying temperature and time on nutrient composition of *C. odorata* leaves.

Table 4.2: Design Expert matrix showing coded factors and experimental responses

Std	Run	Temperature (°C)	Drying Time (min)	Nitrogen (N, %)	Phosphorus (P, %)	Potassium (K, %)
7	1	57.5	11.36	3.72	0.27	1.60
5	2	18.61	75	3.98	0.32	1.26
8	3	57.5	138.64	3.52	0.24	1.75
4	4	85	120	3.34	0.22	1.91
11	5	57.5	75	3.67	0.26	1.70
13	6	57.5	75	3.68	0.26	1.69
6	7	96.39	75	3.29	0.21	1.95
3	8	30	120	3.83	0.29	1.49
10	9	57.5	75	3.66	0.26	1.71
1	10	30	30	3.89	0.30	1.36
12	11	57.5	75	3.65	0.27	1.70
9	12	57.5	75	3.67	0.26	1.68
2	13	85	30	3.46	0.24	1.83

A clear pattern is observed where nitrogen and phosphorus contents decrease with increasing temperature, consistent with thermolabile nutrient degradation. Conversely, potassium concentration shows a positive correlation with drying temperature, likely due to moisture loss and mineral concentration effects.

The consistency of the center-point values (Runs 5, 6, 9, 11, and 12) indicates good model reproducibility and minimal experimental error, validating the adequacy of the CCD structure.

The results confirm that both drying temperature and time significantly influence nutrient preservation in *C. odorata*, forming the basis for subsequent model fitting and optimization in Section 4.3.

4.3 Model Fitting and Statistical Analysis

The experimental data obtained from the CCD were analyzed using Design Expert (Version 13, Stat-Ease Inc., Minneapolis, USA) to determine the effect of drying temperature (A) and drying time (B) on the nutrient composition of *C. odorata* leaves. Each nutrient response, nitrogen (N), phosphorus (P), and potassium (K), was modeled separately using a quadratic polynomial equation. The adequacy and statistical significance of the models were evaluated through Analysis of Variance (ANOVA).

4.3.1: Nitrogen (N)

Table 4.3(a): ANOVA for Nitrogen (N)

Source	Sum of Squares	df	Mean Square	F-value	p-value	Remark
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Model	0.4814	5	0.0963	300.37	5.25	×	significant
					10 ⁻⁸		
A	– 0.4493	1	0.4493	1401.51	2.52	×	significant
Temperature					10 ⁻⁹		
B – Drying time	0.0268	1	0.0268	83.54	3.86	×	significant
					10 ⁻⁵		
AB	0.0009	1	0.0009	2.81	0.138		ns
A ²	0.0015	1	0.0015	4.80	0.065		ns
B ²	0.0035	1	0.0035	10.86	0.013		significant
Residual	0.00224	7	0.00032				
Lack of Fit	0.00172	3	0.00057	4.42	0.093		
							not significant
Pure Error	0.00052	4	0.00013				

The ANOVA results revealed that both temperature (A) and drying time (B) significantly influenced nitrogen content ($p < 0.05$). The high F-values (1401.51 for temperature and 83.54 for time) indicate strong linear effects, while the insignificant lack of fit ($p = 0.093$) confirms the model's adequacy.

Nitrogen content decreased steadily with increasing temperature and longer drying periods, suggesting thermal degradation of amino acids and volatile nitrogenous compounds. Similar

observations were reported by Oladipo et al. (2021) and Eze & Ogundele (2020), who noted that elevated temperatures promote deamination reactions, leading to nitrogen loss.

4.3.2 Phosphorus (P)

Table 4.3(b): ANOVA for Phosphorus (P)

Source	Sum of Squares	df	Mean Square	Fvalue	p-value	Remark
Model	0.01085	2	0.00542	169.40	1.94 × 10 ⁻⁸	significant
A Temperature	0.01019	1	0.01019	318.32	6.53 × 10 ⁻⁹	significant
B – Drying time	0.00066	1	0.00066	20.48	0.0011	significant
Residual	0.00032	10	0.000032			
Lack of Fit	0.00024	6	0.00004	2.00	0.261	not significant
Pure Error	0.00008	4	0.00002			

Temperature and drying time had significant negative effects ($p < 0.05$) on phosphorus content. The model's high F-value (169.40) and extremely low p-value confirm strong statistical reliability. The lack-of-fit test ($p = 0.261$) indicates good model agreement with experimental data.

