PROJECT REPORT

2024

PROJECT TITLE

Green Hydrogen Applications in Fertilizer Production in Namibia

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About the Report

Climate change remains a significant issue in Africa, making it essential to adopt new approaches. Namibia, a country in Southern Africa, has a population of about 3 million and a land mass of approximately 825,615 square kilometers. The nation is severely impacted by climate change, facing intense drought and minimal rainfall. In response, Namibia is exploring smart climate technologies to cope with these challenges.

Blessed with high solar irradiance and wind, Namibia has substantial renewable energy resources and a coastline along the Atlantic Ocean. With these assets, the country is considering hydrogen production from water using renewable energy, coining the term "green" hydrogen. As a predominantly arid nation, Namibia aims to produce green fertilizers in the form of ammonium sulfate from this green hydrogen while extracting nitrogen from the atmosphere. This initiative positions Namibia to achieve food self-sufficiency and potentially export fertilizers to regional and global markets. The project is divided into four categories:

1. **Extraction of Ammonia from Animal Manure**: Animal manure is rich in ammonia and is commonly used as fertilizer due to its ability to enhance soil nitrogen levels. However, nitrogen often escapes into the atmosphere or is not effectively taken up by plants. It is crucial to establish techniques for effectively extracting ammonia and converting it into ammonium sulfate.
2. **Evaluation of Organic Material Composts**: This project compares various organic composts with commercially available fertilizers to assess their effectiveness.
3. **Mechanical Design and Energy Efficiency of Green Ammonia Production**: This project focuses on optimizing the design of the Haber-Bosch process for producing green ammonia from hydrogen and nitrogen.
4. **Economic Feasibility Analysis**: We analyzed the economic viability of the anticipated green ammonia-based fertilizers compared to existing commercial options.

Overall, the project was a success. We extracted ammonia from manure and synthesized "renewable ammonium sulfate fertilizer," confirming its pH properties while pending further chemical analyses. We also assessed the effectiveness of various composts through testing on potatoes. Additionally, we examined the Green Ammonia Haber-Bosch design, its effective parameters, and its potential for success in Namibia. Lastly, we conducted an economic feasibility study and are drafting a manuscript for policy advice and publication purposes.

We want to extend our gratitude to 3'E for Africa for this opportunity. Our students obtained academic qualifications through this project, which has positively impacted communities and the government. Furthermore, they have been absorbed into large green hydrogen projects in Namibia, an opportunity created by 3'E for Africa. Our objective is to continue working on these projects due to their immense potential to improve the lives of many Namibians through enhanced agriculture, food security, and economic opportunities.

List of Abbreviations

GH2 – Green Hydrogen

H2 – Hydrogen

UNAM – University of Namibia

NMU – Nelson Mandela University

UP – University of Pretoria

NUST – Namibia University of Science and Technology.

About 3'E for Africa

3 E's 4 Africa e.V. is a non-profit association and carries out activities and projects to promote education of African students and researchers. Furthermore, the association is dedicated to the empowerment of the above-mentioned African students and researchers at universities in Africa and to the Ecofriendliness of the funded research projects. The name **3 E's 4 Africa** originates from these three pillars.

Biography of the Students

Dr. Simeon Hamukoshi (Project Lead)

Qualifications: PhD Chemistry (NMU), MSc Chemistry (NMU), BSc Honours Organic Chemistry (NMU), BSc Honours Chemistry and Geology (UNAM), BSc Water Utilization Engineering (UP).

Dr Simeon Hamukoshi is a Researcher at the National Commission on Research Science and Technology, the Namibia Green Hydrogen Research Institute and a Lecturer at the University of Namibia. He was a team leader on the project and also a co-supervisor. Dr Hamukoshi managed to ensure that the project objectives on time and also guided the students to ensure that a quality report is put together.

Mr. Seuna Pendukeni Paulus

Qualifications: MSc Agriculture (Crop Sciences) candidate, BSc Honours Agriculture (Crop Sciences).

Mr Seuna Paulus is currently in his final year MSc in Agricultural (Crop) Sciences at UNAM Ogongo campus. He was responsible for project 1 which was on Extraction of Ammonia from manure for ammonium sulphate synthesis. Mr Seuna is also a student leader at the University.

Mr. Leonard Tsheehama

Qualifications: MSc Logistics and Supplies Chain Management, Economics (NUST), BSc Business Management Honours (NUST). BSc Logistics and Supplies Chain Management, Economics (NUST). Mr Leornard Tsheehama is a Procurement officer and also a partime research consultant. Leonard was responsible with for the Economic feasibility study of green ammonia based fertilizers in Namibia. Leonard managed to get the desired findings from initially cnductiong inperson survey, writing a report and following up on the recommendations by sharing awareness.

Ms. Maria Nekandu

Qualifications: MSc Agriculture (Crop Sciences) candidate, BSc Honours Agriculture (Crop Sciences).

Ms Nekandu is a hardworking and dedicated professional. Ms Maria was responsible for trying of various fertilizer materials on potatoes to determine which fertilizer is ideal for potato growth. She is very knowledgeable and the project was blessed to have her.

Mr. George Hamukoshi

Qualifications: BSc Honours Mechanical Engineering (UNAM).

Mr George Hamukoshi is a Mechanical Engineer by profession who was responsible for the mechanical and energy efficiency design of the ammonia Haber borsch reactor. George currently works on green hydrogen related projects and he is also employed as a mechanical operator at a local manufacturing and design workshop.

CHAPTER 1: AN OVERVIEW OF ENERGY EFFICIENCY AND DESIGN FOR GREEN AMMONIA PRODUCTION VIA THE HABER BOSCH REACTOR

Abstract

This study focuses on the production of green hydrogen through electrolysis, which is vital for sustainable ammonia synthesis via the Haber-Bosch process. Green hydrogen, derived from renewable sources, is preferred due to its environmental benefits, contrasting with hydrogen from fossil fuels, which results in grey and blue variants. The Haber-Bosch process synthesizes ammonia, crucial for fertilizers that support nearly half the global population, but it is energy-intensive, consuming 1-2% of the world's energy supply and contributing significantly to CO_2 emissions.

The objectives of this research include evaluating the overall efficiency of the Haber-Bosch process, analyzing the specific functions of reactor components—especially catalysts, identifying effective catalysts for optimizing ammonia production, and proposing energy-efficient approaches utilizing renewable energy sources. Key process parameters, such as pressure, temperature, and feedstock ratios, are critical for optimizing ammonia synthesis.

This study emphasizes the importance of iron-based catalysts, which provide effective nitrogen activation and stability, while exploring alternative catalysts like cobalt, nickel, and ruthenium. The research aims to enhance ammonia synthesis efficiency and sustainability while addressing challenges related to energy input and the costs associated with electrolysis and renewable energy integration.

Key words: Green Hydrogen, Ammonia Synthesis, Haber-Bosch Process, Electrolysis, Renewable Energy, Catalysts, Energy Efficiency, CO_2 Emissions, Sustainable Fertilizers, Energy Storage Solutions.

1.1. Introduction

1.1.1. Green Hydrogen and Green Ammonia

Hydrogen, one of the least produced chemical elements, can be generated through electrolysis (**Fig. 1**), which splits water into hydrogen and oxygen using electric current [1]. It powers fuel cells in electric vehicles and is a key component in fertilizers and chemicals. Producing hydrogen from renewable sources like wind and solar energy is preferred for its environmental benefits, leading to its designation as "green" hydrogen. In contrast, hydrogen from fossil fuels results in grey and blue hydrogen; grey hydrogen emits carbon dioxide, while blue hydrogen captures it, though it is costlier [2]. The production of green hydrogen is expected to rise due to decreasing renewable energy costs and the need for integrating variable power supplies.

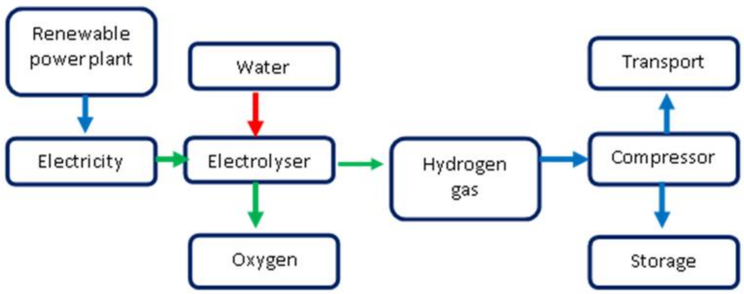


Figure 1: Schematic diagram for green hydrogen production via electrolysis.

