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# Assessment of legume species for biological nitrogen fixation potential in smallholder farming systems of kiambu county, Kenya: A participatory approach

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**Abstract**
This study examined the Biological Nitrogen Fixation (BNF) potential of various legume species in Limuru, Kiambu County, Kenya, focusing on smallholder mixed crop-livestock farmers. Nitrogen is vital to plant growth, particularly for protein synthesis and photosynthesis. Biological nitrogen fixation (BNF), a process by which legumes transform atmospheric nitrogen into a usable form, increases soil fertility and decreases synthetic fertilisers need. The problem addressed was identifying the most effective legumes for improving soil fertility in this region. Using purposive sampling, community-based organisations (CBOs) participated in focus group discussions, where farmers planted experimental plots, collected soil samples, and counted nodules. Destructive sampling was employed during flowering to assess nodulation, with nodules classified based on their ability to fix nitrogen. Results showed Rose coco beans ranked highest due to their efficient nitrogen fixation and adaptability to varying soils and temperatures, followed by Albus lupin and Black and White faba beans. Desmodium also demonstrated persistent nodulation, while indigenous Kienyeji legumes, though less efficient, improved soil fertility. Garden peas, cowpeas, and green grams had lower nitrogen-fixing performance in Limuru's cool, humid climate. This study concludes that Rose coco beans and Albus lupins are highly suitable for improving soil fertility in the region. Participatory methods strengthened farmers' knowledge of sustainable agriculture, and qualitative data highlighted the practical value of BNF legumes. Future research should expand legume trials and explore the use of rhizobia inoculants to further enhance BNF efficiency, supporting long-term agricultural sustainability.

**Key words**: Albus lupin, Biological Nitrogen Fixation (BNF), Legumes, Rose coco beans, Soil fertility.

## INTRODUCTION

Nitrogen is the backbone of plants. It is an important building block for proteins and DNA, as well as plant growth and photosynthesis. Nitrogen is vital for chlorophyll synthesis, the pigment responsible for photosynthesis, and it plays a significant role in cell division and elongation, influencing overall plant vigour and productivity (Taiz et al., 2015). It is a vital component of amino acids, which are the building blocks of proteins and nucleic acids like DNA and RNA (Epstein & Bloom, 2005). Nitrogen is the main component of plant structures for their internal and external metabolic processes. During the vegetative phase of plant growth, nitrogen acts as the main control mechanism, regulating the plant's ability to produce new tissues and sustain metabolic processes (Marschner, 2012). A deficiency in nitrogen can lead to chlorosis, characterised by a reduction in chlorophyll content, which adversely affects photosynthesis, flowering, fruiting, and the accumulation of starch and proteins, ultimately leading to yield losses (Barker & Pilbeam, 2015).

Planting nitrogen-fixing plants, e.g. leguminous plants, is one of the most natural methods to increase nitrogen in the soil. Bacteria that absorb nitrogen from the air and convert it into nitrogen required for bacterial growth colonise the roots of the plants. Once the bacteria does not need the nitrogen any more, it becomes available to plants. Rhizobia bacteria, which transform atmospheric nitrogen into nitrogen compounds for plant usage, are found on the roots of nitrogen-fixing plants (Giller, 2001). This process enhances the nutrients in the soil. With an average dry-weight nitrogen concentration of 1.5 per cent—which can reach as high as 5.0 per cent in certain species—legumes are very good at fixing nitrogen (Peoples & Herridge, 1990). However, different legume species have different rates of nitrogen fixation due to differences in soil composition, climate, and cropping practices (Barker & Pilbeam, 2015). For instance, peas and beans can be utilised as cover crops that fix nitrogen and improve the soil, whereas lupins fix nitrogen and function as green manure (Marschner, 2012). Among these plants, the efficiency of nitrogen fixation can vary greatly (Taiz et al., 2015).

Biological Nitrogen Fixing (BNF) is the term used for a process in which nitrogen gas ($N_2$) from the atmosphere is incorporated into the tissue of certain plants. Only a select group of plants is able to obtain N this way, with the help of soil microorganisms, e.g. legumes. They have symbiotic rhizobia bacteria in their root nodules, which produce nitrogen compounds that help the plant develop and compete with other plants. Access to the fixed nitrogen allows the plant to produce leaves fortified with nitrogen that can be recycled throughout the plant. Farmers who find ways to maximise the amount of N acquired from the atmosphere via BNF will be able to lower their fertiliser costs while maintaining soil fertility and high yields. Chemical reactions, which are processes known as BNF, take place in the nodules. The fixed nitrogen is released when a plant dies, allowing other plants to use it to fertilise the soil. The BNF process is vital for sustaining soil fertility and supporting plant growth without the need for synthetic fertilisers. The primary enzyme involved in BNF is nitrogenase, which catalyses the reduction of atmospheric nitrogen ($N_2$) to ammonia ($NH_3$). Rhizobium forms symbiotic relationships with leguminous plants (e.g., beans and peas). They inhabit root nodules and provide the plant with fixed nitrogen in exchange for carbon compounds.