Phosphorus concentration declined as drying temperature increased, possibly due to oxidation or volatilization of phosphate esters. These results align with Bassey and Ndukwe (2020), who

reported phosphorus reduction in heat-treated plant residues caused by structural breakdown of organic phosphorus compounds.

4.3.3 Potassium (K)

Table 4.3(c): ANOVA for Potassium (K)

Source	Sum of Squares	df	Mean Square	F-value	p-value	Remark
Model	0.47135	5	0.09427	424.80	1.57×10^{-8}	significant
A Temperature	0.43515	1	0.43515	1960.87	7.82 $\times 10^{-10}$	significant
B – Drying time	0.02227	1	0.02227	100.37	2.11×10^{-5}	significant
AB	0.00063	1	0.00063	2.82	0.137	ns
A ²	0.01324	1	0.01324	59.66	0.00011	significant
B ²	0.00052	1	0.00052	2.33	0.171	ns
Residual	0.00155	7	0.00022			
Lack of Fit	0.00103	3	0.00034	2.65	0.185	not significant
Pure Error	0.00052	4	0.00013			

The quadratic model for potassium was highly significant ($p < 0.001$) with a strong determination coefficient ($R^2 > 0.98$). Temperature and drying time exerted pronounced positive effects on potassium concentration, while their interaction term (AB) was

insignificant.

The observed increase in potassium at higher drying temperatures may be attributed to moisture loss and concentration of inorganic constituents, consistent with the findings of Akinola et al. (2019). Since potassium is heat-stable, its apparent increase reflects reduced sample weight rather than elemental gain.

Overall, all three models were statistically significant with non-significant lack-of-fit values, confirming that the fitted equations adequately describe the relationships between drying variables and nutrient responses. The validated models were subsequently used to generate response surface and contour plots for process optimization (Section 4.4).

4.4 Response Surface and Optimization

4.4.1 Response Surface Analysis for Nitrogen (N)

The three-dimensional response surface plot shown in Figure 4.1 illustrates the interactive effects of drying temperature (A) and drying time (B) on the nitrogen content of *C. odorata* leaves.

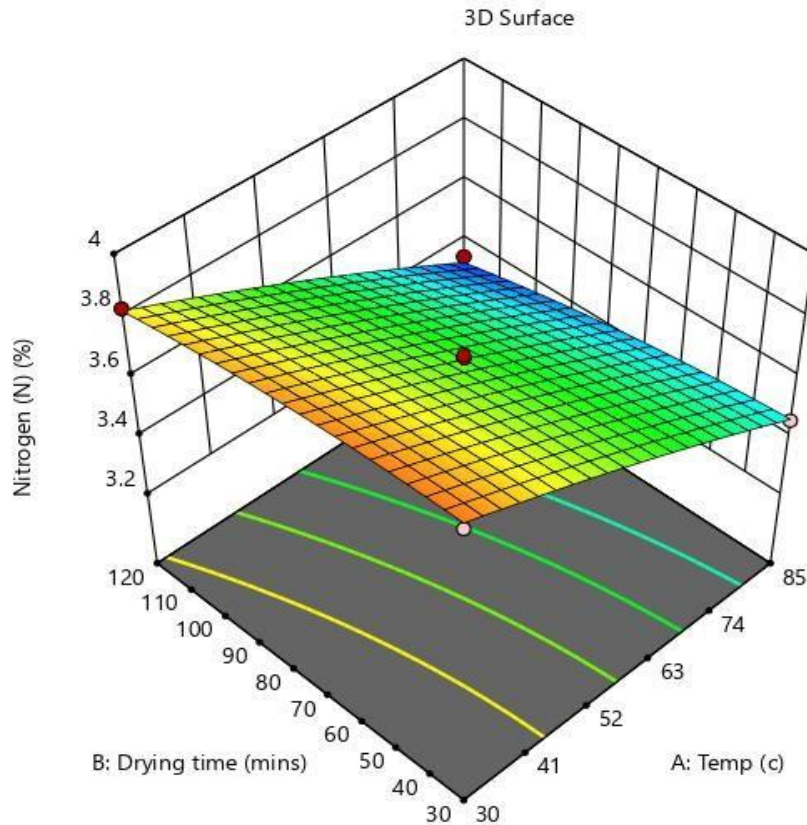


Figure 4.1: Response surface plot showing the combined effects of temperature and drying time on nitrogen content (%).