Ammonia (NH_3) is essential in agricultural fertilizers that support nearly half of the global population [3].The Haber-Bosch process synthesizes ammonia by reacting nitrogen (N_2) and hydrogen (H_2) under high pressure and temperature, often utilizing renewable energy. With a high hydrogen density of 17.8 wt%, ammonia is also valuable as a fuel for vehicles, ships, and power generation [4]. This highlights a shift toward sustainable energy solutions. Green ammonia production involves three key stages: 1) Electrolysis to produce hydrogen from water; 2) Air separation to extract nitrogen; 3) The Haber-Bosch process to combine N_2 and H_2 into NH_3. This section (**Fig. 2**) details each stage of the green ammonia production process.

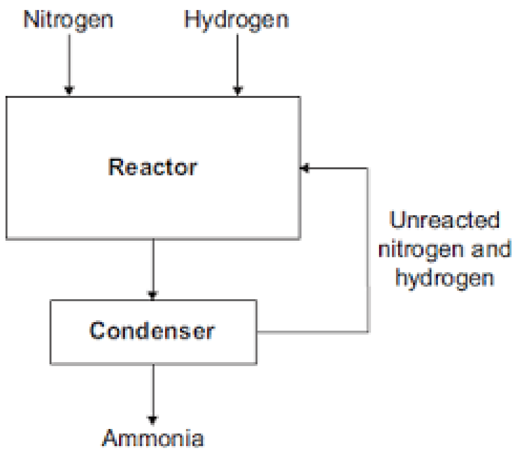


Figure 8: Schematic diagram for green ammonia production via Haber Bosch reactor.

1.1.2. Problem Statement

The production of ammonia via the Haber-Bosch process is highly energy-intensive. As Namibia explores the use of renewable energy sources to power this process, it is crucial to consider energy-efficient approaches. Reducing energy consumption not only lowers the cost of ammonia production but also minimizes the need for high-strength materials, resulting in a more sustainable and economically viable process.

1.1.3. Aims and Objectives

1. Evaluate the Haber-Bosch Reactor Process: Assess the overall efficiency and effectiveness of the Haber-Bosch process for ammonia production.
2. Analyze Component Functions: Examine the specific functions of each component within the reactor, with a particular focus on the role of catalysts.
3. Identify Effective Catalysts: Determine the most effective catalysts for optimizing ammonia production.
4. Recommend Energy-Efficient Approaches: Propose strategies for enhancing energy efficiency in the Haber-Bosch process, utilizing renewable energy sources.

1.2. Requirements engineering

1.2.1. Engineering design

The Haber-Bosch process requires precise engineering design and optimization for efficient, cost-effective ammonia production. Due to its complexity, careful monitoring is essential for product quality, safety, and sustainability. Key requirements include high-pressure vessels capable of withstanding 150 to 300 atmospheres for optimal reaction conditions [5]. Reactor design ensures effective mixing and contact of reactants, enhancing kinetics and thermodynamics. Selecting catalysts improves reaction rates and selectivity while ensuring stability. Energy management strategies focus on heat integration and power generation to enhance cost-effectiveness [6]. Gas separation and purification methods, such as distillation and absorption, are vital for ammonia recovery. Lastly, safety measures prevent explosions and detect leaks, minimizing risks. These elements are fundamental to the successful operation of the Haber-Bosch process which are also properly summarised in **Table 1** below.

Table 1: Engineering Requirements for the Haber-Bosch System.

Aspect	**Description**
High-Pressure Vessels	Engineered to withstand pressures of 150 to 300 atmospheres for optimal reaction conditions.
Reactor Design	Ensures proper mixing and contact of reactants, optimizing reaction kinetics and thermodynamics.
Catalysts	Selected to enhance reaction rates, selectivity, and ensure long-term stability.
Energy Management	Involves strategies for heat integration and power generation to enhance cost-effectiveness.
Gas Separation and Purification	Essential for ammonia recovery, utilizing technologies like distillation and absorption.
Safety Considerations	Includes measures for explosion prevention and gas leak detection to mitigate risks.

Ammonia Yield assesses the efficiency and economic viability of the Haber-Bosch process, while Selectivity measures the percentage of nitrogen and hydrogen converted to ammonia, aiding in cost reduction for separation [7]. Energy Efficiency impacts operating costs and environmental effects, and Catalyst Activity and Stability ensure consistent performance [8]. Equipment Reliability is vital for safety under high pressures, and evaluating Safety and Environmental Impact helps mitigate risks related to reactive gases. Together, these KPIs (**Table 2**) offer a comprehensive view of the process's effectiveness and sustainability.

Table 2: Key Performance Indicators of the Haber-Bosch Process

Parameter	**Description**
Ammonia Yield	Amount of ammonia produced per unit of reactants; critical for efficiency and economics.
Selectivity	Percentage of nitrogen and hydrogen converted to ammonia; important for reducing separation costs.
Energy Efficiency	Affects operating costs and environmental impact; essential for process viability.
Catalyst Activity and Stability	High performance ensures consistent operation and efficiency.
Equipment Reliability	Necessary to maintain safety and efficiency under high pressures and temperatures.
Safety and Environmental Impact	Critical to minimize risks associated with reactive gases.

The essential operating conditions for the Haber-Bosch process, which are critical for optimizing ammonia production, are highlighted in **Table 3**. The process typically operates at pressures ranging from 150 to 300 bar and temperatures between 400 and 550°C, balancing reaction rates with catalyst stability. A standard hydrogen to nitrogen feedstock ratio of 3:1 influences both yield and safety [9], [10]. Iron-based catalysts are commonly used, with their effectiveness affected by factors such as concentration and particle size [11]–[13]. Residence time varies according to reactor design; while longer residence times can enhance yield, they also increase the risk of catalyst deactivation. Additionally, gas purification techniques, including absorption and distillation, are vital for achieving high ammonia purity and ensuring the quality of the final product [12], [14]. Together, these conditions enhance the overall efficiency of the Haber-Bosch process.

Table 3: Effective Operating Conditions

Condition	**Typical Values**	**Description**
Pressure	150 to 300 bar	Influences yield and energy input.
Temperature	400 to 550°C	Balances reaction rate and catalyst stability.
Feedstock Ratio	3:1 hydrogen to nitrogen	Affects yield and safety considerations.
Catalyst Type	Iron-based (common)	Performance impacted by concentration and particle size.
Residence Time	Varies based on reactor design	Longer times may increase yield but risk catalyst deactivation.
Gas Purification	Methods like absorption/distillation	Essential for achieving high ammonia purity.

The process parameters for the Haber-Bosch process are essential for optimizing ammonia synthesis. Pressure, critical for yield and selectivity, typically ranges from 150 to 300 bar. Temperature is maintained between 400 and 550°C, significantly affecting reaction kinetics and catalyst performance [9], [10]. The nitrogen to hydrogen feedstock ratio is vital for overall reaction efficiency. Catalyst type and concentration options include iron, ruthenium, cobalt, and nickel also influence reaction rates [15]–[17]. Optimizing gas velocity and residence time is necessary for achieving desired outcomes. Effective gas purification methods are required to separate ammonia from unreacted gases, ensuring product quality. Lastly, energy input is crucial for maintaining the high pressure and temperature needed, directly impacting operational costs. Together, these parameters are integral to the successful operation of the Haber-Bosch process, as shown in the **Table 4** below.

Table 4: Process Parameters

Parameter	**Description**
Pressure	Affects yield and selectivity; typically between 150 and 300 bar.
Temperature	Operates between 400 to 550°C, impacting reaction kinetics and catalyst performance.
Feedstock Composition	The ratio of nitrogen to hydrogen affects reaction efficiency.
Catalyst Type and Concentration	Critical for reaction rate, with variations including iron, ruthenium, cobalt, and nickel.
Gas Velocity and Residence Time	Optimize to achieve desired reaction rates and selectivity.
Gas Purification	Essential for separating ammonia from unreacted gases, using various methods.
Energy Input	Required to maintain high pressure and temperature, influencing operational costs.

1.3. Catalysts

Reactions in ammonia synthesis can take a considerable amount of time without a catalyst [8]. The Haber-Bosch process, developed in the early 20th century, is the primary industrial method for producing ammonia, a vital component in fertilizer production [3]. This process combines nitrogen from the air with green hydrogen generated from water through electrolysis [2], currently supporting nearly half of the world's population. However, it is also one of the most energy-intensive industrial processes, consuming approximately 1-2% of the global energy supply and significantly contributing to CO_2 emissions[18], [19].

