PERFORMANCE OF COMMON BEAN (*Phaseolus vulgaris* L.) IN RESPONSE TO CATTLE MANURE AND FOLIAR SPRAYS OF BLACKJACK (*Bidens pilosa* L.) AND COMFREY (*Symphytum officinale* L.) EXTRACTS

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Master of Science Degree in Agronomy of Egerton University

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented for examination in this or any other University for award of degree.

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Recommendation

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DEDICATION

This thesis is dedicated to my lovely mother, siblings and the entire family.

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ABSTRACT

Common bean (*Phaseolus vulgaris* L.) is important legume crop for food and nutritional security in Kenya. Low yields are obtained in small holder farms, and this is majorly because of declining soil fertility. The use of inorganic fertilizer to replenish lost nutrients is limited because of rising costs. The aim of the study was to investigate the effect of cattle manure combined with foliar sprays of blackjack (*Bidens pilosa* L.) and comfrey (*Symphytum officinale* L.) extracts on nutrient uptake, growth, yield and nutritional quality of common bean. A 4 x 6 factorial experiment in a randomized complete block design (RCBD) with 3 replicates, was conducted in Egerton university's research Field 7. There were four fertilizer levels: cattle manure, applied at 0, 5, 10 t ha^{-1}, and NPK (27-27-27) fertilizer applied as a positive control at rate of 148.15 kg ha^{-1}. Six foliar spray treatments were used: no spray (control), comfrey spray applied once (C1) or twice weekly (C2), blackjack spray applied once (B1) or twice (B2) weekly and commercial Easy Grow spray (EG) (positive control), applied every 14 days at the rate of 3 kg ha^{-1}. The experiment was repeated two times consecutively, from June 2024 to December 2024. Soil samples were collected before the experiment was set up for analysis texture, moisture content, N, P, K, OC, pH and CEC. Plant tissue were collected at R1(flowering stage) for analysis of nutrient uptake. Data on growth which included height, number of branches, biomass, pod number, days to flowering and days to pod set were collected. Data on yield parameters, such as harvest index, hundred seed weight, yield per ha^{-1}, and protein content in seeds were collected at harvest. The Shapiro-Wilk test was used to ascertain the normality of data. Analysis of variance was performed using Proc GLM in Statistical Analysis Software (SAS). Tukey's Honestly Significant Difference was used to compare the means at $p<0.05$. Treatment M2 (10 t ha^{-1}) of manure produced plant tissues with high N content of 24.87% while the control (M0) had the lowest, 19.37%. For foliar spray, F0 (no foliar spray) produced plant tissues with lowest N content, 19.29% but B2 (Black jack twice a week) had the highest N, 23.95%. In addition, M2 produced highest yield (1652.31 kg ha^{-1}) compared to the control (M0) which had the lowest yield 1016.05 kg/ha^{-1}. For foliar sprays, C2 (comfrey twice a week) produced the highest yield (1669.77kg ha^{-1}) while no foliar spray (F0) had the lowest yield (1041.04 kg ha^{-1}). The combination of M2 and C2 produced the maximum yield (2373.88 kg ha^{-1}), which can be recommended for common bean production.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
HI	Harvest Index
HSW	Hundred Seed Weight
K	Potassium
KALRO	Kenya Agriculture and Livestock Research Organization
KES	Kenyan Shillings
MLE	Moringa Leaf Extract
N	Nitrogen
NPK	Nitrogen, Phosphorus and Potassium
OC	Organic carbon
P	Phosphorus
RCBD	Randomized Complete Block Design
SDG	Sustainable Development Goal
TDS	Total Dissolved Solid
WHC	Water Holding Capacity

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Common bean (*Phaseolus vulgaris* L.*)* is a crucial legume plant globally (Cortinovis *et al.*, 2021; Nadeem *et al.*, 2021). In Kenya, common bean plays a vital role in food and nutrition security for many Kenyan households and stands as an important dietary staple, particularly among low-income populations (Gondar, 2021). The plant is valued for its protein, fiber, vitamins and minerals (Keller *et al*., 2020). Its ability to adapt to different climates and soils renders it a sustenance and economic stability to farmers.

The largest producer of common beans worldwide was Myanmar with a production volume of over 6.59 million metric tons in 2023 (FAOSTAT, 2023). The estimated average production of common beans in Kenya, 2023 was 610,000 metric tons, with a mean yield of 0.6 tons per hectare (Tabara, 2023). Approximate of 1.5 million smallholder farmers grow common beans across one million hectares, primarily in the Rift valley, eastern , and Lake Victoria regions (Duku *et al*., 2020). Common beans' national consumption is projected around 755,000 metric tons annually and leads to a supply deficit of about 145,000 metric tons (Muteti *et al*., 2022).

Despite its nutritive importance, growing common bean faces difficulties from several biotic and abiotic factors (Diaz *et al*., 2018). According to Nadeem *et al*. (2019) its productivity and quality are often hindered by abiotic constraints such as drought and poor soil fertility particularly low phosphorus, potassium and nitrogen availability. Low soil fertility positions a significant challenge to common bean production in Kenya (Okumu *et al.*, 2018). The exhaustion of essential nutrients in soil, particularly nitrogen and phosphorus, delays the crop growth and causes low yields among smallholder farmers in the country (Lone *et al.*, 2021; Pasley *et al*., 2019) and harm nutritional quality of the harvested beans (Karavidas et al., 2022a). Limited or none application of external inputs by smallholder farmers in Kenya also contributes to the depletion of soil nutrients (Amann *et al., 2021).*

To solve the challenge of the soil infertility and advance the productivity as well as the resilience of common bean in Kenya, researchers and agricultural extension facilities have been actively emerging and promoting sustainable agricultural practices (Tadele, 2017). The solutions include foliar application of organic inputs, as discussed by Elzaawely *et al*. (2017) and Mashamaite *et al.* (2022). The effect of foliar application of Moringa (*Moringa oleifera)* leaf extract (MLE) on common bean and maize yield has been noted where the researchers sprayed different concentrations of MLE onto bean and maize crops and measured their growth and yield parameters. Results showed that foliar application of MLE significantly improved crop yield and quality. Definitely, the highest rate of moringa application resulted in the highest yield, with maize exhibiting a yield increase of 128% and common beans displaying an increase of over 100 %. Beans treated with MLE showed increased vegetable growth, distinguishable biochemical qualities, and higher yield compared to plants without treatments.

Comfrey (*Symphytum officinale* L.) also proves positive efficacy as a plant extract for foliar spray in organic farming, particularly in escalating plant growth and development. As revealed in a study by Godlewska *et al*. (2019), the application of comfrey extract resulted in significant enhancement in the length of shoots and roots, as well as wet and dry biomass of cabbage compared to untreated groups. Comfrey extracts likely lifted the bioavailability and protects the activity of compounds present in biomass, suggesting its efficacy in adding active compounds to the plant (Furber, 1982). While extra research is required to characterize its chemical composition completely and recognize its molecular mechanisms, comfrey extract proves sustainable potential as a feasible bio stimulant for boosting plant growth and yield in organic agriculture practices (Godlewska *et al*., 2019b). Once combined with other methods, such as nitrogen-fixing legumes in crop rotations, it can successfully contribute to greater yields (Snapp, 2017).

According to Khasabulli *et al*. (2018) *Bidens pilosa* improved the quality of green manure due to its allelopathic properties. This study shows that when included into the soil, the fresh leaf biomass of *B. pilosa* significantly enlarged the shoot height, leaf number, and leaf area of *Amaranthus dubius* crops. The allelopathic effects of *B. pilosa* when applied in the soil, can also conquer weeds emerging, making it a valuable green manure for sustainable crop production (*Valiño et al*., 2023). Furthermore, black jack leaf extracts possess weed and fungus-suppressing qualities which mitigate nutrient competition and pave the way for optimized nutrient uptake by common bean plants (Deba *et al.*, 2007).