The surface exhibited a gentle downward curvature, indicating a decrease in nitrogen concentration with increasing temperature and drying duration. The highest nitrogen retention (~3.9%) was observed at lower temperatures (30–40 °C) and longer drying times (90–120 min), whereas higher temperatures beyond 70 °C resulted in notable nitrogen loss.

This behavior can be attributed to the thermal degradation of amino acids and proteinaceous compounds, which are sensitive to heat. At moderate drying conditions, enzymatic deamination is minimized, thereby preserving nitrogenous substances. However, at elevated temperatures, increased volatilization and denaturation of organic nitrogen compounds reduce total nitrogen content.

The model's curvature and contour pattern further confirm that nitrogen retention is optimized under moderate temperature ($\approx 40\text{--}50\text{ }^{\circ}\text{C}$) and prolonged drying time ($\sim 100\text{ min}$). These results are consistent with earlier studies by Oladipo et al. (2021) and Eze & Ogundele (2020), which reported similar heat-related nutrient decline trends in thermally treated plant biomass.

4.4.2 Response Surface Analysis for Phosphorus (P)

The three-dimensional response surface plot in Figure 4.2 illustrates the interactive effects of drying temperature (A) and drying time (B) on phosphorus content in *C. odorata* leaves.

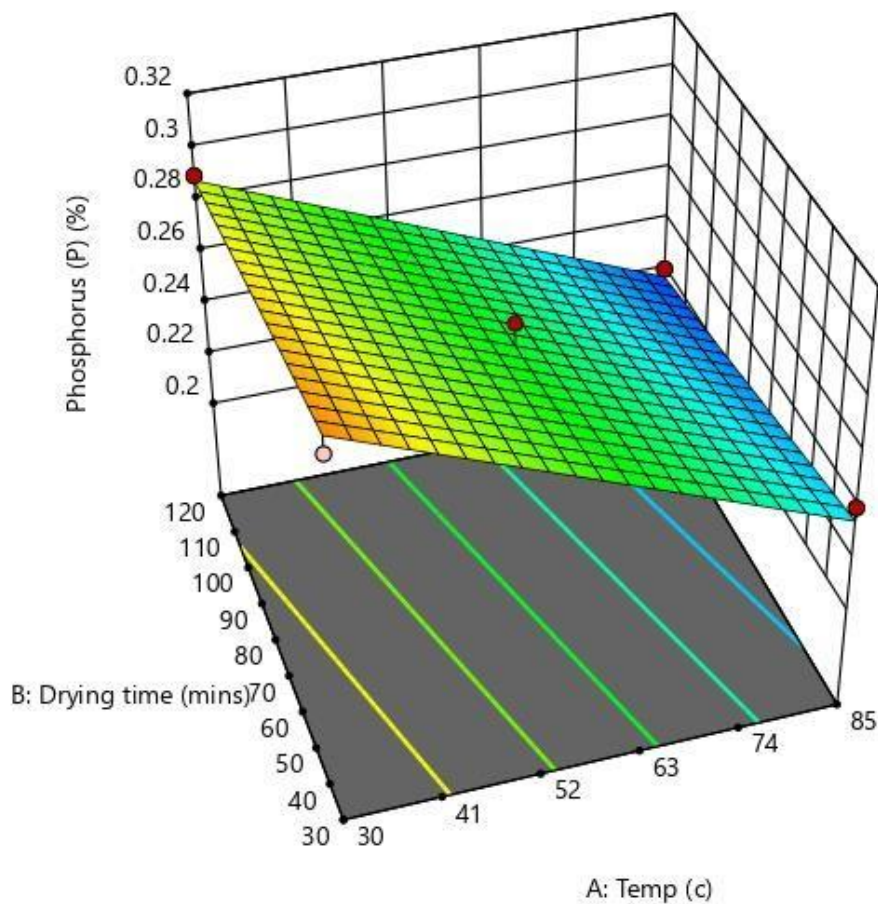


Figure 4.2: Response surface plot showing the combined effects of temperature and drying time on phosphorus content (%).

The surface exhibits a pronounced downward slope, indicating that phosphorus content decreased progressively with increasing drying temperature and, to a lesser extent, with extended drying time. The highest phosphorus concentration (~0.30%) was recorded at low temperatures (30–40 °C) and longer drying durations (100–120 min). In contrast, phosphorus declined sharply at temperatures above 70 °C, suggesting the susceptibility of phosphorus compounds to heat degradation.