At the heart of the Haber-Bosch process is an iron-based catalyst, which has been the focus of ongoing research and optimization. These efforts aim to reduce the energy intensity of the process while maintaining or enhancing ammonia yield. This optimization is essential not only for minimizing the environmental impact of ammonia production but also for improving its economic viability in an increasingly energy-conscious world. The figure below illustrates the reaction of nitrogen and hydrogen in a Haber-Bosch reactor using iron as a catalyst.

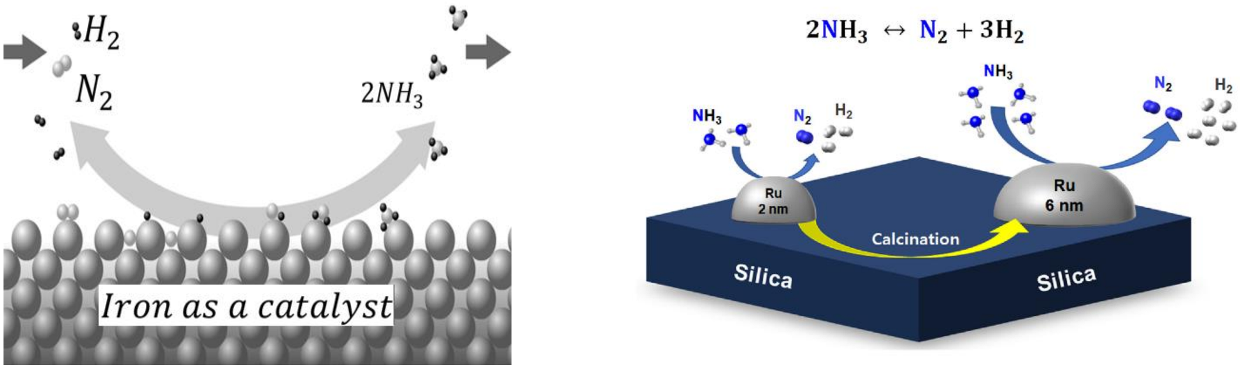


Figure 1: Reaction between Nitrogen and Hydrogen in the presence of iron and ruthenium as a based catalyst [20], [21].

1.3.1. Iron-Based Catalysts Composition for the Haber-Bosch Process

The composition of iron-based catalysts used in the Haber-Bosch process is critical for optimizing their performance. The primary component is iron (Fe), which makes up 90-95% of the catalyst, typically in the form of magnetite (Fe_3O_4) or reduced to α-Fe. Various promoters enhance the catalyst's properties: Aluminium Oxide (Al_2O_3) constitutes 4-10% and serves as a structural promoter, increasing both surface area and stability. Calcium Oxide (CaO) and Magnesium Oxide (MgO), also comprising 4-10%, improve mechanical strength and contribute to a longer catalyst lifespan, respectively. Potassium Oxide (K_2O) and Cesium Oxide (Cs_2O), each at 0.5-2%, function as electronic promoters that enhance electron donation to adsorbed nitrogen (N_2). Additionally, silica is noted as an optional component[22]–[24]. This specific composition is essential for optimizing catalyst performance in ammonia synthesis.

Table 5: The chemical composition of iron-based catalysts used in the Haber-Bosch process, presented in a diagrammatic format.

Component	**Type**	**Weight Percentage**	**Function**
Iron (Fe)	Primary Component	90-95%	Active component, typically as magnetite (Fe_3O_4) or α-Fe after reduction
Promoters			

- Aluminium Oxide (Al_2O_3)	Structural Promoter	4-10%	Enhances surface area and stability
- Calcium Oxide (CaO)	Structural Promoter	4-10%	Improves mechanical strength
- Magnesium Oxide (MgO)	Structural Promoter	4-10%	Increases catalyst lifespan
- Potassium Oxide (K_2O)	Electronic Promoter	0.5-2%	Enhances electron donation to adsorbed N_2
- Cesium Oxide (Cs_2O)	Electronic Promoter	0.5-2%	Similar function to K_2O
Optional Components			
- Silica			

1.3.2. Factors that make iron-based catalysts particularly suitable for the Haber-Bosch process:

Iron-based catalysts are ideal for the Haber-Bosch process due to their effective nitrogen activation, optimal binding energies, and stability under high temperatures and pressures. When promoted with materials like Al_2O_3 and CaO, they enhance surface area and electron donation, aiding bond cleavage [25]. These catalysts are cost-effective, abundant, and highly selective for ammonia formation while minimizing side reactions. Their ability to regenerate extends their operational lifespan, maintaining their critical role despite ongoing research into alternatives that have yet to match their industrial effectiveness.

In contrast, cobalt, nickel, and ruthenium-based catalysts offer distinct advantages and challenges. Cobalt catalysts enable effective nitrogen activation at lower temperatures but are limited by higher costs and the dominance of iron. Nickel is more abundant and cost-effective, showing good selectivity for ammonia, though it may deactivate over time. Ruthenium catalysts are highly active and energy-efficient, operating at lower temperatures and pressures, but their high cost and supply issues hinder wider use. Ongoing research aims to improve ammonia synthesis efficiency and sustainability by maximizing the benefits of these alternative catalysts while addressing their limitations[26]–[28].

Table 5: Catalyst Options for the Haber-Bosch Process

Catalyst	Advantages	Temperature Sensitivity	Resistance to Poisons	Cost	Yields and Efficiency	Challenges
Cobalt	Effective N_2 activation, lower operating temperatures, good stability with support	Operates at lower temperatures than iron	Better resistance to sulfur compounds	Higher than iron	Potentially higher ammonia yields per pass	Higher cost limits adoption, extensive optimization of iron catalysts
Nickel	Effective N_2 activation, lower energy requirements, good stability	Operates at lower temperatures than iron	Resistance to certain poisons	More abundant, cost-effective	High selectivity towards ammonia formation	Lower overall activity in some conditions, sensitive to carbon deactivation
Ruthenium	Extremely high activity, lower temperatures and pressures, high	Operates efficiently at lower temperatures and pressures	Excellent resistance to common poisons	Very high	Higher ammonia yields per pass, reduces need for	High cost and limited supply, mass transfer limitations

	resistance to poisons				gas recycling	in large reactors

1.4. Green Ammonia Production Performance and Cost

The most advanced Haber-Bosch plants achieve an energy conversion rate of 8 MWh per ton of ammonia, while ammonia itself has a net calorific value of 5.2 MWh per ton, resulting in an energy efficiency of 65% [29]. The energy required to produce hydrogen through electrolysis accounts for over 90% of the total energy input [30]. Additionally, the capital cost for electrolysis equipment is significant, estimated at around 1 million USD per megawatt (MW) of capacity. The established alkaline electrolysis technology is already highly optimized, leaving little room for future cost reductions. In contrast, the proton exchange membrane (PEM) electrolyzer, with its higher current density, presents opportunities for cost reduction and ongoing research aimed at efficiency optimization [31]. Another major challenge for green ammonia production is the reliance on intermittent renewable energy sources, such as wind and solar, to power both the high-temperature electrolyzer and the continuous Haber-Bosch process [32]. This reliance necessitates energy storage solutions, which can significantly increase capital costs.

Table 4: Water & Energy Input Estimates for Green H-B Process.

Water & Energy Inputs Required	**Qty**	**Units**
Energy for electrolysis*	50	MWh per ton H2
Energy for H-B process	1.2	MWh per ton NH3
Water required for hydrolysis	1.8	Tons H2O per ton NH3
Energy required for sea water desalination	3 – 5	kWh per ton H2O
Energy required for air separation	80	kWh per ton N2

CHAPTER 2: APPLICATION AND ECONOMIC VIABILITY OF GREEN AMMONIA FOR EFFECTIVE CROP YIELD AND NUTRIENT RETENTION.

Abstract

This project addresses challenges in using animal manure as a nitrogen-rich fertilizer in Namibia and Southern Africa, such as inefficient nitrogen absorption and ammonia emissions. We utilized PTFE membrane technology and sulfuric acid to extract ammonia from cattle manure, producing a renewable ammonium sulfate-based fertilizer. Despite issues with low pressure in the PTFE system, the acid-base titration method yielded promising results. Our goal is to scale production of this sustainable fertilizer at competitive prices, empowering communities to produce their own fertilizers for improved crop yields. The project has received significant support at conferences, advancing sustainable agricultural practices.