Though its nutrients are released gradually through mineralization procedures in the soil, cattle manure is a useful source of nitrogen, phosphorus, potassium and other micronutrients. The immediate nutrient availability to crops may be restricted by this slow release, particularly during the times of high demand as the nitrogen mineralization is very low in organic manure (Eckhardt *et al*., 2016). Combining foliar sprays of blackjack and comfrey with cattle manure treatments helps to overcome this limit. Foliar sprays extend a rapid and an active way for nutrient to be absorbed by the leaves, addressing nutrient scarcity in a short period of time (Patil, 2018). This method improves crop health and productivity more efficiently than either technique alone by using the foliar spray to provide quick nutritional correction and the slow continuous nutrient input from manure to keep long -term soil fertility. Moreover, the study aims not only sustain the productivity and nutritional quality of common bean crops but also to upgrade food security and prosperity for Kenyan households. By improving the critical aspect of nutrient management, specifically focusing on nitrogen, phosphorus and potassium levels in the soil, the study aimed to pioneer a transformative approach using three natural remedies: comfrey (*Symphytum officinale* L.*)*, blackjack (*Bidens pilosa* L.*)* leaf extracts and cow manure.

1.2 Statement of the Problem

Common bean (*Phaseolus vulgaris* L.) is the most broadly consumed in East Africa region. In Kenya, it is a major source of proteins, especially for resources- limited families. Low yields, however, continue in smallholder farms. This is mainly due to deficiencies of nitrogen, potassium and phosphorus in soils. Inorganic fertilizers are typically not applied directly to beans. In contrast, farmers usually apply fertilizers to associated crops, except in cases where beans are intercropped with them. This method rises up due to numerous reasons, including the high costs associated with inorganic fertilizers and the precise nutrient requirements of other crops. Consequently, common beans often face nutrient deficiencies, leading to a prominent yield gap between the potential (2.5 t ha^{-1}) and actual yield (1.2 t ha^{-1}). Additionally, the adverse effects of synthetic fertilizers on human health and the environment highlight the urgent need for alternative soil enrichment methods in bean cultivation. However, there is insufficient knowledge regarding combined effects of cattle manure and foliar sprays of comfrey and blackjack extracts on growth, nutrient uptake, nutritional quality and yield of common bean. In this study cattle manure was used in combination with extracts of comfrey and blackjack to enhance nutrient uptake, nutritional quality, growth and yield of common bean

1.3 Objectives

1.3.1 Broad Objective

The broad objective of the study was to contribute to food and nutritional security in Kenya by enhancing common bean (*Phaseolus vulgaris* L.) production through application of cattle manure and foliar sprays of blackjack (*Bidens pilosa* L.) and comfrey (*Symphytum officinale* L.) leaf extracts.

1.3.2 Specific Objectives

The specific objectives of the study were:

i. To determine the effect of cattle manure combined with foliar sprays of blackjack (*Bidens pilosa* L.) and comfrey (*Symphytum officinale* L.) leaf extracts on nitrogen, phosphorus and potassium uptake by common bean.

ii. To determine the effect of cattle manure combined with foliar sprays of blackjack (*Bidens pilosa* L.) and comfrey (*Symphytum officinale* L.) leaf extracts on the growth, yield and nutritional quality of common bean.

1.4 Hypotheses

The hypotheses postulated for the study were:

i. Application of cattle manure combined with foliar sprays of blackjack (Bidens *pilosa* L.) and comfrey (*Symphytum officinale* L.) leaf extracts have no significant effect on nitrogen, phosphorus and potassium uptake by common bean.

ii. Application of cattle manure combined with foliar sprays of blackjack (*Bidens pilosa* L.) and comfrey (*Symphytum officinale* L.) leaf extracts have no significant effect on growth, yield and nutritional quality of common bean.

1.5 Justification of the Study

The research discoveries from the study on balanced fertilization strategies for common bean production offer a transformative opportunity to empower smallholder farmers and enhance agricultural sustainability as common beans are the major source of proteins in poor families who cannot access animal proteins in Kenya. Farmers can optimize common bean yields, reduce environmental impact, and improve soil health by developing and implementing this fertilization strategy which is delivered from organic sources. This approach has the capacity to reduce the production cost and stabilize bean production in Kenya as it offers a pathway to reduce the dependence on costly synthetic fertilizers. Including nutrients from organic sources, farmers can potentially reduce the production costs while promoting environmentally aspects and agronomic systems that diminish pollution and sustain soil health. Since these plants are mostly taken as weeds on farms, farmers do not pay planting costs, allowing them to foster their availability for nutrient-rich foliar sprays. Cattle manure which is estimated approximately $15 per ton contain desired nutrients; for instance, solid cattle manure typically provides about 5,000 grams of nitrogen, 3,600 grams of phosphorus, and 5,900 grams of potassium per ton (Toungos *et al.*,2019). On the other hand, for optimum crop yield, NPK 27-27-27 fertilizer which costs about $150 per hectare when using 300 kg is required, whereas easy grow fertilizer is around $19 per kg, with an optimal application of just 2-5 kg per hectare, this make these organic sourced amendments more economically valuable.

The limitations associated with synthetic fertilizers, for example environmental degradation and soil nutrient depletion are addressed in this ecological fertilization, with maximizing the bean yield and nutrition in Kenya. The study contributes to achieve SDG 2: Zero Hunger by increasing the productivity and nutrition content of common beans. Through elevation of nutrient absorption and yield, the study intended to upsurge food security mostly for limited resources Kenyan households. Additionally, it supports SDG 3: Good Health and Well-Being by expanding the use of alternatives to synthetic fertilizers. This strategy diminishes the adverse effects of chemical inputs on human health and the environment contributing to a better and more sustainable food system. Besides, the study aligns with SDG 12: responsible consumption and production through promoting agricultural practices which are sustainable as they utilize natural resources efficiently. To conclude, the study's emphasis on improving soil fertility and nutrient management through organic amendments contributes to SDG 15: life on land by supporting the protection, restoration, and sustainable use of terrestrial ecosystems.

1.6 Definition of Terms

Cattle manure: Well-decomposed cattle dung used as an organic fertilizer to improve soil.

Foliar spray: A fertilizer solution applied directly to the leaves of plants through spraying to enhance nutrient uptake and promote growth.

Extracts: a liquid solution obtained from plant materials such as comfrey and blackjack used as foliar spray in this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Classification and Botany of Common Bean

Common bean (*Phaseolus vulgaris* L.*)* is an annual plant categorized as either bush beans or climbing beans depending on their growth habits, with different varieties falling into these classifications (De Ron *et al*., 2015). Botanically common beans, scientifically known as *Phaseolus vulgaris* belongs to Plantae kingdom, the order is Fabales, family Fabaceae, and the Subfamily is Faboideae.

2.2 Origin of Common Bean

Common bean, has its origin in Mesoamerica, particularly in Mexico (Bitocchi *et al*., 2012). Initially, there was debate about whether the common bean originated in the Peruvian–Ecuadorian region or Mexico (De Ron *et al*., 2016)**.** However, recent genetic analyses have clarified that the common bean was first domesticated in Mexico before splitting into the Mesoamerican and Andean gene pools. This domestication process began around 8000 years ago, leading to the development of two distinct gene pools for the common bean (Ron Pedreira *et al.,* 2016).

2.3 Economic Importance of Beans

Common bean ranks as the most extensively cultivated grain legume, followed by soybean and ground nut for oilseed and grain legumes collectively (Patel, 2019). Worldwide, beans are cultivated on every continent except Antarctica (Jones, 2021). Beans particularly the common bean, play a significant role in the global economy (Carbas *et al*., 2020a; Kan *et al*., 2017). The global bean harvest (18.9 million tons) has an estimated annual economic value of approximately US$11 billion, underscoring its substantial economic impact (Moreira *et al.,* 2020). The economic importance of beans is further emphasized by their role in providing income to farmers, contributing to the agricultural economy of regions where they are grown.