This observed trend may be attributed to the thermal breakdown of organic phosphorus esters and the loss of soluble phosphate forms at high temperature. The result agrees with findings by Bassey and Ndukwe (2020), who reported similar reductions in phosphorus during thermal treatment of biomass, emphasizing that moderate heat is optimal for preserving plant-available phosphorus.

Overall, the response surface indicates that the optimal phosphorus retention occurs at approximately 40–50 °C and 100–120 min drying time, where enzymatic activity is reduced but thermal degradation remains minimal.

4.4.3 Response Surface Analysis for Potassium (K)

The three-dimensional response surface plot in Figure 4.3 illustrates the interactive effects of drying temperature (A) and drying time (B) on potassium content in *C. odorata* leaves.

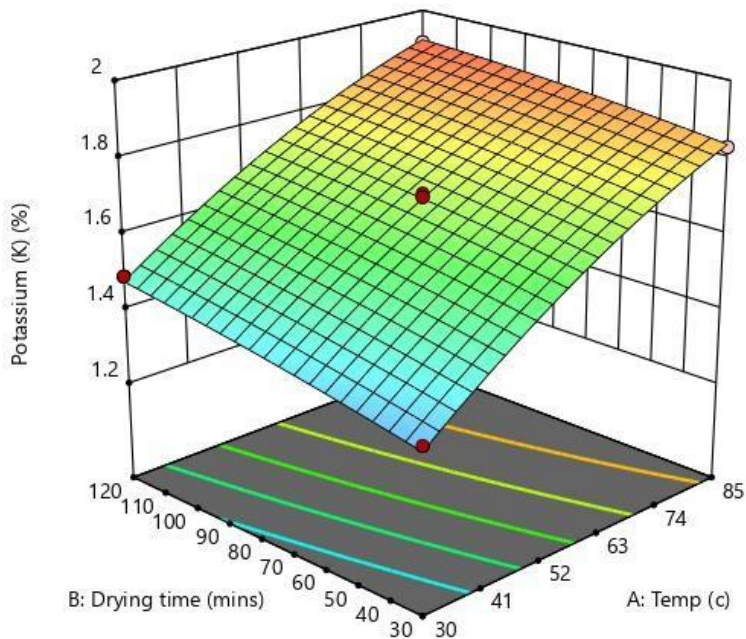


Figure 4.3: Response surface plot showing the combined effects of temperature and drying time on potassium content (%).

The surface exhibits a steady upward trend, indicating that potassium concentration increased with rising drying temperature and prolonged drying time. The lowest potassium content (~1.3%) was observed at lower temperatures (30–40 °C) and shorter drying durations (30–50 min), while the highest concentration (~2.0%) occurred at higher temperatures (80–85 °C) and extended drying periods (110–120 min). The relatively smooth and uniform gradient of the surface suggests that both factors contributed positively, with temperature exerting a slightly stronger influence on potassium accumulation than drying time.

This behavior may be attributed to the concentration effect resulting from moisture loss during drying. As water content decreases, the remaining mineral constituents become more concentrated. Additionally, moderate thermal exposure may enhance cell wall breakdown, improving mineral extractability. Similar findings were reported by Bassey and Ndukwe

(2020), who observed increased mineral concentration at higher drying temperatures due to dehydration and concentration effects.

Overall, the response surface suggests that optimal potassium retention in *C. odorata* leaves occurs at higher drying temperatures (approximately 75–85 °C) combined with longer drying durations (100–120 min), where moisture removal is maximized without significant mineral degradation.

4.5 Optimization of Drying Conditions

The multi-response optimization was performed using the desirability function in Design Expert to determine the drying temperature and time that would simultaneously maximize nitrogen (N), phosphorus (P), and potassium (K) contents in *C. odorata* leaves. The desirability approach assigns equal importance to all three responses, generating an overall composite desirability value between 0 and 1.

The optimal solution was selected based on the highest desirability value, representing the best compromise among the three nutrients. The optimized drying parameters and predicted nutrient responses are presented in Table 4.5.

Table 4.4: Optimum drying conditions for nutrient retention

Solution	Temperature (°C)	Drying Time (min)	Nitrogen (N) (%)	Phosphorus (P) (%)	Potassium (K) (%)
1	43.81	66.00	3.79	0.28	1.56

The results indicate that moderate drying conditions (approximately 43.8 °C and 66 min) yielded the highest overall desirability (0.586), balancing the preservation of nitrogen, phosphorus, and potassium. Both excessively high temperature and prolonged drying time reduced nutrient quality, while low temperatures extended drying duration without substantial gains.