Keywords: Animal Manure, Nitrogen-Rich Fertilizer, Namibia, Southern Africa, PTFE Membrane Technology, Ammonia Emissions, Ammonium Sulfate, Sustainable Agriculture, Crop Yields, Acid-Base Titration.

2.1. Introduction

Animal manure is rich in nitrogen, making it an effective fertilizer for plants worldwide [33], [34]. In Namibia and Southern Africa, cattle and goat manure is typically applied to fields just before the rainy season to support the growth of crops such as maize and millet. This practice has significantly enhanced soil fertility and improved agricultural yields. However, several challenges hinder its effectiveness. One major issue is that nitrogen is not always effectively absorbed by plants, and they may also take in unwanted materials present in the manure, negatively impacting both plant growth and food quality [35], [36]. Additionally, ammonia often escapes into the atmosphere during application, contributing to greenhouse gas emissions and exacerbating climate change [36], [37].

To address these challenges, this project explored two innovative approaches which are the extraction of ammonia from cattle manure involves utilizing polytetrafluoroethylene polymer (PTFE) membrane technology [38], [39] and the use of an acid-based reaction between manure extract and sulphuric acid. The extracted product is then termed renewable ammonium sulfate-based fertilizer. The product was chemically characterized to confirm its composition and will now be produced in larger quantities for testing on crops to determine its effectiveness compared to conventional manure and commercial fertilizers. This initiative is part of a Master's degree program in Agriculture for participating students and has been presented to the department for approval. The results have also been shared at various conferences and community engagements, receiving substantial support.

The goal is to produce this fertilizer on a large scale and sell it to farmers at a lower price than commercial alternatives. Additionally, communities will be trained to produce their own fertilizers, enabling them to grow their crops more effectively.

2.1.1. Problem Statement

Despite the benefits of using animal manure as a nitrogen-rich fertilizer in Namibia and Southern Africa, several challenges undermine its effectiveness. Nitrogen is often not efficiently absorbed by plants, and unwanted materials in the manure can negatively impact plant growth and food quality. Additionally, ammonia released during application contributes to greenhouse gas emissions, exacerbating climate change. Addressing these issues is essential for maximizing the benefits of manure while minimizing its environmental impact.

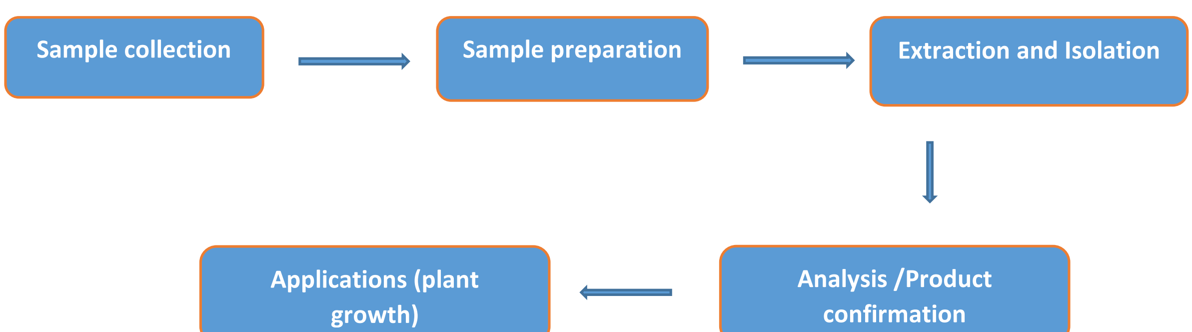
2.1.2. Aims

To develop an environmentally sustainable process for extracting ammonia from cattle manure using renewable energy, directly synthesizing it into ammonium sulfate crystals, and creating a high-quality fertilizer product.

2.1.3. Objectives

1. Design and implement an efficient ammonia extraction system powered by renewable energy derived from cattle manure.
2. Develop a direct titration method to synthesize ammonium sulfate from the extracted ammonia and sulfuric acid.
3. Ensure the quality of the produced ammonium sulfate by verifying its pH falls within the range of 5-6.

2.2. Experimental



2.2.1. Extraction using Polytetrafluoroethylene Polymer (PTFE) membrane technology

2.2.1.1. Sample collection and sample preparation

Manure (225 g) was dissolved in 250 mL of tap water and the solution mixture was filtered using the vacuum filtration machine to obtain a dark gray filtrate and brown solid residue (**Fig. A** and **B**). The pH of the filtrate was measure as 7.35 and about 150 mL was poured into a 500 mL jar with a polytetrafluoroethylene (EPTFE) membranes submerged in it.

Figure 4: (A) Cattle Manure; (B) Manure dissolved in water and filtered using a vacuum pump.

2.2.1.1.1. Extraction and Isolation

The extraction setup was completed, consisting of two separate jars: an alkaline manure jar and an acidic jar. The system also includes a peristaltic pump, a battery, and a pH meter. When the battery is activated, the pressure generated by the pump pushes the liquid manure through a permeable membrane into the acidic jar, which is equipped with a PTFE membrane that facilitates the escape of ammonia. As ammonia enters the acidic jar, the pH level increases, as summarized in **Table 5** below.

Figure 6: (A) A student setting up the PTFE extractor: (B) A complete PTFE set up with manure extraction in progress.

Table 5: below shows the change in pH of the prepared sulphuric acid solutions as ammonia diffused into the acid jar through the ePTFE membrane.

Acid concentration (M)	Initial pH	Final pH	Time (hours)
2	1.54	1.89	26
3	1.78	1.90	31
4	2.10	2.43	43

2.2.1.1.2. Analysis and product confirmation

The results indicate an increase in the pH of the acidic solution, suggesting ammonia diffusion into the solution. However, the experiment faced challenges in maintaining prolonged operation due to factors such as the low-pressure pump used, which limited the diffusion rate, and batteries that typically died within 24 hours, resulting in pH stabilization or even decrease.

Literature supports the expected formation of ammonium sulfate crystals around a pH of 5-6. Future adjustments, such as preparing an acidic solution with a pH of approximately 4.5 and utilizing a higher-pressure pump with efficient batteries, are anticipated to facilitate crystal formation

2.2.1.2. Extraction of Renewable Ammonium sulfate from Manure using Titration Methods

2.2.1.2.1. Sample collection, sample preparation, extraction and Isolation

Sample collection and preparation methods were consistent with those used in the PTFE section. The extraction process began with the preparation of a 25 M sodium hydroxide solution (200 g dissolved in 200 mL of water). Meanwhile, 225 g of manure was mixed with 250 mL of tap water and filtered through a vacuum filtration system, producing a dark gray filtrate and brown solid residue.

Next, 100 mL of the NaOH solution was combined with 100 mL of diluted cattle manure. This mixture was heated to 100°C and boiled for 2 hours to convert ammonia into ammonium hydroxide. A membrane connected the reaction flask to a new 250 mL flask placed in an ice bath, which collected approximately 100 mL of the ammonium hydroxide vapour, as illustrated in **Figure 7** below.

Figure 7: (A) The process of converting Ammonia into Ammonium hydroxide; (B) Titration process to form Ammonium sulfate by means of Crystal formation; (C) Flask placed in ice to induce the production of Crystals.

Solutions of sulfuric acid at concentrations of 0.1 M, 0.01 M, and 0.001 M were prepared. Approximately 20 mL of each solution was added dropwise to 100 mL of ammonium hydroxide solution while boiling at 100°C with continuous stirring until a white precipitate formed (**Figure 7B).** The beaker containing the precipitate was then placed in an ice bath to induce crystallization (**Figure 8A**). The resulting product was filtered to obtain a white precipitate (**Figure 8B**).