In Kenya, beans are the most widely grown pulse plant, cultivated by about 2 million smallholder farmers on approximately one million hectares, making Kenya the largest bean producer by area in Africa and ranking seventh globally (Kenya National Bureau of Statistics, 2024; Stats Kenya, 2024). However, average yields remain low at about 492 kg/ha, well below the crop's yield potential (2.5t/ha) under optimal conditions (Economic survey, 2023). In 2023, the value of beans was Ksh 113 billion, the second after maize in Kenya's food plant economy, underscoring their economic importance (Kenya National Bureau of Statistics, 2024; Stats Kenya, 2024).

2.4 Chemical Composition of Common Beans

Common bean has an essential role in addressing food security and meeting dietary needs, especially in Latin America and sub-Saharan Africa where it serves as staple food (Catarino *et al.*, 2021). Beans are taken as vegetables (leaves and pods) and dry seeds. They are often called the "poor man's meat" due to their accessibility and high protein content, making them an easy source of nutrition for people with low resources (Loko *et al.*, 2018a). According to Alcázar *et al*. (2020), chemical composition of common bean includes various nutrient and phytochemicals. Common beans are rich in nutrients such as carbohydrates (60-70%), proteins (15-30%), crude fiber (5-7%), crude ash (4-5%), and crude fat (2-3%) (Jepleting *et al.*, 2022) and they encompass non-nutrient phytochemicals like flavonoids, tannins, and phytates, which have healthy benefits such as minimizing the hazards of aging-related diseases (Santos *et al.*, 2020). According to Kan *et al*. (2018) and Ramírez *et al.* (2018), common beans denotes an exceptional gluten-free food and they are also an everyday staple in plant-based diets recently identified by the Intergovernmental Panel on Climate Change (IPCC) as advocates of climate change mitigation by lowering meat consumption and its concomitant production costs (IPCC Climate Change and Land Report, August 2019).

Common bean holds complex carbohydrates, folic acid, iron, magnesium, copper, potassium, zinc and other essential dietary elements (Banti & Bajo, 2020; Carbas *et al*., 2020b; Hoque *et al*., 2023; Messina, 2014). It is an affordable and plentiful source of dietary fiber, vitamins, phenolic acids, flavonoids, and protein (Carbas *et al.*, 2023). Their protein boast outstanding digestibility and are gluten-free, aiding in cholesterol reduction and diabetes management (Keskin *et al*., 2022). Common beans' phenolic composition contributes to various advantages such as lowering cancer and heart disease risks, along with antioxidant and anti-inflammatory effects (Singh *et al*., 2017). Additionally, phenolic acids and flavan-3-ols in beans reduce digestive tract disease risks and their starch content lowers the glycemic index, mitigating chronic disease risks, and increases satiety for those with metabolic syndromes (Carbas *et al*., 2020).

2.5 Common Bean's Growth Requirements and Challenges

2.5.1 Environmental and Nutrient Requirements for Common Bean in Kenya

Common beans same as other many crops desire well-drained, slightly acidic loams with decent organic matter content, thriving best in soils with a pH of 5.5-6.8 (Savita, 2023), although they can adapt to a wider range of soil types with appropriate management. The major production zones in Kenya include Central Regions (Embu, Meru), Western Regions (Bungoma, Kakamega), Nyanza Regions (Kisii, Nyamira), and Eastern Regions (Machakos, Kitui) (Recha, 2018). Common bean needs specific nutrient requirements to attain ideal yields, principally, the main nutrients are macro nutrients which are nitrogen (N), phosphorus (P), and potassium (K). For nitrogen, the estimate of 40 to 80 kg N per hectare is required (Garcia *et al*., 2020), exclusively in soils which are poor in nitrogen content to support their growth and enhance yield potential as beans are capable to fix nitrogen. For phosphorus, research proposes that the quantity of 30 to 40 kg P2O5 per hectare is also recommended for optimum yield, as phosphorus is pivotal for root development and effective nitrogen fixation (Chekanai *et al*., 2018). The last macro nutrient needed is potassium which is nearby 30 to 60 kg K2O per hectare, which supports overall crop health through enhancement of crop resistance to diseases (Garcia *et al.*, 2020).

2.5.2 Challenges in Common Bean Production

The production of common bean faces a number of challenges and constraints that affect both yield and quality. The challenges include the insects' outbreak that lower crop vigor and grain quality and diseases for instance, angular leaf spot, common bacterial blight, anthracnose, and root rots (Girma *et al*., 2022). The abiotic factors such drought stress, weed competition, uneven distribution of rainfall, and deteriorating soil fertility also affect production negatively (Muteti *et al.*, 2022). Insufficient technical assistance, restricted access to improved seed varieties, and poor agronomic practices are further constraints. Production and commercialization are further hindered by socioeconomic problems like ineffective extension services, price volatility, excessive input costs, a lack of finance, and inadequate market ties.

2.6 Russian Comfrey (*Symphytum officinale*)

2.6.1 Importance and Ways of Application of Comfrey

Russian Comfrey (*Symphytum officinale* L.**)** is a perennial herbs (Fig.1) belonging to the Plantae kingdom, Eudicot class and Boraginaceae family mainly grown in moderate moist areas (Salehi *et al.*, 2019). Due its nutritional value it is found under the same class as Lucerne (Hills, 2011). Since it belongs to the Boraginaceae family, it is shielded from the nematode and viral infections that bother many modern plants (Teschke *et al*., 2021)**.** Comfrey fertilizer is a nutrient-rich organic fertilizer made from its leaves that provides essential nutrients for plants. Comfrey is highly esteemed for its capacity to gather essential nutrients such as nitrogen, phosphorus, potassium, and trace elements from the depths of the subsoil (Oster *et al.*, 2021), rendering it a prized reservoir of plant nourishment. This makes comfrey an excellent nutrient accumulator. Making comfrey extract fertilizer entails the collection of fresh comfrey leaves, immersing them in water for multiple weeks until they undergo decomposition and transform into a dense liquid.

Comfrey fertilizers can be produced and applied in several ways to maximize their nutrient-rich benefits. One traditional method involves anaerobically fermenting comfrey leaves in water for several weeks to create a potent liquid fertilizer rich in nutrients. For a quick homemade option, blending fresh comfrey leaves with hot water and using the resulting liquid as a fertilizer drench near plants is effective and comfrey leaves can also be spread as mulch around plants for slow nutrient release or added to compost to enhance its nutrient content and speed up decomposition (Bolcer, 2020).

2.6.2 Comfrey Extract Production Procedures

Like other plant extract, comfrey extract production involves steeping comfrey leaves in water to generate a liquid fertilizer with abundant nutrient beneficial to crops (Joe *et al.,* 2017). To guarantee the effectiveness of produced comfrey extract, it is advisable to utilize water without chlorine in brewing process (Hinke, 2022). Commonly, chlorine is found in tap water, and it is dangerous to the microorganisms like bacteria and fungi essential in decomposition of plant material and nutrients release. To maintain microbial activity and ensure a successful production of extracts, it is recommended to use non-chlorinated water such as rainwater, distilled, or de-chlorinated tap water.

Comfrey extract production includes the harvest of comfrey leaves before they develop flower and the soaking the collected leaves in water in the ratio of 1:5 for several weeks. Before application to crops, the extracted solution must be strained and diluted (Cresswell, 2019). The production time can vary based on environmental conditions, as the hot places take shorter brewing period of around 3 weeks compared to colder regions where it may take up to 6 weeks foe the extract to be ready for use. Dilution of the extract done by adding water at a ratio of 1:10 before spraying it onto crops to ensures optimal distribution and effectiveness across the cultivated area (*Fryd*, 2023)**.** The nutritional composition and water quality parameters of liquid manures made from Russian comfrey (Figure1), pig weed, and water hyacinth plants are contrasted in the table below with water as a control (Table1).