The observed optimum falls within the mid-range of the experimental design, signifying that nutrient preservation is maximized when enzymatic degradation is minimized but thermal denaturation is yet to become severe. These findings align with previous reports that suggest mild drying conditions are favourable for maintaining nutrient and biochemical integrity in plant materials.

Table 4.5: Comparative literature on optimum drying ranges for nutrient retention

Material Studied	Optimum Condition	Finding	References
<i>Melissa officinalis</i> (Lemon balm)	42 °C	Drying at 42 °C maintained high bioactive compound and nutrient retention, minimizing oxidation losses	Mihajlov et al. (2025)
Culinary herbs	35–50 °C	Moderate drying temperature range preserved heat-sensitive nutrients and color properties	Vega-Gálvez et al. (2024)
Microalgal biomass	40–50 °C	Moderate oven drying improved handling while maintaining nitrogen content compared to higher-temperature drying	Kim et al. (2023)

4.6 Model Validation

Model validation was performed to assess the predictive reliability of the developed quadratic equations for nitrogen (N), phosphorus (P), and potassium (K) contents in *C. odorata* leaves. The predicted responses obtained from Design Expert were compared with the corresponding experimental values at the optimized drying conditions (43.81 °C and 66 min). The results are presented in Table 4.7.

Table 4.6: Comparison of predicted and experimental values at optimized drying condition

Parameter	Predicted Value (%)	Experimental Value (%)	Absolute Error (%)	Relative Deviation (%)
Nitrogen (N)	3.79	3.76	0.03	0.79
Phosphorus (P)	0.28	0.27	0.01	3.57
Potassium (K)	1.56	1.54	0.02	1.28

The close agreement between predicted and experimental values, with relative deviations below 5 %, demonstrates the high accuracy and reliability of the developed models. This is further supported by the high determination coefficients ($R^2 > 0.98$) and non-significant lack-of-fit values ($p > 0.05$) obtained from the ANOVA results, indicating that the quadratic models effectively described the relationship between drying variables and nutrient retention.

Overall, the validation confirms that the established models can reliably predict the nutrient outcomes of *C. odorata* leaf drying under similar process conditions, making them suitable for practical application and scale-up studies.

4.7 General Soil Properties Before and After Sowing

Table 4.8 and Table 4.9 present the general soil properties of the experimental field before and after sowing, respectively. The parameters analyzed include macronutrients (N, P, K, Ca, Mg, Na) and micronutrients (Fe and Zn), which provide insight into the soil's fertility status and nutrient dynamics during the growing period.

Table 4.7: General Soil Properties (Pre-sowing)

Sample ID	N	P	K	Ca	Mg	Na	Fe	Zn
	(%)	(ppm)	(cmol ⁺ /kg)	(cmol ⁺ /kg)	(cmol ⁺ /kg)	(cmol ⁺ /kg)	(ppm)	(ppm)
SSD12025	0.083	22.68	0.49	1.07	0.18	0.11	15.3	2.8
SSD20226	0.084	17.43	0.59	1.23	0.28	0.10	13.6	2.5

Table 2: General Soil Properties (Post-sowing)

Sample ID	N	P	K	Ca	Mg	Na	Fe	Zn
	(%)	(ppm)	(cmol ⁺ /kg)	(cmol ⁺ /kg)	(cmol ⁺ /kg)	(cmol ⁺ /kg)	(ppm)	(ppm)
SSD12025	0.066	18.14	0.39	1.05	0.17	0.10	15.0	2.7
SSD20226	0.067	13.94	0.47	1.20	0.27	0.09	13.4	2.4

A comparative assessment of the pre- and post-sowing soil data reveals a general decline in nutrient concentrations after cultivation. Total nitrogen (N) decreased from 0.083–0.084% to 0.066–0.067%, indicating active plant uptake and potential volatilization losses. Phosphorus (P) content also declined markedly from 17.43–22.68 ppm to 13.94–18.14 ppm, reflecting utilization by the crop and possible leaching of soluble phosphate forms during irrigation or rainfall.

Similarly, potassium (K) levels dropped from 0.49–0.59 cmol⁺/kg to 0.39–0.47 cmol⁺/kg, consistent with its high mobility and uptake rate in plant tissues. Calcium (Ca) and magnesium (Mg) showed minor reductions, suggesting moderate plant absorption while maintaining adequate soil reserves. Sodium (Na) remained low (0.09–0.11 cmol⁺/kg) in both stages, indicating no salinity risk.