The purpose of this study was to conduct a participatory evaluation of the Biological Nitrogen Fixation (BNF) potential of selected local legumes in Limuru, Kiambu, Kenya.

1. Participatory nodule count and data collection
2. Correlate data, i.e. number of nodules=nitrogen fixing
3. Choose the best bet from the nodulation

The 9 local legumes on trial were:

- Common bean/Kienyeji= Gikaara
- New variety beans= Rose coco
- Lupin= Sweet Lupin and Albus Lupin
- Desmodium
- Faba bean= Black and White noe/faba bean
- Lucerne

- Cowpeas
- Garden peas
- Green grams

The results of this study provide information on how to improve soil fertility and structure by increasing organic matter and nutrient availability, decreasing the need for synthetic nitrogen fertilisers, which can save money and have less negative environmental impact. They can also support plant growth in soils deficient in nitrogen, encourage biodiversity and ecosystem stability, contribute to the nitrogen cycle, guarantee the continuous availability of usable nitrogen for plants and other organisms, and improve soil health by rotating crops with legumes and using cover crops.

## LITERATURE REVIEW

Biological nitrogen fixation (BNF) is a crucial natural process that plays an important role in improving soil fertility and supporting agricultural productivity. It involves the conversion of atmospheric nitrogen ($N_2$) into ammonia by symbiotic microorganisms, particularly rhizobia, which inhabit the roots of leguminous plants. This conversion reduces the need for synthetic nitrogen fertilisers, which are not only costly to produce but also contribute to environmental challenges like waterway eutrophication and greenhouse gas emissions (Galloway et al., 2020). Legumes, such as peace and beans, are especially important in sustainable farming systems as they form symbiotic associations with nitrogen-fixing bacteria, enhancing nitrogen levels in the soil and increasing crop yields, particularly in mixed-cropping systems (Gepts et al., 2019).

Recent developments in microbial inoculants have shown that bio fertilisers containing nitrogen-fixing bacteria not only enhance nitrogen uptake by crops but also improve soil health overall. These bio fertilisers are increasingly recommended for use in smallholder farming systems to boost productivity while promoting environmental sustainability (Hungria et al., 2020). The significance of BNF extends beyond legumes, as non-leguminous crops in intercropping systems also benefit from the nitrogen fixed by legumes through root exudates and the breakdown of legume residues (Bever et al., 2022).

Furthermore, BNF contributes to the goals of sustainable agriculture by enhancing biodiversity and reducing the reliance on chemical inputs. Research has shown that integrated cropping systems incorporating legumes and nitrogen-fixing bio fertilisers can lead to long-term improvements in soil structure, nutrient cycling, and resilience to the effects of climate change (Ordoñez et al., 2018).

## METHODOLOGY

### Study site

This study took place in Limuru, Kiambu County, Kenya, an area recognised for its highly productive smallholder livestock dairying systems. The region experiences a mean temperature of 26°C and follows a bimodal rainfall pattern, which, along with its fertile, well-drained soils, makes it ideal for agricultural activities. Dairy farming is widespread in the area, complemented by poultry, goat, and sheep farming. Purposive sampling was applied to select community-based organisations (CBOs) to gather participants, while self-help groups were chosen through random sampling.