Table 1: Chemical Composition in Water Hyacinth, Pig weed and Water Vs Russian Comfrey

	Water Hyacinth	Pig weed	Russian Comfrey	Tap water (as the control)
pH	6.7	6.8	**7.8**	6.8
TDS	980±40	1844±20	**972±88**	91
%N	3.72±0.33	1.54±o.37	**2.90±0.1**	0.00
%P	2.86±0.41	2.98±0.24	**2.94±0.05**	0.00
%K	2.89±0.02	2.01±0.4	**3.90±0.06**	0.00
%S	0.91±0.21	0.70±0.34	**1.60±0.34**	0.05
%Mg	0.08±0.02	0.16±0.03	**0.08±0.02**	0.00
%Ca	0.06±0.01	0.38±0.11	**0.06±0.03**	0.00
%Zn	0.05±0.01	0.05±0.01	**0.04±0.02**	0.05

Source: Govere *et al.* (2011**) Key:** TDS= Total Dissolved Solids, N= Nitrogen, P= Phosphorus, K= Potassium, S=Sulphur, Mg=Magnesium, Ca= Calcium, Zn= Zinc

Figure 1: White comfrey, *Symphytum officinale* (Pavlis, 2016)

2.7 Importance of Incorporating Blackjack in Foliar Spraying Liquid Manure

The black jack (*Bidens pilosa* L.)(Fig.2) originates in South America (Mtenga & Ripanda, 2022), and has now spread to every tropical and subtropical region on Earth.

Figure 2: Blackjack, *Bidens Pilosa*

Table 2: Macro and Micro Elements in *Bidens Pilosa* Comparing to *Chenopodium album*

Macro and micro elements (mg/100g d.w.)	***Bidens pilosa***	***Chenopodium album***
Magnesium	0.640	0.719
Calcium	1.971	2.172
Potassium	3.285	6.938
Phosphorus	0.519	0.317
Sodium	0.053	0.370
Iron(ppm)	986	255
Zinc	51	50
Copper	24	13
Manganese	115	118
Total Kjeldahl nitrogen	3.05	4.23

Source: Adedapo *et al.* (2011)

Black jack, with its nutrient content and miscellaneous biochemical composition (Table 2), holds significant promise for improving plant health and yield when incorporated into foliar spray liquid manure. Its crucial nutrient like polyphenols and flavonoids not only increase the grade of the foliar sprays but also partakes antioxidant properties vital for plant resilience (Ramabulana *et al.*, 2020). Additionally, bioactive compounds such as alkaloids, tannins, and flavonoids found in black jack can further boost plant growth and defense mechanisms (Mboya, 2018). The presence of sesquiterpenes and polyacetylenes in its chemical composition adds to its potential multifaceted benefits, promoting overall plant health and stress tolerance. The inclusion of *Bidens pilosa* in green manure to be utilized as a foliar spray is beneficial due to its potential as a natural herbicide (Reyes-Ardila *et al.*, 2024). The plant's extracts have been shown to exhibit phytotoxic action against various weeds, including *Bidens pilosa* itself, as well as antifungal activity against phytopathogens (Mtenga & Ripanda, 2022).

2.8 Importance of Foliar Spray

Foliar spraying is an important technique for delivering essential nutrients directly to plants' leaves, providing several key benefits. Foliar uptake of nutrients is much faster than root uptake, allowing for rapid correction of deficiencies and boosting plant growth (Patil, 2018). Besides, foliar fertilization is more efficient than soil application because chelated nutrients are fully plant-available, resistant to leaching, and environmentally friendly by reducing nutrient losses (Alshaal & El-Ramady, 2017). Foliar sprays can improve plant growth and plant quality, manage the nutritional status of plants, enhance disease resistance, and regulate nutrient deficiencies, especially in medicinal and aromatic plants (Shahrajabian, 2022).The dosage required for foliar application is often lower than soil fertilization, yet it can lead to significant yield increases of 30-40% in some case (Dimka, 2013).

2.9 Cattle Manure

Cattle manure is a valuable organic fertilizer for common beans, offering several benefits. It improves soil structure and fertility by increasing water-holding capacity and aeration, allowing for better root growth and water absorption (Musaninkindi, 2013). Additionally, manure contains macro- and micro-nutrients that promote plant growth and development, including nitrogen, phosphorus, and potassium (Table 3). The nitrogen content in Cattle manure is particularly beneficial for common beans, as it supports leaf growth and development (Basdemir *et al.*, 2022a). However, its slow nutrient release and low nitrogen content must be considered, as over-application can lead to over-fertilization and potential environmental issues (Brummerloh & Kuka, 2023). Over-fertilization can cause nutrient imbalances, leading to reduced yields and decreased plant health. Moreover, excessive nitrogen levels in soil can contribute to eutrophication and water pollution (Tiwari & Pal, 2022). Some studies provide evidence that Cattle manure application rates in the range of 5-10 t/ha can significantly improve legume plant yields compared to control treatments without manure (Upenji *et al.*, 2020). In addition, research carried out in the Democratic Republic of Congo found that applying 5 t ha^{-1} of Cattle manure significantly improved common bean yields, highlighting the importance of optimal application rates (Upenji *et al.*, 2020).

Table 3: Chemical Composition of Cattle Manure

Nutrient component	% composition
Total N (%)	0.73
P (%)	0.18
K (%)	0.71
S (%)	0.58
Zn(mg/kg)	16
Total carbon (%)	25.9
Lignin (%)	13.8
Cellulose (%)	38.3

Source: Ghosh *et al*. (2004)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Experimental Site

The study was carried out in Field 7 research field, situated within Egerton University's Njoro campus in Kenya (Figure 3) in the Rift Valley region of Nakuru County, Njoro. The latitude of the University is 0.1801° S and the longitude is 35.9718° E. The region is situated at an elevation of roughly 2,238 meters above sea level. About 1200 mm of rain falls on average each year and its distribution is bimodal, with short rains occurring from October to December and long rains from April to June. Because of the high elevation, the temperatures are generally mild all the year, its average range is between 10.2°C and 22.0°C (Taiy, 2017). The soils at the experimental site consist of well-drained, dark reddish clays that are classified as mollic Andosols (Agutaa, 2015). The field experiment was conducted two times consecutively; starting from June 2024 to December 2024.