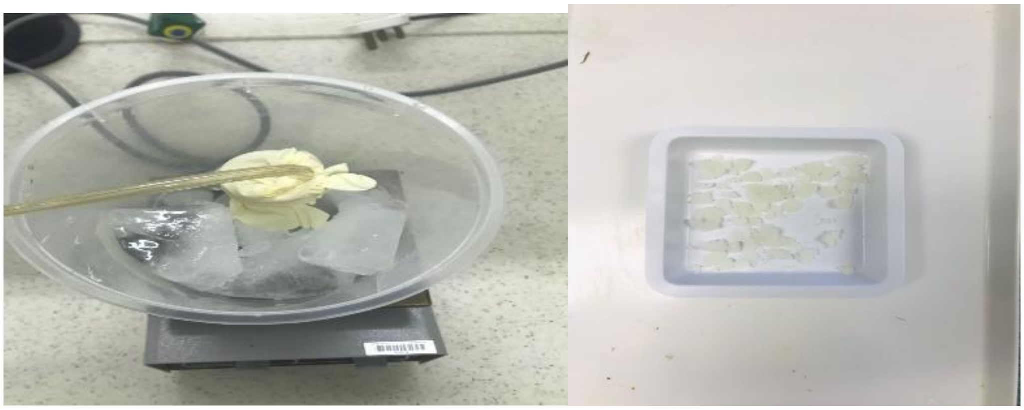


Figure 8: (A) Inducing crystals; (B) White Crystals (Ammonium Sulfate)

2.3. Conclusion

This project highlights the potential of converting cattle manure into a renewable ammonium sulfate-based fertilizer through innovative ammonia extraction methods. By addressing nitrogen inefficiency and ammonia emissions, we aim to enhance sustainable agriculture in Namibia and Southern Africa. While initial trials with PTFE membrane technology showed promise, acid-base titration yielded better results. Future work will involve chemical analysis to confirm product quality and purity, followed by applications on potatoes and tomatoes. Once verified, we will develop a market introduction strategy, empowering local communities to produce affordable fertilizers and improving crop yields and food security in the region.

PROJECT 3: EFFECT OF DIFFERENT NITROGENOUS FERTILIZERS ON GROWTH AND YIELD OF DIFFERENT POTATO VARIETIES

ABSTRACT

The study evaluated the effectiveness of six nitrogenous fertilizers on four potato cultivars Spunta, Barcelona, Rainbow, and Nicola at UNAM Ogongo Campus during the 2023 winter-summer cycle. Namibia imports over 30% of its potatoes annually due to low yields, prompting this research to identify optimal fertilizers for boosting local production. The fertilizers tested were UREA, potassium nitrate, UREA and super phosphate, NPK, vermicompost, and compost, arranged in a completely randomized blocked factorial design, resulting in 28 treatments. Results showed significant differences among fertilizers and potato varieties, with Rainbow producing the highest marketable tubers (0.76 kg/m^2) and total tubers (1.114 kg/m^2). Potassium nitrate enhanced chlorophyll content, while NPK improved plant height.

Keywords: Nitrogenous Fertilizers, Potato Cultivars, UNAM Ogongo Campus, Local Production, UREA, Potassium Nitrate, NPK, Marketable Tubers.

3.1. Introduction

Potato (Solanum tuberosum L.), a member of the Solanaceae family, is the third-most important food crop globally, following rice and wheat [40]. In Namibia, potatoes are vital, providing essential nutrients like potassium and dietary fiber [41]. They deliver more calories and vitamins than crops such as sweet potatoes [42]. However, Namibia's average potato yield is just 14,328 tonnes, significantly below its potential [43].

Potatoes are particularly sensitive to nutrient stress due to their sparse root system, necessitating adequate fertilization for optimal yields [44]. Nitrogen (N) is crucial for potato growth and development; insufficient N results in pale yellow leaves, reduced plant size, and early leaf drop, ultimately leading to lower yields and fewer tubers. Proper nitrogen fertilization enhances photosynthesis, maximizing energy production [45].

Soil fertility significantly influences potato yield, with newer cultivars requiring more fertilizer than traditional ones [46], [47]. However, high fertilizer costs often hinder farmers' ability to meet these needs [46], [47]. Research indicates that applying nitrogen, phosphorus (P), and potassium (K) can boost potato production, with nitrogen promoting mineral uptake, vegetative growth, and dry matter accumulation.

Due to low domestic production, Namibia imports a substantial quantity of potatoes from neighboring countries [43]. This study aims to evaluate the effectiveness of various nitrogenous fertilizers on different potato varieties, providing recommendations for optimal fertilization to enhance local potato yields.

3.1.1. Problem statement

Namibia imports over 30% of its potatoes annually due to poor crop yields and low local production [43]. Farmers are using various fertilizers, but their yield potential remains largely unknown. Furthermore, there is limited information on the effects of nitrogenous fertilizers on the growth and yield of different potato varieties in Namibia. Therefore, this study aims to evaluate the impact of various nitrogenous fertilizers on the yield and growth of these potato varieties.

3.1.2. Objectives

To evaluate the effect of different nitrogenous fertilizers on the growth and yield of potatoes.

1. To compare the yield of potatoes under different nitrogenous fertilizers.
2. To select the best-performing potato variety under different nitrogenous fertilizers.
3. To recommend the best performing nitrogenous fertilizer and potato variety.

3.2. Methodology

3.2.1. Study area

Research experiment was carried out at the UNAM Ogongo Campus experimental field from July to September 2023. The field is located at latitude -17.6784°, or 17° 40’ 42” south, and longitude 15.2967°, or 15° 17’ 48” east. The annual precipitation range is between 350 and 500 mm, and temperature generally ranges.

3.2.2. Experiment design and treatment

The study focused on the growth of four potato cultivars of French origin - Spunta, Barcelona, Rainbow, and Nicola - grown at UNAM Ogongo Campus under local agro-ecological conditions during the 2023 winter-summer cropping cycle. Six different nitrogenous fertilizers were compared: urea (CH_4N_2O), potassium nitrate (KNO_3), a combination of urea and calcium dihydrogen phosphate ($CH_4N_2O + Ca(H_2PO_4)_2$), NPK, vermicomposting, and compost.

The experimental design included 28 treatments, consisting of six fertilizers, four cultivars, and a control, arranged in a completely randomized, blocked factorial design. The total experimental area was 588 m², comprising 84 plots (**Figure 9**). The fertilizers used were urea (45% N), superphosphate (P), potassium nitrate, and ammonium nitrate (2:3:2 NPK). Application rates were 43.6 kg/ha for nitrogen, 20.6 kg/ha for phosphorus, 26.6 kg/ha for potassium, and 5 tons/ha for compost and vermicomposting.

Figure 9: (A) Chemical based fertilizers; (B) Students preparing the field for Potato growth.

3.3. Results and discussion

This chapter presents the outcomes of the data collected during the research aimed at Evaluating the Effect of different nitrogenous fertilizers on the growth and yield of different potato varieties at the University of Namibia, Ogongo campus, in the Omusati region.

ANOVA shows that there is a significant difference in plant height, spad value, Number of stems, small-size tuber weight, total tuber weight, and marketable tuber weight. There was no significant difference in baby-size tuber weight, medium-size tuber weight, large-size tuber number, medium-large-size tuber number, and rotten tuber weight.

3.1.1. The effect of Nitrogenous fertilizer on the growth of potato-selected varieties

Both potato variety and fertilizer type significantly affected the stem number per hill ($P > 0.05$). Notably, compost had a pronounced positive effect on the growth of the Spunta variety. This observation is consistent with previous studies that demonstrated the influence of nitrogen application rates on potato stem numbers [48]–[50].

Fertilizer type also had a significant influence on plant height ($P < 0.05$). The highest average plant height was recorded in the plots treated with NPK, while the lowest was observed in another treatment of which the results are in alignment with previously reported data[51]–[53]. Additionally, indicated that plant height is strongly correlated with tuber yield (**Figure 10**).

Fertilizer type influenced the SPAD value, which measures chlorophyll content. The highest average SPAD value was recorded for plots treated with potassium nitrate, while the lowest was observed for compost. Several studies have reported similar findings, indicating that the impact of nitrogenous fertilizers on SPAD values can vary based on factors such as plant species, soil conditions, and environmental factors [54]–[56].

Figure 10: Potatoes plant with bright leaves during inspection.

3.1.2. The effect of Nitrogenous fertilizers on the yield and quality of selected potato varieties

Potato variety significantly influenced small-sized tuber weight ($P < 0.05$), with Rainbow producing the highest weight and Spunta the lowest, indicating that Spunta is best for seed production. These findings align with previously reported results which noted genetic control over small-sized tuber yield [57].

Similarly, potato variety significantly affected marketable tuber weight ($P < 0.05$), with Rainbow again yielding the highest weight and Spunta the lowest. This supports the conclusion that Spunta is ideal for seed production (**Fig. 11**).

ANOVA analysis of total tuber weight revealed significant differences among varieties, with the F-statistic exceeding the critical F-value at a 0.05 significance level, and the p-value confirming these differences are statistically significant. Overall, the study indicates substantial variations in total tuber weight among the treatment groups.