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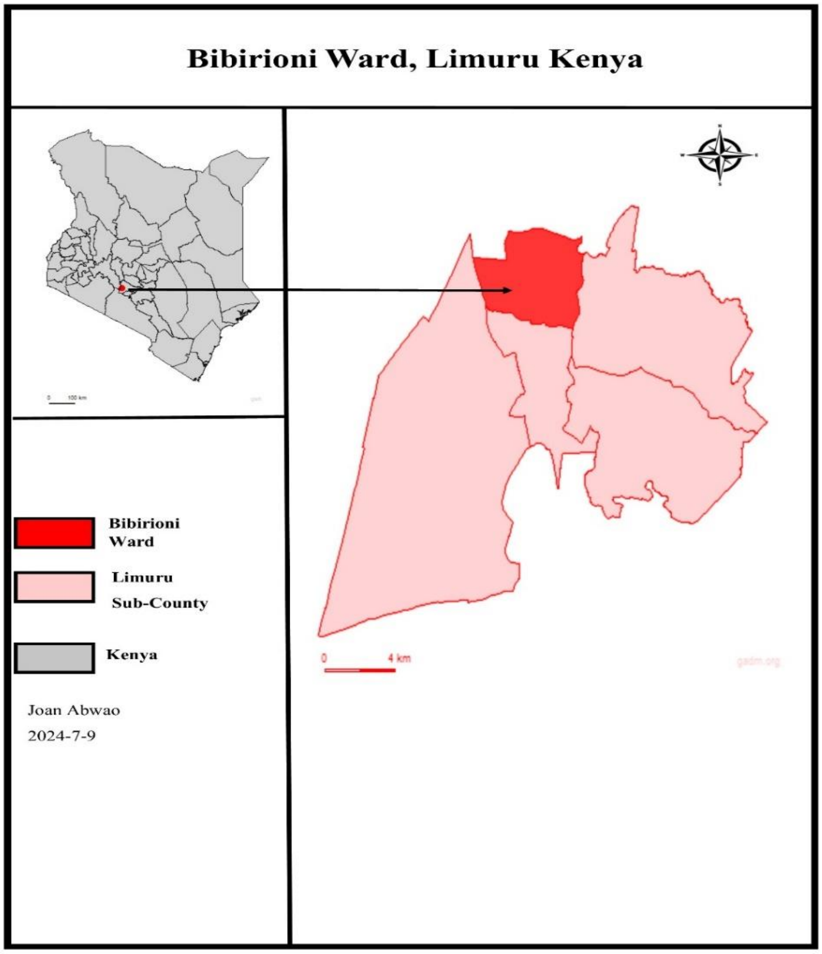


**Figure 1: Bibirioni Ward, Limuru Kenya**

**Experimental design**

A preliminary unreplicated trial was conducted in 9 plots with 6 legume varieties and 3 pasture varieties, all without rhizobia inoculation. The legume crops included Rose coco, Gikaara, faba bean, green grams, cowpeas, and garden peas, while the pasture crops were desmodium, lupin, and lucerne.

**Identification of sample**

Community-based organisations (CBOs) are vital for local service delivery, relying on volunteer efforts. After surveying various sub-counties in Kiambu, Limuru was chosen for its fertile land, dairy farming, and support from the Kiromo Dairy Farmers SHG. Mr. Jacob Kibet, the extension officer, facilitated project collaboration and site identification.

**Figure 2: Site Identification and Selection of Strategic Farmer Group**

A Focus Group Discussion led by a soil scientist from Pwani University explored legume nitrogen fixation and its role in agricultural systems. Farmers participated in planting legumes, while initial soil samples were collected from each prepared plot for analysis.

**Figure 3: Participatory Planting of 9 Legumes**

**Data Collection and Analysis**

Destructive sampling assessed nodule counts from legume treatments, focusing on active nitrogen-fixing nodules (pink inside) versus inactive ones (white, brown, or green). Farmers participated in uprooting, counting, and evaluating nodules.

Through qualitative analysis, they ranked the legumes based on nodulation, identifying the best-performing Biological Nitrogen Fixation (BNF) species.

**Figure 4: Farmer Observing Nodules**

## RESULTS AND DISCUSSION

### Ranking best bet Performing Legume for Biological Nitrogen Fixing (BNF)

Destructive sampling was done whereby selected samples of legumes from each treatment were uprooted. Through observational skills, the farmers identified which varieties had more nodules formed per plant and also collectively. They ranked the best bet performing legumes in Biological Nitrogen Fixation (BNF). Nodulation varied with legume species. Among the legumes, Rose coco plants were the most nodulated, while green grams were the least nodulated. This could be attributed to agroecological differences with green grams and cowpeas. Rhizobia strains in the study site did not effectively nodulate green grams and cowpeas.

The ranking of legumes based on their BNF potential provides valuable insights for optimising legume selection in agricultural practices. High-performing legumes like Rose coco and Albus Lupin should be prioritised for planting to enhance soil nitrogen levels and promote sustainable farming. Understanding the compatibility of legumes with local rhizobia strains is crucial for maximising BNF and improving soil health.