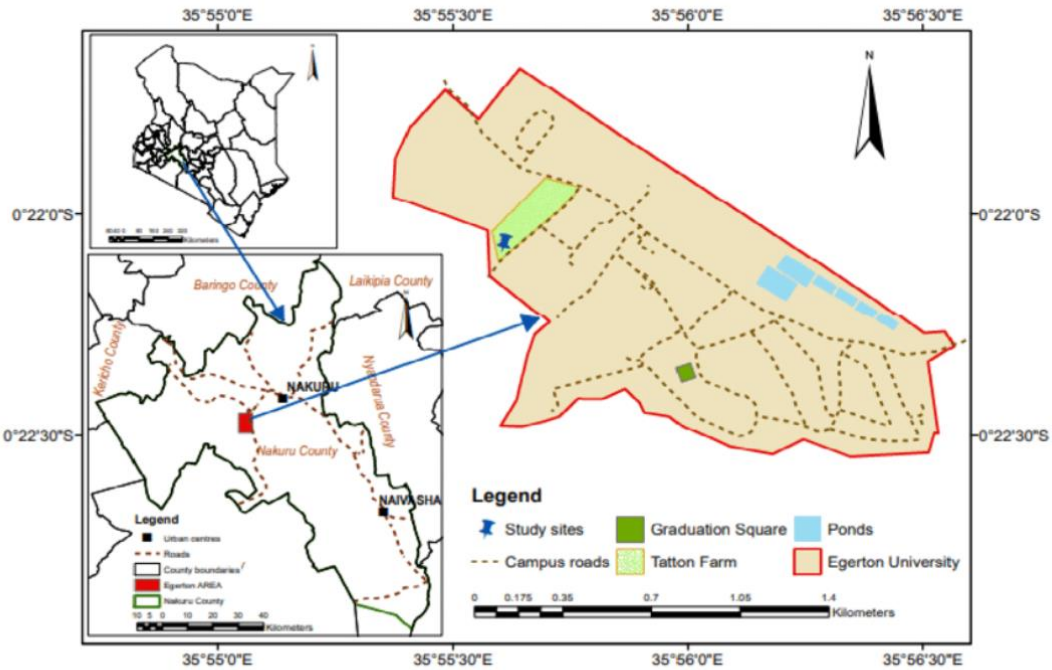


Figure 3: Map of Egerton University

3.2 Experimental Materials

3.2.1 Test Plant

Nyota bean, a popular common bean variety in Kenya, was used in the study. It is known for its exceptional taste, versatility, and high nutritional value. The variety was bred by the Kenya Agricultural and Livestock Research Organization (KALRO) specifically for the Kenyan market (Muoki & Goldstein, 2022a). Nyota beans are typically determinate, meaning they have a more compact growth habit and stop growing once they reach a certain size (Odongo, 2022.). Nyota beans are usually mottled or speckled in color, often brown or red. They generally mature in about 70-90 days, depending on environmental conditions. Nyota beans are known for their high yield potential, making them a popular choice among farmers. The yield of Nyota beans typically ranges from 1400 to 2200 kg per hectare (Muoki & Goldstein, 2022b), which is approximately 6 to 10 bags (90 kg each) per acre. Under optimal conditions, some farmers have reported yields of up to 12 bags per acre. The seeds were sourced from Agro science park, Egerton university.

3.2.2 Analysis of Cattle Manure

Cattle manure was analyzed for organic carbon, nitrogen, phosphorus, potassium, and moisture content. The process began by collecting cattle manure from farms at Egerton University, then drying the manure in an oven for 24 to 48 hours at 75 °C. The target moisture content after drying was around 10% to 20%, ensuring optimal nutrient concentration and stability for effective use as organic fertilizer. The dried manure was kept in a dry and blowy zone to stop fungus development and uphold its quality. Total nitrogen was analyzed by using the Kjeldahl method at soil science laboratory belonging to Crops, Horticulture and Soils department. The method involved digesting the sample in sulfuric acid to translate nitrogen into ammonium sulfate, subsequently distillation and titration to ascertain the nitrogen percentage in manure (Lithourgidis *et al.*, 2007). The total phosphorus content in cattle manure was calculated with the molybdenum blue method which involved digesting the sample to alter forms of phosphorus into orthophosphate. The orthophosphate then reacted with ammonium molybdate and ascorbic acid which formed a blue complex. The strength of the resulted blue color was estimated using a UV-Vis spectrophotometer at a wavelength of 420 nm, and it was comparative to the concentration of phosphorus in in the manure (He *et al.*, 2003). The potassium in cattle manure was determined by means of the ammonium acetate method, the sample was mined through ammonium acetate solution, and then the removed potassium was quantified by using an Atomic Absorption Spectrophotometer (Bazargan *et al*., 2022). The Walkley-Black method was employed for organic carbon present (Enang *et al.,* 2018). Also, the moisture content in manure was computed by drying 200g of the cattle manure in an oven at 105°C till a constant weight was reached. The change in weight before and after drying represented the moisture content.

3.2.3 Preparation and Analysis of Content of Comfrey and Blackjack Extracts

Fresh leaves from comfrey (*Symphytum officinale* L.) grown in field 7, and blackjack (*Bidens pilosa* L.) present in the fields at Egerton University were collected at vegetative stage. The extracts from the plants were prepared in separate buckets using a proportion of 1 kg of comfrey and 5 litres of non-chlorinated water, and 1 kg of blackjack leaves and 5 litres of non-chlorinated water (Rozie, 2022). The mixtures were stirred every 1-2 days. After 1-3 weeks, when no more foam formed during stirring, the extracts was ready for use (Mahaffee & Scheuerell , 2002)**.** Since 1 kg of leaves was mixed with 5 litres of water, the resulting concentration was 0.2 kg/L. Before application, the liquid was sieved, then 1 litre of this resulting solution was diluted with 10 liters of water, increasing the total volume to 11 litres. Since 1 litre of the original solution contained 0.2 kg of leaves, the final concentration after dilution was calculated as 0.2 kg divided by 11 litres, resulting in a final concentration of approximately 0.01818 kg/L for each extract. For spraying on an entire hectare of common beans, approximately 200 kg of comfrey leaves and 200 kg of blackjack leaves were needed to prepare nutrient-rich solutions (*foundations for farming*)**.** The nutrient content of comfrey and black jack extracts were analyzed from 0.3 ml sample. The same methods as those used for cattle manure analysis were used in the analysis of nitrogen, phosphorus and potassium content of the extracts (section 3.2.2). The pH was analyzed using a pH meter.

3.3 Soil Preparation and Planting

Prior to the start of the rainy season, land management activities such as ploughing and harrowing were undertaken. Bean seeds were planted at a spacing of 50 cm between the rows and 20 cm between the plants on the same row. Each plot had 40 plants, while for the whole hectare, the estimation was about 100,000 plants. Planting was carried out manually, with seeds being sown at a depth of 2.5 cm. After sowing, the seeds were lightly covered with soil. Weeding commenced two weeks after the seeds had emerged, followed by second weeding three weeks later.

3.4 Experimental Design and Treatments

The field experiment was conducted at Field 7 research fields of Egerton University, from June to December 2024, using a 4x6 factorial design implemented in a randomized complete block design (RCBD). The experiment was repeated two times, consecutively, without regard to season. The individual plot size was 2 m x 2 m, with blocks and plots separated by 1 m and 0.5 m respectively (Figure 4). The factors included fertilizers applied directly to the soil during planting and foliar feeds applied through spraying. Four fertilizer treatments were used: no cattle manure (negative control), 5 tonnes ha^{-1} (50 g per hole), cattle manure, 10 tonnes ha^{-1} (100 g per hole), cattle manure, and NPK fertilizer, at a rate of 148.15 kg ha^{-1} as a positive control (Table 4). Foliar sprays treatments were: two leaf extracts-*Symphytum officinale* (Comfrey) and *Bidens pilosa* (Blackjack), were applied at different frequencies (once and twice per week), along with a positive control consisting of Easy Grow (Easy Grow vegetative NPK ratio of 27:10:16 and Easy Grow fruit and flower NPK ratio of 14:11:33) applied every two weeks for a total duration of six weeks, and a negative control with no foliar application (Table 4). The leaf extracts were applied as foliar sprays two weeks after germination in a ratio of 1:10 (1 liter of each plant extract diluted with 10 liters of water).

Table 4: Treatments and their Levels

Factor A (Fertilizers), 4 levels	Factor B (Foliar feeds), 6 levels
M0: **no application of cattle manure**	**C1**: Comfrey spray, once a week
M1: 5 tonnes ha^{-1} or 50 g per hole of cattle manure	**C2**: Comfrey spray, twice a week
M2: 10 tonnes ha^{-1} or 100g per hole of cattle manure	**B1**: Blackjack, once a week
NPK (27-27-27): application of 148.15 kg ha^{-1} of NPK, also acted as a positive control	**B2**: Blackjack, twice a week
	F0: no foliar spray, which acted as a negative control
	EG: Easy grow (Easy grow vegetative at NPK ratio 27:10:16 and Easy grow fruit and flower at NPK ratio 14:11:33)

The study consisted of a total of 24 treatments as indicated below:

M0 C1	M0 C2	M0 B1	M0 B2	M0 EG	M0 F0
M1 C1	M1 C2	M1 B1	M1 B2	M1 EG	M1 F0
M2 C1	M2 C2	M2 B1	M2 B2	M2 EG	M2 F0
NPK C1	NPK C2	NPK B1	NPK B2	NPK EG	NPK F0

The treatments were replicated across 3 blocks making a total of 72 plots.