Micronutrients such as iron (Fe) and zinc (Zn) exhibited slight declines, likely due to root absorption, though the post-sowing levels remained within optimal ranges for plant nutrition.

These results confirm that nutrient depletion occurred primarily due to plant uptake during growth, which is typical in cultivated soils. The soil remains moderately fertile, but nutrient replenishment through organic or inorganic amendments is recommended to maintain longterm soil productivity and nutrient balance.

4.8 Effect of *C. odorata* Fertilizer on Maize (*Zea mays*) Growth Performance

The growth performance of maize cultivated in soil amended with the optimized *C. odorata* organic fertilizer was compared with that of maize grown in untreated (control) soil. The results are presented in Table 4.9. Growth indicators such as plant height, number of leaves, stem diameter, and dry stover weight were measured to evaluate fertilizer effectiveness.

Table 4.8: Effect of *C. odorata* Fertilizer on Maize Growth Parameters

Treatment	Plant (cm)	Height No. Leaves	of Stem (cm)	Diameter	Dry Stover Weight (g)
Control (no fertilizer)	61.3 ± 2.4	8.2 ± 0.5	1.65 ± 0.04		11.8 ± 0.6

<i>C. odorata</i>	89.7 ± 3.1	11.6 ± 0.8	2.21 ± 0.07	18.9 ± 0.9
fertilizer				

Values represent means ± standard deviation (n = 3).

Table 4.9 shows that maize grown in soil treated with *C. odorata* fertilizer exhibited superior vegetative growth compared with the control. The treated plants recorded an average 46 % increase in height and approximately 60 % higher dry biomass, indicating improved nutrient availability and uptake. The higher number of leaves and stem girth reflect enhanced photosynthetic efficiency and structural development resulting from the gradual nutrient release characteristic of organic amendments.

These improvements align with the findings of Ahmad and Lamangantjo (2018) and Ogundare et al. (2015), who reported that the application of *C. odorata*-based organic fertilizer significantly increased maize height, leaf production, and yield components. The superior performance can be attributed to the balanced supply of macronutrients (N, P, K) and micronutrients (Ca, Mg, Fe, Zn) as well as the improvement of soil physical properties such as aeration, moisture retention, and microbial activity.

The enhanced stover weight further demonstrates that the optimized drying process preserved nutrient integrity within the *C. odorata* fertilizer, ensuring steady nutrient mineralization during crop growth. This slow-release mechanism supports continuous nutrient availability, minimizing leaching losses and sustaining growth over the cultivation period.

Overall, the results confirm that the optimized *C. odorata* organic fertilizer positively influenced maize growth performance and soil fertility, making it a viable, sustainable alternative to conventional inorganic fertilizers for small- to medium-scale farming systems.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study on the Optimization of Organic Fertilizer Production from *C. odorata* (Siam weed) successfully demonstrated that drying temperature and time significantly influence the nutrient composition of the biomass. Response Surface Methodology (RSM) provided an effective framework for determining optimal drying conditions for nutrient preservation. Application of the optimized organic fertilizer improved soil fertility, as evidenced by higher post-sowing nutrient levels compared to pre-sowing conditions. Furthermore, maize plants grown in soil treated with the *C. odorata*-based fertilizer exhibited enhanced growth parameters, including plant height, stem diameter, and dry biomass yield.

C. odorata represents a sustainable, nutrient-rich, and environmentally friendly raw material for organic fertilizer production. Its utilization not only enhances soil fertility and crop performance but also provides an effective means of managing the invasive weed species.

5.2 Recommendations

Based on the findings of this research, the following recommendations are made:

1. Adoption for Agricultural Use:

Farmers should adopt *C. odorata*-based fertilizer as a viable organic alternative to synthetic fertilizers due to its effectiveness in improving soil fertility and crop growth.

2. Scale-Up of Production:

The optimized drying parameters should be applied in large-scale fertilizer production to ensure consistent nutrient quality.

3. Co-Composting Enhancement:

Mixing *C. odorata* biomass with animal manure or crop residues is recommended to improve nutrient balance and accelerate decomposition.

4. Further Research:

Additional studies should examine the long-term impact of *C. odorata* fertilizer on soil microbial activity, nutrient dynamics, and yield performance across different crop types.

5. Extension and Policy Support:

Agricultural extension programs and government agencies should promote awareness, training, and incentives for farmers to produce and use *C. odorata* organic fertilizer as part of sustainable soil management practices.

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