The best bet performing legumes on Biological Nitrogen Fixation were ranked as follows:

**Table 1**

*Ranking the best bet performing legume for Biological Nitrogen Fixing (BNF)*

| Rank Number | Legume Plant |
|---|---|
| 1. | Rose coco |
| 2. | Albus Lupin |
| 3. | Faba bean (white and black) |

| | |
|---|---|
| 4. | Desmodium |
| 5. | Gikaara/Kienyeji bean |
| 6. | Garden peas |
| 7. | Cowpeas |
| 8. | Green grams |

**NOTE:** Sweet Lupin and Lucerne were not ranked (awaiting flowering so as to ascertain that nodule formation has occurred), and the final ranking will be determined after all the pastures flower.

***1. Rose coco (Rank 1)***

Rose coco is a popular cover crop in Kiambu County, especially in Limuru, and is highly prized for its capacity to fix nitrogen. It can produce a substantial amount of biomass and grows effectively in cool-season environments. Its high ranking was probably influenced by its effective nitrogen fixation as well as its tolerance to different soil types and climates. It developed the greatest number of nodules, all of which were actively fixing nitrogen.

***2. Albus Lupin (Rank 2)***

Albus Lupin (Lupinus albus), a legume renowned for its nitrogen-fixing capabilities and adaptability to poor soils, ranked second in a participatory evaluation for Biological Nitrogen Fixation (BNF) among smallholder farmers in Kiambu County, Kenya. This legume is valued not only for its soil fertility enhancement but also for its utility as animal feed and as a green manure crop (Marschner, 2012). Despite the current El Niño conditions in Kenya, which typically pose agricultural challenges (Kenya Meteorological Department, 2019), Albus Lupin demonstrated robust performance in BNF. The introduction of Albus Lupin was novel to local farmers, highlighting its potential in temperate and subtropical climates prevalent in Kenya (Kenya Meteorological Department, 2019). Its adaptability extends to various soil types, including those of low fertility, making it a versatile choice in crop rotation systems aimed at nitrogen replenishment and pest management (Marschner, 2012). Furthermore, its ability to be intercropped with other crops offers synergistic benefits such as enhanced pest control and improved soil structure (Marschner, 2012). This study underscores the significance of Albus Lupin in sustainable agricultural practices, contributing to soil fertility and crop productivity in smallholder farming systems.

***3. Black and White Faba Bean (Rank 3)***

Faba bean is a cool-season legume that fixes nitrogen effectively. They are well suited to cooler temperatures and can handle higher moisture levels, making them a good fit for Limuru's climate. It is cultivated for both human consumption and as a cover crop. Its dual purpose as a food crop and a nitrogen-fixing cover crop likely contributed to its high ranking.

***4. Desmodium (Rank 4)***

Desmodium spp. are well known for their ability to fix nitrogen and increase soil fertility. They serve as cover crops, fodder, and erosion control. Their involvement in sustainable agricultural methods, such as soil conservation, may have influenced their ranking. Its consistent nodulation performance shows that it can be utilised effectively as a cover crop and feed to increase soil nitrogen levels. These legumes serve multiple agricultural purposes, including being used as cover crops, forage, and erosion control agents (Marschner, 2012).

***5. Kienyeji/ Gikaara (Rank 5)***

Kienyeji varieties are indigenous legumes known for their adaptation to local conditions and potential for nitrogen fixation. One member of the Kiromo Dairy Farmers SHG had supplied the local variety, Gikaara. Their cultural significance, role in local farming systems, and adaptability to the weather likely influenced their ranking despite their lower nitrogen-fixing efficiency compared to others. This traditional legume's BNF potential supports its continued use in local farming systems, contributing to soil fertility.

*6. Garden Peas (Rank 6)*

Garden peas are cool-season legumes suitable for the climatic conditions in Kiambu that fix nitrogen effectively and are cultivated as food crops. Their popularity as a food crop and their nitrogen-fixing capabilities contributed to their ranking.

*7. Cowpeas (Rank 7)*

Cowpeas are heat-tolerant legumes that serve as food, fodder, and cover crops. Limuru is a cold and rainy environment that proved unsuitable for cultivating cowpeas. Cowpeas are one of the most effective and highly rated legumes used in biological nitrogen fixation, however, they performed badly. They fix nitrogen effectively in warm regions. Their adaptability and capacity to thrive in a variety of environments most likely influenced their ranking. Soil pH, temperature, and nutrient availability can all have an impact on BNF's performance. Understanding these elements can help you optimise nitrogen fixation conditions.