3.5 Experimental Layout

The experimental layout is shown in Figure 4.

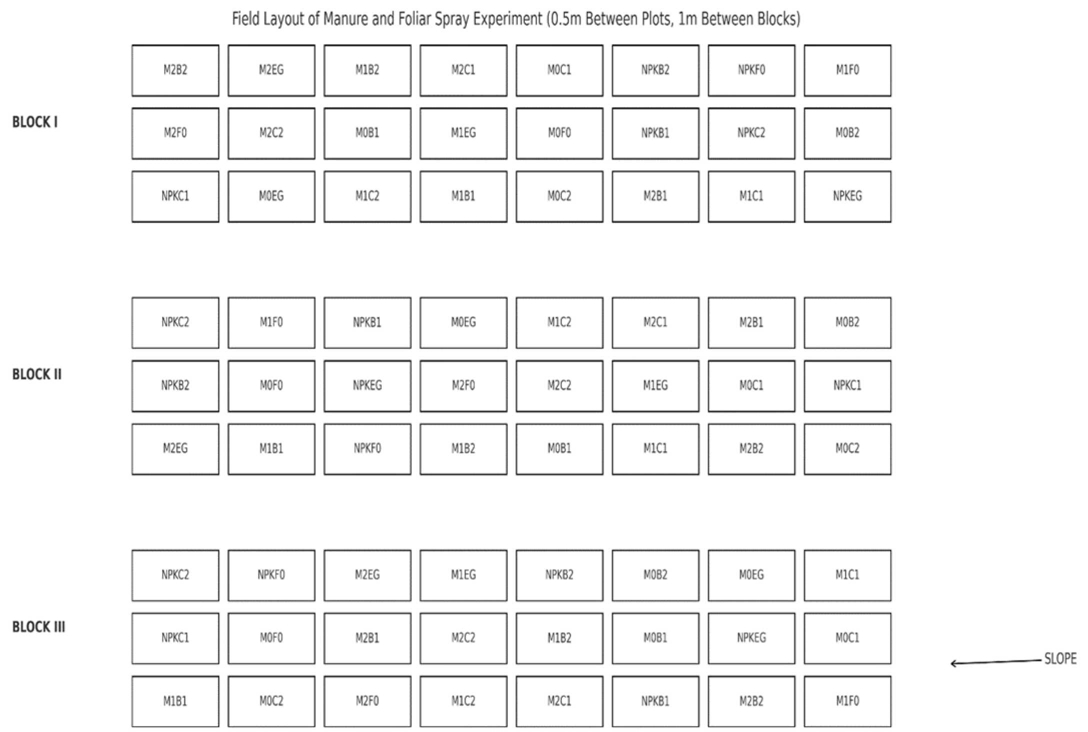


Figure 4: Experiment Layout

3.6 Soil Sampling and Analysis Before Experimental Set up

Before setting up the experiment, soil samples were collected and analyzed for chemical and physical properties. The process began by dividing each block into sections and then, using a zigzag pattern, selecting five different points within these sections for representative composite samples for each block. Needed tools, like soil augers, plastic bags, permanent markers, sample containers, a clean mixing surface, and labels, were collected in preparation. Soil samples were taken from a depth of 0–20 cm. At each sampling point, soil cores were extracted using a soil auger, combining samples from each block into clean containers. The soil was mixed thoroughly on a clean plastic sheet to form a complex sample. Subsamples of about 500 grams were taken from each composite mix, clearly labeled with relevant information, and stored in airtight containers to prevent contamination and moisture loss. To analyze soil samples for available nitrogen (N), phosphorus (P), potassium (K), and water holding capacity (WHC), specific techniques were employed.

The Kjeldahl method was used to analyze available nitrogen, which involve sulfuric acid digestion and ammonia distillation (Sáez-Plaza *et al.*, 2013). Available phosphorus was studied using the molybdenum blue colorimetric method, with perchloric acid digestion (King, 1932*)*. pH was measured using a pH meter by signifying the hydrogen ion in the solution (Bishnoi *et al.*, 2006*)*, and potassium analysis was run through acid digestion followed by Atomic Absorption Spectroscopy (AAS). WHC was estimated by drying soil samples at 105°C overnight and calculated moisture content (Ross, 1989). In addition to the earlier stated soil analyses, initial soil analysis also encompassed the assessment of soil texture and organic carbon content. Soil texture was determined by the hydrometer method based on Stokes's law to find the percentage of sand, silt and clay in soil *(*Mozaffari *et al.*, 2024), which exposed the proportion of sand, silt, and clay, influencing water retention, drainage, and nutrient availability (Osanyinpeju & Dada, 2018). Organic carbon content was analyzed by the Walkley-Black method *(*Bhattacharyya *et al.*, 2015*)*.

$$\textit{\% moisture content} = \frac{Weight\ of\ moist\ soil - weight\ of\ dry\ soil}{Weight\ of\ dry\ soil} X\ 100$$

Equation 1

3.7 Analysis of Plant Tissues Nutrient Content

3.7.1 Nitrogen, Phosphorus and Potassium

Destructive sampling was employed to collect plant samples for nutrient analysis, took place in the soil science laboratory at Egerton University. Total nitrogen (N), phosphorus (P), and potassium (K) were measured at the flowering stage (R1), which corresponds to 50% of the plants in flower, precisely at the initial bloon stage (González *et al., 2023*). At that time, three plants were harvested from each experimental plot randomly, with only the above-ground parts involved. The shoots, comprehending stems and leaves, were cautiously cut and cleaned to remove any soil and de and dried in an oven at 70°C until a constant weight was reached, then ground into a fine powder. Two outer rows of plants from each experimental plot were used as guard rows.

i) Nitrogen Analysis

The Kjeldahl method was applied for nitrogen analysis. The analysis was done in the soil science laboratory at Egerton University. Established by Johann Kjeldahl in 1883, this method involved the particular determination of total nitrogen content through the procedure of strong acid digestion, liberating nitrogen for succeeding titration. the nitrogen content was calculated using this formula according to Sáez et al (2013):

$$\%N = \frac{VXNX14X100}{W} \qquad \text{Equation 2}$$

where;

V: the volume of acid used in titration (in ml),

N: the normality of the standard acid, and

W: the weight of the sample (in grams).

%N: is the percentage of nitrogen in the sample.

ii) Phosphorus Analysis

Phosphorus concentration in plant tissue was determined using the molybdenum blue method. The analysis was conducted in the soil science laboratory at Egerton University. This process commenced with the digestion of the sample to transform all phosphorus forms into soluble orthophosphate. The digested solution was then treated with ammonium molybdate in an acidic medium, forming a phosphomolybdic complex. This compound subsequently was reduced with ascorbic acid, creating a blue-colored complex known as molybdenum blue. The intensity of the blue color, measured using a UV-Vis spectrophotometer at a wavelength of 420 nm, was directly proportional to the concentration of phosphorus in the sample. A calibration curve was made the standard phosphorus solutions to compute the phosphorus content based on absorbance readings (Rana et al., 2020).

Phosphorus concentration (mg/kg) =

$$\frac{Phosphorus\ in\ extract\frac{(mg)}{L} * Extractant\ volume\ (ml)}{Dry\ weight\ of\ plant\ tissue(g)} \qquad \text{Equation 3}$$

where:

Phosphorus in extract (mg/L) is the concentration of phosphorus measured in the filtered extract using colorimetric methods and calibration curve.