Figure 11: Students harvetsing potatoes and conducting the required analysis

3.4. Conclusion

In conclusion, the study demonstrated that different nitrogenous fertilizers significantly impacted the growth and yield of various potato varieties, with notable improvements in stem numbers, SPAD values, plant height, small tuber weight, total tuber weight, and marketable tuber weight. NPK and potassium nitrate were particularly effective, with Rainbow producing the highest number of marketable potatoes and the greatest weight of small-sized tubers, making it the best choice for commercial farmers. These findings reinforce the recommendation to tailor nitrogen fertilizer applications to specific crop and soil conditions, enhancing overall agricultural productivity.

PROJECT 4: APPLICATION OF GREEN AMMONIA DERIVATIVES IN FERTILIZERS FOR EFFECTIVE CROP YIELD AND NUTRIENT RETENTION AS WELL AS THEIR ECONOMIC VIABILITY.

Abstract

Namibians in Omaheke, Omusati, Kavango, Hardap, Otjozaondupa and other regions across the country depend on agriculture activities for food and financial means. This study aimed to explore the application of green ammonia derived fertilizers for effective crop yield and nutrient retention and their economic viability in Namibia using a qualitative research methodology and a sample of 30 individuals with diverse agricultural experience. The study found that the participants preferred conversional (chemical) based traditional fertilizers because they believe they are better for the ecosystem and the soil. All the participants agreed that chemical fertilizers enhance soil quality and raise crop production. However, it became evident that individuals might not be able to use these type of fertilizers to its full potential due their high cost. The existence of green ammonia-based fertilisers was however not well known by the farmers. The participants were curious to find out more about green ammonia and observe its practical applications in the agricultural space. The results indicated that the mentioned regions would be ideal for testing and applying green ammonium based fertilizers. Farmers in these area and around Namibia should be given more information about green ammonia based fertilisers and perhaps even a demonstration of their advantages and how they work, as they are more environmentally friendly and effective. The study further recommends that the regions be encouraged to use green fertilizers as an alternative approach and to educate more people about the advantages and uses of green ammonium-based fertilisers in order to close the knowledge gap. Furthermore, it is imperative to promote policy measures that could result in lower fertilizer pricing if the regions maximize the benefits of fertilizers and long-term agricultural techniques.

Keywords: Namibia, Green Ammonia, Fertilizers, Crop Yield, Nutrient Retention, Economic Viability, Qualitative Research, Agricultural Experience, Chemical Fertilizers, Soil Quality, Environmental Sustainability, Farmer Education, Policy Measures.

4.1. Introduction

Global attention is drawn to sustainable farming practices due to population growth, climate change, and the need to produce more food. Namibia's economy and way of life depend heavily on its agricultural industry. Chemical fertilizer and traditional farming such as the application of manure have been linked to environmental and soil-related issues. As part of this plan, a feasibility study on the application of green ammonium derived fertilizers will be carried out to determine its potential to increase agricultural yields, retain more soil nutrients, and improve the soil quality and improve the social and economic activities in Namibia.

Increasing food production through agricultural activities while mitigating environmental impacts for the ever increasing global population has been a challenge lately. Conversional fertilizers have been applied however they are faced with ecological risks such as soil degradation, water pollution and greenhouse gas emissions. Green ammonium derived fertilizers coupled with soil amendments presents less environmental impacts from their production to their respective applications. Green ammonia is described as ammonia that is entirely produced using environmentally safe water, air, and renewable energy sources. Its primary derivative ammonium surphate is a source of nitrogen in fertilizers. It is important that soil amendments are coupled to the fertilizers so that nutrients are not lost through volatilization, leaching, and agricultural waste.

The application of effective green ammonium based fertilizers have the potential to mitigate productivity, environmental and economic challenges currently faced by chemical and traditional based fertilizers. These fertilizers can be affordable to locally since Namibia will be producing the critical raw material which is green hydrogen. Namibia holds to produce green hydrogen at much cheaper price due to the availability of water and renewable energy sources such as wind and solar. To date, there are four pilot projects which will be producing green hydrogen and subsequently green ammonia. There is also an availability of surphuric acid production by a local copper smelter mine. The two products (green ammonia and surphuric acid) are reacted to form green ammonium surphate.

Namibia is a semi-arid country and agriculture plays a significant role in the national economy and the way of life for a large portion of the population. Numerous sectors, including the agricultural industry, are looking into how they might exploit the nation's enormous potential for renewable energy, especially solar electricity [58]. By the use of various agricultural practices, the Omusati, Omaheke, Kavango, Otjozondjupa and Kunene Regions in Namibia are home to most of the country's crop production. However, low food production results from poor fertilization and infertile soils [59]. Namibians farmers in these regions use manure as fertilizers while some of them apply conventional fertilizers. However, the later are considered are costly, hard to locate, and challenging to apply correctly [60].

Green ammonia-based green fertilizers have the potential to be Namibia's best long-term option for increasing crop yields and maximizing the use of renewable energy sources. Green ammonia based fertilizers will also improve and importantly reduce greenhouse gas emissions and environmental protection during their production [61]. Namibia will adopt more profitable and sustainable agricultural practices that will benefit lawmakers, farmers, and the agriculture industry overall. In this study, the perception of green ammonium based fertilizers will be examined. Additionally, amicable solutions to address the existing knowledge gap on green ammonia based fertilizers will be identified. It's important to ensure that this new green ammonium based fertilizers are utilized effectively by plants hence the study will also provide currently utilized materials or soil amendments used with fertilizers. Lastly, the study will cover the economic performance of conversional fertilizers in comparison to the new green ammonia based fertilizers.

4.1.1. Problem Statement

Efforts to enhance nitrogen consumption efficiency, decrease waste, and minimize ecological harm demonstrate a collective commitment to making agriculture more sustainable and environmentally conscious [62]. However, integrating green ammonia into long-term, carbon-free solutions poses challenges that require innovative solutions. Improved electrolysis techniques are crucial for efficient green hydrogen generation which minimizing environmental impact by utilizing renewable energy sources. Additionally, advancements in catalysts for ammonia production from hydrogen and nitrogen are essential to enhance efficiency and durability in the Haber-Bosch process. These efforts are part of a larger initiative aimed at increasing the effectiveness and sustainability of green ammonia production.

Furthermore, safety considerations regarding the handling, storage, and transportation of ammonia are paramount. Strong containment systems and stringent safety measures are necessary to safeguard workers and the environment. Developing safe and reliable storage and transportation methods is crucial to gaining public and governmental trust in the viability of green ammonia. Despite these challenges, the numerous advantages of green ammonia, such as its dual role as a carbon-free fuel and a sustainable nutrient source, make it an attractive option for environmentally friendly solutions. With proper research, innovation, and regulatory support, green ammonia has the potential to significantly contribute to global sustainability efforts. It represents a dynamic path towards achieving sustainability and carbon neutrality, exemplifying the collective global endeavor towards a more sustainable future [63].

4.1.2. Objectives

- Assess Fertilizer Preferences and Practices
- Investigate the Economic Challenges of Fertilizer Use
- Explore the Potential of Ammonia-Based Green Fertilizers
- Evaluate Community-Based Adoption Strategies
- Develop and Test Green Fertiliser Innovations:
- Examine the Impact of Education and Awareness Programs
- Analyze the Potential for Sustainable Agricultural Practices
- Identify Barriers and Opportunities for Fertiliser Adoption

4.2. Methodology

4.2.1. Research Methodology and Designed

4.2.1.1.Research Design

This study used both qualitative and quantitative methods to better understand green ammonia-based fertilizers. Quantitative analysis will compare crop yields and nutrient retention with traditional fertilizers, while qualitative research will explore potential issues and perspectives from focus groups. Combining these approaches provides a comprehensive view for informed policy recommendations.

4.2.1.2.Research Methods

The research plan includes surveys, field testing, and interviews to evaluate green ammonia-based versus traditional fertilizers. By comparing their effects on crop yield and soil nutrients, and gathering farmers' opinions and expert insights, the study aims to assess the economic feasibility and potential barriers of adopting green ammonia-based fertilizers.

4.2.1.3.Population of the Study

The population of this study consisted of crop producers from the Omusati, Omaheke, Kavango, Otjozondjupa, and Kunene Regions of Namibia. Additionally, agricultural extension officers, policymakers, and agro-industry representatives from the region will be included in the population.

4.2.1.4.Sampling and Sample Size

Farmers were selected using stratified random sampling for a representative sample across different farming systems. Sample size was determined using the Krejcie and Morgan (1970) table. For stakeholder interviews, a purposive sampling technique was used to identify key participants with significant experience in Northern Namibia’s agricultural sector.