*8. Green Grams (Rank 8)*

Green grams are legumes valued for their quick growth, nutritional value, and moderate nitrogen-fixing capabilities. Green gram grows best in areas with moderate humidity. They prefer warm temperatures and can tolerate higher temperatures. They are sensitive to waterlogging, so well-drained soils and avoiding heavy rains are crucial. While less efficient in nitrogen fixation compared to other legumes, the high humidity levels in Limuru increased the risk of root rot, which was detrimental to the green gram crops, thereby influencing their ranking. Their low BNF potential indicates they are not suitable for improving soil nitrogen levels in the current agroecological context.

**Nodulation Count Data**

Determination of nodules was manually counted. The sampled number of plants varied per variety. Plants with nodules were counted from the sampled number. The number of nodules per plant was counted and averaged. The nodules were cut open to look for a healthy pink colour to indicate effective nitrogen-fixing. Some were found to be white and others green, which indicated that they were inactive in nitrogen fixation. Good nodulation is usually averaged at $\geq$70 per cent. Anything $\leq$50 per cent is said to be poor in BNF.

A thorough understanding of the chosen legumes' ability for Biological Nitrogen Fixation (BNF) is provided by the nodulation count data. There are notable differences in nodulation efficiency between several species of legumes (Peoples & Herridge, 1990). An in-depth examination of the nodulation count data is provided in this part, along with a discussion of each legume variety's performance and how it affects the increase of soil nitrogen and overall agricultural output (Giller, 2001). Among the nine local legumes evaluated in Bibirioni Ward, Kinyogori, Limuru, Kenya, including common bean (Gikaara), new variety beans (Rose coco), lupins (Sweet Lupin and Albus Lupin), desmodium, faba bean (Black and White noe/faba bean), lucerne, cowpeas, garden peas, and green grams, variations in nodulation efficiency were evident (Marschner, 2012). This data provides insights into the effectiveness of these legumes' capacity to fix nitrogen, which is important for maintaining soil fertility and promoting plant development in agricultural settings.

**Table 2**

*Nodulation Count Data*

| Variety | Sampled Plant Number | Plant with nodules | Average no. of nodules/plant | Live | Dead | % |
|---|---|---|---|---|---|---|
| Cowpeas | 34 | 7 | 3 | 3 | 0 | 21% |
| Green grams | 30 | 3 | 2 | 1 | 1 | 10% |
| Garden Peas | 29 | 3 | 5 | 5 | 4 | 10% |

| | | | | | | |
|---|---|---|---|---|---|---|
| Desmodium | 50 | 25 | 5 | 5 | 0 | 50% |
| Albus lupin | 4 | 4 | 10 | 10 | 0 | 100% |
| Black faba bean | 9 | 5 | 12 | 5 | 0 | 56% |
| White faba bean | 7 | 5 | 16 | 5 | 0 | 71% |
| Rose coco | 35 | 35 | 50 | 50 | 0 | 100% |
| Gikaara | 34 | 15 | 17 | 15 | 2 | 44% |

**High Performing Legumes**

1. **Rose coco**
   - **Nodulation Efficiency:** (100%)
   - **Average No. of Nodules/Plant:** 50

   Rose coco had the highest nodulation efficiency of any plant studied; all of the plants had nodules that were actively growing. It is very helpful for soil nitrogen enrichment because each plant has a significant number of nodules, indicating a strong capacity for nitrogen fixation.

2. **Albus Lupin**
   - **Nodulation Efficiency:** (100%)
   - **Average No. of Nodules/Plant:** 10

     Albus Lupin showed remarkable effectiveness in nodulation. Even though each plant had fewer nodules than Rose coco, the continuous presence of active nodules suggests a dependable capacity for nitrogen fixation, even in low-quality soils.

   **White Faba Bean**
   - **Nodulation Efficiency:** (71%)
   - **Average No. of Nodules/Plant:** 16

     Most White Faba Bean plants formed a sizable number of active nodules, demonstrating strong nodulation efficiency. This makes it a good option for raising the nitrogen level of soil in colder climates.