Extractant volume (mL) is the volume of Olsen solution used in extraction, which is typically 100 ml

Dry weight of plant tissue (g) is the weight of the dried, ground plant sample used for extraction.

iii) Potassium Analysis

To analyze potassium (K) content in common bean (*Phaseolus vulgaris* L.) tissues, the Atomic Absorption Spectroscopy (AAS) was used. The analysis was done at Safe food laboratory at Egerton university. The ground plant tissues underwent digestion using concentrated nitric acid and hydrogen peroxide to release potassium (K) into the solution. The resulting solutions were diluted and analyzed using atomic absorption spectroscopy (AAS). The absorbance of light at a specific wavelength corresponding to potassium was measured to determine its concentration (Ozbek & Akman, 2016).

3.7.2 Growth and yield component analysis

For growth analysis, three plants per plot (experiment unit) were randomly selected and monitored for each growing stage. The parameters measured included plant height, biomass, number of pods, days to 50% flowering, days to 50% pods, grain yield, harvest index and hundred seed weight. Plant height at V3, V4, V5 and R6 growing stages was measured from the soil surface to the tip of tallest leaf/pod using a ruler, then recorded in centimeters. Biomass was calculated by drying three harvested above-ground plant samples at stage R1 at 65°C until a constant weight was reached, providing the shoot dry weight (Aserse *et al.*, 2020). Hundred seed weight was calculated by accurately counting and weighing 100 pure seeds, then recorded weight in gram (ISTA, 2023). The growth data was collected at every growing stage throughout the season, starting from the initial establishment of the plants and continuing until physiological maturity. To calculate the plant yield data, the Harvest Index (HI) was calculated as the ratio of the dry weight of the grain to the total dry weight of the plant. For quality, protein content in seed was determined using the Kjeldahl method (Mutungi *et al.*, 2022). The used nitrogen-to-protein conversion factor for calculating protein content was 6.25. According to Kemanian *et al*. (2007) the formula for Harvest Index is:

HI:

$$\frac{\boldsymbol{Dry\ weight\ of\ the\ grain}}{\boldsymbol{Total\ crop\ dry\ weight}} \qquad \text{Equation 4}$$

While, the total yield was calculated.

***Yield*(*kg/hectare*)** (Mekbib, 2003)**:**

$$\frac{\boldsymbol{Average\ seeds\ per\ pod\ XAverage\ pods\ per\ plantXplant\ per\ hectare}}{\boldsymbol{Average\ seeds\ per\ kg}} \qquad \text{Equation 5}$$

3.8 Statistical Analysis

Statistical Model: Y_{ijkl}: u+Li+Aj+Bk+AiBj+ ε_{ijkl}

μ: overall mean

L_i: Effect due to the ith block

A_j: Effect due to the jth fertilizer

B_k: Effect due to the kth foliar feed

A_jB_k: Interaction due to the jth fertilizer and kth foliar feed

ε_{ijkl}**:** Random error term

The data obtained from this study was first be tested for normality using the Shapiro-Wilk test. Following, Analysis of Variance (ANOVA) was performed using a random effects model in the statistical software SAS 9.4 general linear model (GLM) technique developed by Anthony James (Vanderziel *et al*., 2025). Where significant differences were detected, means were separated using Tukey's Honestly Significant Difference (HSD) test at a 5% significance level. Additionally, correlation analysis was performed at a 5% significance level to explore the relationships between growth, yield, and quality metrics of the common beans.

CHAPTER FOUR

RESULTS

The pre-characteristics of the soil without treatments applied and the nutrient content of cattle manure and extracts are indicated in Table 6.

Table 5: Pre- experiment Analysis of Soil, Cattle Manure and Extracts

Parameter	Unit	Soil	Comfrey Extract	Blackjack Extract	Cattle Manure
Texture	–	Sandy loam	–	–	–
Moisture content	%	24.87	–	–	21.07
pH	–	5.45–6.21 (slightly acidic)	6.14	6.50	–
Organic C	–	2.72–3.48	–	–	17.28
CEC	meq $100g^{-1}$	15–24 (moderate)	–	–	–
Total N	%	0.21–0.94 (moderate)	5.13	4.90	1.40
Available P	ppm	38–60	247.67	223.50	2047.60
Available K	ppm or %	12–24 ppm	0.033%	0.032%	7500 ppm
Remarks		Moderate fertility; suitable pH for common bean growth	High N and P; low K due to dilution	Slightly lower N and P than comfrey; low K	High P, K, and C; improves soil fertility and structure

4.1 Effect of Cattle Manure Combined with Foliar Sprays of Blackjack and Comfrey Leaf Extracts on Nitrogen, Phosphorus and Potassium Concentration in Common Beans at Flowering (R1) Stage

4.1.1 Nitrogen Concentration

The main effect of foliar sprays and cattle manure on nitrogen concentration (%) in common bean at flowering (R1) was significant ($p < 0.05$) (Appendix G). The highest average concentration (24.87) was observed in M2 (10 tonnes ha^{-1} or 100 g of cattle manure per hole). Treatment M0 (no manure application) resulted in lowest nitrogen concentration (19.37), although not significantly different from M1 (Table 7). For foliar spray treatments, the untreated control, i.e. no foliar spray (F0), resulted in lowest average plant nitrogen concentration (19.29) but treatments B2 (blackjack sprayed twice a week) had the highest N concentration (Table 7). The interaction effect of manure and foliar sprays on nitrogen concentration in common bean at flowering (R1) was not statistically significant at $p < 0.05$) (Table 8).

Table 6: Main Effect of Manure and Foliar Spray Treatments on Nitrogen Content in Common
Beans Tissues at R1 Growing Stage (%)

Manure treatment	N (%)	Foliar spray treatment	N (%)
M0	19.37 ^{c}	F0	19.29 ^{b}
M1	21.91^{bc}	C2	23.23^{a}
M2	24.87^{a}	B1	21.32 ^{ab}
NPK	22.15^{b}	B2	23.95 ^{a}
MSD (α=0.05)	2.6079	C1	22.37 ^{ab}
		EG	22.76 ^{ab}
		MSD (α = 0.05)	3.5627
	CV (%): 6.45		

Table 7: Interaction Effect of Manure and Foliar Sprays on Nitrogen Concentration

Foliar Sprays						
Manure	**B1**	**B2**	**C1**	**C2**	**EG**	**F0**
M0	18.64[a]	22.10[a]	18.33[a]	21.65[a]	19.41[a]	16.09[a]
M1	21.12[a]	24.31[a]	22.82[a]	23.26[a]	20.78[a]	19.16[a]
M2	25.21[a]	25.55[a]	25.09[a]	26.30[a]	27.07[a]	20.03[a]
NPK	22.16[a]	23.83[a]	21.49[a]	21.71[a]	21.81[a]	21.88[a]
Mean	21.78	23.45	21.93	23.23	22.27	19.29
		CV (%): 6.45				

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1= Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week.

4.1.2 Phosphorus and Potassium Concentration

Analysis of variance showed no significant ($p <0.05$) main effects of manure ($p = 0.6406$), and foliar spray ($p = 0.5107$), and their interaction ($p = 0.3596$) on phosphorus concentration in common bean at flowering (R1) stage (Table 9) (Table 10). Similarly, for potassium, no significant ($p< 0.05$) main effects of foliar spray ($p = 0.3192$) and manure ($p = 0.8872$) (Table 9) and their interaction ($p = 0.9462$) were observed (Table 9) (Table 11).