4.2.1.5.Data Collection Instruments

A semi-structured interview guide was the data-gathering tool for the stakeholder interviews. The interview guide was designed to gather information about the perceived economic feasibility of fertilisers based on ammonia and green waste, possible obstacles to their acceptance, and suggestions for a successful launch [64].

4.2.1.6.Data Collection Procedure

Stakeholder interviews were conducted to obtain data. The researchers visited the chosen farms and other pertinent areas to conduct the interviews. All ethical principles, including informed permission and confidentiality, were respected during the data collection process [64].

4.2.1.7.Data Analysis Techniques

Data from stakeholder interviews were collected, coded, and thematically analyzed using NVivo software. This process involved transcribing interviews, categorizing, and analyzing differing viewpoints on the financial sustainability and barriers to green ammonia-based fertilizers. Thematic analysis identified key themes, patterns, and insights, enhancing understanding of the economic and ecological benefits and challenges.

4.2.1.8.Research ethics

The research on the social and economic effects of switching to environmentally friendly ammonia-based fertilizers adhered to strict ethical standards. Informed consent was obtained from all participants, ensuring they understood the study's goals and their rights. Anonymity was preserved, with data securely stored and only accessible to the research team. The study was conducted transparently, with all findings and procedures presented honestly, and potential conflicts of interest disclosed. Ethical concerns included the study's societal impact and cultural sensitivity, ensuring respect and dignity for all participants. The research aimed to contribute ethically sound and relevant insights to sustainable agriculture.

4.2.2. Study area

The Study sampled 31 participants with a diverse range of backgrounds. Statistics show that only one participant is between the ages of 25 and 34, while most participants are between 18 and 24. Based on this age distribution, the region appears to have a youthful population involved in farming or farming-related intellectual pursuits.

The participants represent a diverse range of farming experiences. Some say they have four or five years of experience in horticulture, while others declare they have five years of agricultural experience. Someone claimed to be completely ignorant of farming. This breadth of knowledge offers us several fresh ideas that help us better understand the challenges and farming methods in the Omusati, Omaheke, Kavango, Otjozondjupa, and Kunene Regions.

One person indicated a special interest in agriculture, while other participants identified as academics. Because it demonstrates their interest in and inclination towards agriculture, which is necessary for the successful implementation of contemporary methods in the agricultural sector of the Omusati, Omaheke, Kavango, Otjozondjupa and Kunene Regions, the involvement of students in this study is vital.

Study participants were assigned code names to preserve their privacy and guarantee the accuracy of the data. Using the collected personal data, the ideas and remarks of the participants can be connected to the study's overall framework. Insight into the region's vibrant and possibly innovative agricultural society is offered by the participants' young population and diverse educational and professional agrarian backgrounds.

4.3. Results and discussion

4.3.1. Demographic Information

The study sampled 31 participants with varied backgrounds, revealing a predominantly youthful population engaged in farming or farming-related intellectual pursuits. The majority of participants are between the ages of 18 and 24, with only one participant in the 25-34 age range.

4.3.2. Age Distribution of Participants

Table 1: Age Distribution of Study Participants

Age Range	Number of Participants	Percentage (%)
18-24	30	97%
25-34	1	3%

Participants' farming experience varies widely: some have four to five years in horticulture, others have five years in agriculture, and one participant reported no prior farming knowledge. This diversity in experience provides a broad perspective on the challenges and methods used in the Omusati, Omaheke, Kavango, Otjozondjupa, and Kunene regions.

Table 2: Farming Experience of Study Participants

Experience Level	Number of Participants	Percentage (%)
0 years	1	3%
1-4 years	10	32%
5+ years	20	65%

The sample also includes individuals with different interests and roles, such as one participant with a special interest in agriculture and others identified as academics. The involvement of students and academics is particularly significant as it reflects their engagement with contemporary agricultural methods and their potential contribution to the sector.

Figure 3: Participants' Roles and Interests

Role/Interest	Number of Participants	Percentage (%)
Special Interest in Agriculture	1	3%
Academic	4	13%
General Participants	26	84%

To ensure privacy and data accuracy, participants were assigned code names. The collected data provides valuable insights into the region's dynamic agricultural landscape and highlights the diverse educational and professional backgrounds of the participants.

4.3.3. Theme 1: Perceptions and Experiences with Traditional and Inorganic Fertilizers

Participants expressed a strong preference for organic fertilizers over inorganic ones, citing concerns about environmental damage and health risks associated with synthetic options. They believe organic fertilizers enhance soil health and crop productivity by improving soil composition, water retention, and microorganism growth. Participant ERTNAM1 encapsulated this view, stating, "Traditional fertilizer is safer than artificial; it improves soil structure and is better for the environment." Despite these advantages, the high cost of conventional fertilizers presents a significant challenge. Participants are often faced with the decision between cheaper, riskier inorganic fertilizers and more expensive, safer organic alternatives. Financial constraints are a recurring concern, with participants noting the high expense of fertilizers and a lack of awareness about affordable, eco-friendly options like ammonia-based fertilizers.

In addition to cost concerns, participants acknowledged the benefits of conventional fertilizers in improving crop productivity and soil structure. Organic matter in these fertilizers enhances soil permeability and nutrient retention, crucial for plant growth, while inorganic fertilizers are associated with nutrient loss. Participant ERTNAM3 highlighted, "Traditional fertilizer improves soil structure and is safer than artificial," and Participant ERTNAM29 added, "Traditional fertilizers greatly improve soil health." Overall, the study indicates a clear preference for organic fertilizers due to their safety and ecological benefits, despite their higher cost. This preference underscores the need for more affordable, eco-friendly alternatives, as financial constraints impact optimal fertilizer use and crop health. Participants' insights reflect a broader concern for sustainable farming practices and the need for solutions that balance environmental and economic considerations.

4.3.4. Theme 2: Awareness and Reception towards Green Ammonia-based Fertilizers

The study revealed a significant gap in awareness regarding green ammonia-based fertilizers among participants. Most were unfamiliar with this type of fertilizer, as reflected in responses such as, "No, I have not tried or heard of it before," from Participant ERTNAM5, and similar statements from Participants ERTNAM6 and ERTNAM7. This lack of knowledge suggests a reliance on traditional fertilizers and highlights the need for increased exposure to alternative, sustainable options. Despite this general unfamiliarity, there is some curiosity about green ammonia-based fertilizers. Participant ERTNAM31, for instance, noted, "I would have to read up on it, but there was talk about green ammonia being very environmentally friendly," indicating a growing recognition of its potential benefits.

To address this knowledge gap, participants suggested practical solutions. Participant ERTNAM8 recommended providing samples to help visualize and understand the new fertilizers, stating, "It should come with a few samples so that we can see how it looks like." Similarly, Participant ERTNAM9 expressed a need for more detailed information, noting, "I am curious but need much more information. If people understand this, they will go for it." These suggestions reflect a willingness to explore new technologies if given sufficient information. Targeted educational programs and practical demonstrations could bridge this gap and promote the adoption of green ammonia-based fertilizers, leading to more sustainable farming practices in the Omusati, Omaheke, Kavango, Otjozondjupa, and Kunene regions.

4.3.5. Theme 3: Role and Engagement in Agricultural Practices within the Omusati, Omaheke, Kavango, Otjozondjupa, and Kunene Regions

Participants in the study displayed a diverse range of agricultural engagements, largely driven by the need to provide food for their families and communities. For instance, Participant ERTNAM10 described their involvement in backyard gardening to support their household and inspire others in the Omusati Region. Similarly, Participant ERTNAM11 emphasized their role in food provision and community encouragement for farming as a means to contribute to the local economy. Some participants, like ERTNAM12, are engaged in more structured agricultural activities, such as researching pesticide effectiveness, while others, like ERTNAM13, have a long-standing tradition of farming from childhood, encompassing livestock rearing and crop cultivation. Financial considerations, particularly regarding the cost of fertilizers, emerged as a significant factor affecting agricultural practices. Participant ERTNAM14 noted the expense of fertilizers and their impact on farming decisions. Additionally, Participant ERTNAM28 described their small-scale operation focused on direct sales, and ERTNAM30 and ERTNAM29 highlighted the challenges of adopting new agricultural practices and the need for education and support to promote green ammonia-based fertilizers.