**Moderate Performing Legumes**

1. **Black Faba Bean**
   - **Nodulation Efficiency:** (56%)
   - **Average No. of Nodules/Plant:** 12

   There was a moderate nodulation efficiency in Black Faba Bean. Although it produces a respectable number of nodules, its efficiency raises the possibility that some constraints prevent it from reaching its full potential for fixing nitrogen.
2. **Desmodium**
   - **Nodulation Efficiency:** (50%)
   - **Average No. of Nodules/Plant:** 5

   Desmodium had a somewhat effective nodulation rate. Based on its performance, it can be used as a cover crop and fodder because of its consistent ability to fix nitrogen.
3. **Gikaara (Kienyeji)**
   - **Nodulation Efficiency:** (44%)
   - **Average No. of Nodules/Plant:** 17

   Gikaara showed a passable level of efficiency. Although fewer plants developed nodules, the ones that did had a comparatively large number of nodules, suggesting the possibility of localised nitrogen fixation.

**Low Performing Legumes**

1. **Cow Peas**
   - **Nodulation Efficiency:** (21%)
   - **Average No. of Nodules/Plant:** 3

   The effectiveness of nodulation was low in cowpeas. Limuru's chilly, wet climate could not be ideal for its growth, which would limit its capacity to fix nitrogen.
2. **Green Grams**
   - **Nodulation Efficiency:** (10%)
   - **Average No. of Nodules/Plant:** 2

   The least effective nodulation was seen in green grams. Its ability to nodulate and fix nitrogen was probably hampered by the high humidity and soggy conditions.

*3.* **Garden Peas**

- **Nodulation Efficiency:** 10%
- **Average No. of Nodules/Plant:** 5

Garden Peas showed little efficiency as well. Even while some nodules formed, a large number of them were dormant, suggesting that the circumstances for nitrogen fixing were not ideal.

**Percentage of Nodule Count Data**

For the current legume crop to gain nitrogen (N) and to increase soil N for future rotations, legumes need to be adequately nodulated by root nodule bacteria (rhizobia) at ≥ 50%, but ≥70% is more desirable. The figure below shows the percentage of all the legumes for which nodulation was collected. Sweet lupin and lucerne were not accounted for. Desmodium nodulation was done during flowering, and the final soil sample collected for proximate analysis.

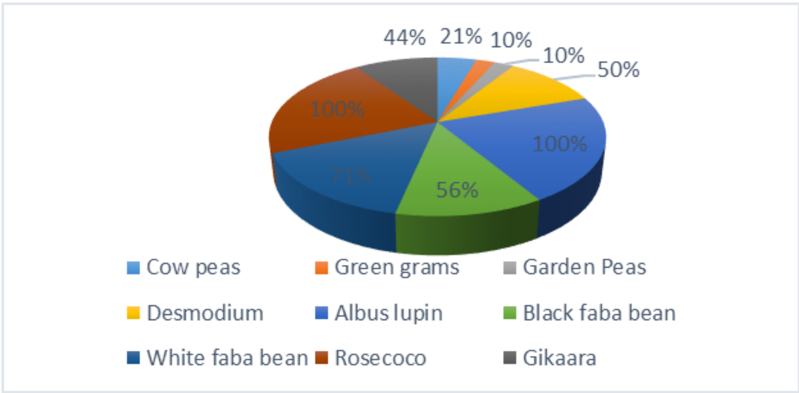


**Figure 5: Percentage of Nodule Count Data**

**CONCLUSIONS AND RECOMMENDATIONS**

**Conclusions:** The study on Biological Nitrogen Fixation (BNF) among legumes revealed significant performance differences, with Rose coco beans outperforming Albus lupin and faba beans in nitrogen-fixing efficiency and nodulation. Conversely, green grams and cowpeas showed the lowest potential. Agroecological factors, such as soil properties and climate, significantly influenced legume performance, with Rose coco beans thriving in Limuru's cool climate. The participatory approach engaged local farmers, enhancing the research's validity and equipping them with knowledge on selecting and cultivating nitrogen-fixing legumes, ultimately promoting crop production and soil fertility. Additionally, adopting high-performing BNF legumes can reduce reliance on synthetic fertilisers, saving costs and minimising environmental impact, thus fostering more sustainable and resilient farming systems.

**Recommendations**

Promoting sustainable agriculture in Kiambu County requires the adoption of high-performing legumes like Rose coco beans, Albus lupin, and faba beans, which enhance soil fertility through Biological Nitrogen Fixation (BNF) and reduce reliance on costly synthetic fertilisers. Educating farmers on BNF benefits, alongside practical training on nitrogen-fixing legume cultivation, will improve soil management and crop yields. Integrating these legumes into crop rotations boosts soil health and pest control, enhancing long-term sustainability. Further research on the impact of BNF legumes and the use of rhizobia inoculants can optimise efficiency. Policy measures incentivising the adoption of BNF practices will support sustainable agriculture and enhance food security.

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