The study underscores the varied roles and challenges faced by farmers in the Omusati, Omaheke, Kavango, Otjozondjupa, and Kunene Regions. From backyard gardening to research and community-based farming, participants' activities reflect a broad spectrum of engagement in agriculture. Financial constraints and the need for education about new practices, such as green ammonia-based fertilizers, were significant themes. The findings suggest a strong need for targeted interventions, including awareness campaigns and practical demonstrations, to support the adoption of sustainable agricultural practices. Addressing these challenges through community-focused education and support could enhance farming practices and contribute to more sustainable and economically viable agriculture in these regions.

4.4. Conclusion

The study conducted across the Omusati, Omaheke, Kavango, Otjozondjupa, and Kunene Regions reveals a complex landscape of agricultural practices, highlighting a clear preference for traditional fertilizers among participants. This preference is rooted in the belief that conventional and organic fertilizers are safer and more beneficial for soil health and environmental sustainability. The participants consistently valued the organic matter in traditional fertilizers for its positive impact on soil structure, water retention, and microbial activity, which enhances soil health and agricultural productivity. Despite this, high costs associated with conventional fertilizers present a significant challenge. Many participants find it difficult to afford these fertilizers and face the dilemma of choosing between cheaper, riskier inorganic options and more expensive, safer organic alternatives. Additionally, a lack of awareness about affordable, green ammonia-based fertilizers further complicates decision-making.

On the other hand, the limited use and recognition of green ammonia-based fertilizers present both a challenge and an opportunity. The study indicates that while these fertilizers are still emerging, they offer a promising, environmentally friendly, and cost-effective alternative to traditional and inorganic options. The potential benefits of ammonia-based green fertilizers, such as reduced farming costs and improved environmental sustainability, could be substantial if farmers are provided with adequate information and guidance. Given the community-based nature of agriculture in these regions, there is significant potential for the adoption of green fertilizers if supported by education and collaborative efforts. The study suggests that a community-focused approach, combined with research and practical demonstrations, could facilitate the transition to more sustainable fertilization practices, ultimately enhancing regional food security and agricultural sustainability.

5. Recommendations

5.1. Recommendation 1: Initiate Large-Scale Education and Awareness Campaigns

As part of our feasibility study, one of the key recommendations was to conduct an awareness campaign among farmers about green hydrogen and green ammonium-based fertilizers. This initiative aimed to educate both small-scale and commercial farmers about the potential benefits of locally produced green ammonium sulfate fertilizers, which could significantly enhance their productivity and profitability.

During the campaign, students presented their research findings on the extraction of renewable green ammonium sulfate fertilizers from cattle manure, as well as comparisons with traditional manure fertilizers, commercial products, and organic alternatives like vermicompost.

Objectives:

- Launch comprehensive education and awareness campaigns in the Omusati, Omaheke, Kavango, Otjozondjupa, and Kunene Regions.
- Promote the benefits of ammonia-based green fertilizers and provide clear instructions on their usage.
- Involve agricultural extension workers, local leaders, and community influencers to ensure that farmers receive and understand detailed information.

The awareness campaign was structured into four main categories:

5.1.1. Awareness for Small-Scale Farmers.

Conducted in the Northern Part of Namibia, specifically in the Omusati Region. The farmers engaged here are small scaled farmers. The awareness on green ammonium based fertilizers was welcomed and the following was obtained from the engagement;

a) Unemployment remains a significant issue, prompting the proposal to establish industrial fertilizer production in their region. This initiative aims to facilitate easier access to fertilizers while creating job opportunities within the industry. This idea is particularly beneficial considering that the green hydrogen and green ammonia industries are concentrated in the coastal and southern parts of the country, where renewable energy and access to seawater are abundant. Therefore, establishing value-added industries like fertilizer production in the northern part of the country is essential.

b) Farmers have expressed a pressing need for training, funding for fertilizers, seeds, and equipment to support them in increasing their productivity and profitability.

c) Furthermore, farmers emphasized the necessity for similar awareness campaigns not only focused on fertilizers but also covering effective farming methods, new technologies, and entrepreneurship training.

d) The awareness campaign took place at the local agriculture training center, where the manager expressed a warm welcome for any research and innovation activities to be conducted at their facility.

Figure 12: Awareness campaign for small scale farmers in Omusati Region, Northern Namibia.

5.1.2. Presentations to Government Officials, Entrepreneurs, and Farmers.

Held in Oshakati. Government officials from the ministry of Youth Development, Ministry of Labor, Ministry of Local Authority plus farmers, entrepreneurs and community leaders where all in attendance. The key outcomes from the awareness include the following;

a) More similar workshops and training of this kind for government officials so that they can make more informed decisions since they have powers to attract local investments in the region.

b) There is an annual exhibition in the northern part of the country which is usually in August and its call

Figure 13: Awareness campaign for Government Officials, Entrepreneurs, and Farmers in Northern Namibia.

5.1.3. Awareness for Commercial Farmers

An awareness campaign was conducted to inform farmers about the benefits of using locally produced, green ammonium sulphate fertilizers. These eco-friendly fertilizers are made from sustainable sources, helping to reduce environmental impact while improving soil health and crop yields. By switching to green ammonium sulphate, farmers can lower input costs, reduce dependency on expensive imports, and promote sustainable farming practices.

The campaign also emphasized opportunities in the carbon credit market. By adopting green fertilizers, farmers can reduce their carbon emissions and qualify for carbon credits, which can be sold to companies aiming to offset their emissions. This provides an additional income stream, offering both environmental and financial benefits for Namibian farmers.

Figure 14: Awareness campaign to a commercial farm in Central Namibia.

5.1.4. Green Hydrogen and Green Ammonia Production Site Visits.

Our students visited the Green Hydrogen and Green Ammonia pilot project in Daures, Namibia, as part of the awareness campaign. This hands-on experience gave students a direct look at how green hydrogen and ammonia will be produced, helping them connect their academic learning with real-world industry practices. They saw firsthand how green fertilizers, like ammonium sulphate, will be made, and gained valuable insights into the technologies driving sustainability in agriculture.

The visit also highlighted career opportunities in the growing green hydrogen and ammonia sector. As Namibia expands its renewable energy projects, new jobs are emerging in sustainable industries. By engaging with these initiatives, students were able to see the skills needed for future roles and how they can position themselves for careers in green energy and agriculture. This exposure is crucial for preparing the next generation to contribute to Namibia's green economy.

Figure 15: Students visit to the Green Hydrogen and Green Ammonia Production Site.

5.2. Recommendation 2: Conduct Trials and Case Studies.

- Implement trials and case studies to showcase the effectiveness of ammonia-based green fertilizers.
- Use demonstration farms to illustrate how these fertilizers improve soil health and crop yields.
- Address and correct any misconceptions about ammonia-based green fertilizers through these demonstrations.

5.3. Recommendation 3: Provide Financial Assistance or Subsidies.

- Explore options for financial assistance or subsidies to reduce the cost burden of ammonia-based green fertilizers for farmers.
- Partner with government and non-governmental organizations to support the adoption of environmentally friendly fertilizers.
- Consider compensation strategies to encourage farmers to switch from traditional artificial fertilizers to ammonia-based green alternatives.

5.4. Recommendation 4: Advocate for Supportive Policies:

- Promote policies that make ammonia-based green fertilizers more affordable and accessible.
- Collaborate with government officials and stakeholders to streamline the licensing and certification processes for these fertilizers.
- Work towards making the use of environmentally friendly fertilizers more feasible for farmers in the Omusati region.

In conclusion, the growing interest from research institutions and private companies in green hydrogen and green ammonia presents a unique opportunity for further collaboration and partnership. As 3's4 Africa has already initiated this research, it is essential to establish conversations with interested stakeholders to explore potential partnerships and drive these recommendations forward. The study has provided students with a comprehensive understanding of the green hydrogen and ammonia sector in Namibia, offering valuable insights through stakeholder engagement and research.

Moreover, the project has had a direct impact on students' academic and career paths. Maria Nekandu is now pursuing her Master's degree, building on the initial findings, while Mr. George Hamukoshi has secured employment as a Mechanical Engineer at the Daures Green Hydrogen Village. Dr. Simeon Hamukoshi is leading green hydrogen and energy projects as a Researcher and Projects Coordinator at the National Commission on Research Science and Technology. These outcomes highlight the immense value and potential of this project, not only for the students involved but for the broader development of green energy in Namibia. We look forward to seeing more students benefit from future research and continue to build on the findings and recommendations that emerged from this study.

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