Table 8: Main Effect of Manure and Foliar Spray on the Phosphorus (P) and Potassium (K) Concentration in the Common Bean Tissues at R1 Stage

Manure treatment	**P(ppm)**	**K (%)**	**Foliar spray treatment**	**P(ppm)**	**K (%)**
NPK	220.45[a]	0.04[a]	EG	221.90[a]	0.04[a]
M0	219.63[a]	0.04[a]	B1	226.53[a]	0.04[a]
M1	219.17[a]	0.04[a]	F0	216.36[a]	0.04[a]
M2	213.09[a]	0.04[a]	C1	215.93[a]	0.04[a]
MSD(α=0.05)	16.92	0.01	B2	214.96[a]	0.04[a]
			C2	212.82[a]	0.04[a]
			MSD(α=0.05)	23.11	0.01
CV: 7.6%					

Table 9: Effect of Manure and Foliar Sprays Interaction on Phosphorus Content in the Common Beans' Tissues

Manure \ Foliar	**B1**	**B2**	**C1**	**C2**	**EG**	**F0**
M0	231.67[a]	221.91[a]	213.07[a]	222.75[a]	214.59[a]	213.79[a]
M1	219.43[a]	217.67[a]	236.06[a]	196.88[a]	232.11[a]	212.88[a]
M2	209.03[a]	211.91[a]	190.72[a]	218.43[a]	234.75[a]	213.67[a]
NPK	227.47[a]	208.36[a]	223.87[a]	213.23[a]	224.67[a]	225.11[a]

Table 10: Mean Separation for Manure × Foliar Spray Interaction on Potassium (K) Content in Common Beans Tissues (%)

Manure \ Foliar	B1	B2	C1	C2	EG	F0
M0	0.04^{a}	0.03^{a}	0.03^{a}	0.03^{a}	0.04^{a}	0.04^{a}
M1	0.04^{a}	0.03^{a}	0.04^{a}	0.04^{a}	0.04^{a}	0.04^{a}
M2	0.03^{a}	0.04^{a}	0.03^{a}	0.04^{a}	0.03^{a}	0.04^{a}
NPK	0.04^{a}	0.04^{a}	0.04^{a}	0.04^{a}	0.03^{a}	0.04^{a}

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week.

4.2 The Effect of Cattle Manure and Foliar Sprays of Blackjack and Comfrey Leaf Extracts on the Growth of Common Beans

4.2.1 Height

i) Third Trifoliate Leaf Fully Expanded (V3)

The findings of the study showed that the main effect of manure on bean height at V3 was statistically significant ($p<0.05$) (Table 12). Treatments M2 had the tallest plants of 10.76 cm while M0 (no manure application) resulted in lowest mean height (8.25 cm) (Table 12). The main effect of foliar spray on common bean height, on the other hand, was not statistically significant at $p<0.05$ (Table 12). Similarly, the interaction effect of foliar spray and manure was not significant at $p<0.05$.

Table 11: Main Effect of Foliar Spray and Manure on the Height (cm) of Common Beans at V3 Stage of Growth (cm)

Manure treatment	Mean height (cm)	Foliar treatment	Mean height (cm)
M2	10.76^{a}	C1	10.33^{a}
M1	10.07^{ab}	EG	10.06^{a}
NPK	9.74^{b}	F0	9.77^{a}
M0	8.25^{c}	C2	9.42^{a}
MSD (α = 0.05)	1.091	B2	9.35^{a}
		B1	9.3^{a}
		MSD (α = 0.05)	1.498
CV: 8.94%			

Means followed by the same letter in a column are not significantly different at $p<0.05$

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week.

ii. Fourth Trifoliate Leaf Fully Expanded (V4)

At V4 growing stage of common beans, the main effects of manure and foliar spray on common bean height at V4 were significant ($p<0.05$). Common bean in treatments M2, M1 and NPK were significantly ($p<0.05$) taller than the control (M0) (table 13). The tallest plants were observed in treatments M2 and M1. There were no significant differences in treatments M1 and NPK. For foliar sprays, treatment C1, EG, B2 and F0 produced the tallest plants. Common bean height in treatment C1 was significantly different ($p<0.05$) from treatment B1 and C2, which produced the shortest beans (table 13). No significant difference was observed for interaction of foliar spray and manure treatments at $p<0.05$.

Table 12: Main effect of manure and foliar spray on the height of common beans at V4 stage of growth (cm)

Manure treatment	Mean height (cm)	Foliar treatment	Mean height(cm)
M2	15.85[a]	C1	15.44[a]
M1	15.33[ab]	EG	15.22[ab]
NPK	14.71[b]	F0	14.77[ab]
M0	12.49[c]	B2	14.34[ab]
MSD(α=0.05)	1.0173	B1	13.93[b]
		C2	13.88[b]
		MSD (α=0.05)	1.3898
	CV: 7.84%		

Means followed by the same letter in a column are not significantly different at p<0.05

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice week, C1 = Comfrey spray once a week EG =Easy grow, C2= Comfrey spray twice a week.

iii. Fifth Trifoliate Leaf Fully Expanded (V5) and Full Pod Fill Stage (R6)

The main effect of manure on height of common bean at V5 growing stage was significant (p<0.05). Common bean was taller in treatments M2 (mean = 20.73 cm) but the control had the shortest plants (M0) (mean = 15.90 cm). There were no significant differences in the height of common beans in M2, M1 and NPK treatments (Table 14). For foliar spray treatments, no statistically significant differences at p<0.05 were detected. The foliar treatments had means ranging from 19.65 cm (C1) to 18.11 cm (C2). Analysis of Variance (ANOVA) did not show statistically significant (p<0.05) interaction effect of manure and foliar spray on height of common bean at V5.

At the full pod fill stage (R6), the main effect of cattle manure on common bean height was statistically significant (p<0.05). Common beans treated with M2, M1, and NPK attained significantly greater average heights compared to the control (M0) (Table 14). The main effect of foliar spray was not statistically significant (p<0.05). Common bean height ranged from 24.60 (B1) to 22.43 cm (B2) in the foliar treatments.

Table 13: Main Effect of Manure on the Height (cm) of Common beans at V5 and R6 Stages of Growth (cm)

Manure	**Mean height(cm) at V5**	**Mean height(cm) at R6**
M2	20.72^{a}	26.25^{a}
NPK	19.73^{a}	25.00^{a}
M1	19.56^{a}	24.78^{a}
M0	17.33^{b}	19.64^{b}
MSD(α=0.05)	1.6314	1.8987
CV (%)	**9.69**	**8.93**

Means followed by the same letter in a column are not significantly different at $p<0.05$

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27)

Table 14: Interactive Effect of Manure and foliar spray on the height of common beans at R6 stage of growth (cm)

	Foliar Sprays					
Manure	F0	B1	B2	C1	C2	EG
M0	22.14^{e}	22.79^{e}	15.75^{f}	19.47^{f}	17.95^{f}	19.71^{f}
M1	23.29^{de}	24.66^{bcd}	24.38^{cde}	26.55^{a}	24.64^{bcd}	26.49^{a}
M2	24.46^{cde}	27.68^{a}	24.84^{bc}	26.41^{ab}	26.97^{a}	27.15^{a}
NPK	26.60^{a}	23.29^{de}	24.76^{bc}	25.29^{abc}	23.99^{de}	24.74^{bc}

Means followed by the same letter in a column are not significantly different at $p<0.05$

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week) EG =Easy grow, C2= Comfrey spray twice a week.

4.2.2 Number of Branches

The main effect of manure on number of branches at V5 and R6 growth stages was statistically significant (p<0.05). Treatments M2, M1 and NPK had the highest number of branches at both stages (Table 16). The means of these treatments were significantly higher than for control (M0) (Table 16). There were no significant differences in number of branches amongst the foliar spray treatments or their combination with manure treatment at both stages at p<0.05. At growing stage V5, foliar spray treatments C1 and F0 had the highest number of branches (3.83), while B1 and C2 had the lowest (3.42)**.** The same results were found at stage R6, where the highest number of branches was observed in F0 (7.42), while C2 had the lowest (6.75) but all were statistically grouped under the same turkey grouping. For treatments combination, the highest number of branches (4.67) was observed in M2× EG, while the lowest (2.33) occurred in M0× C2 at growing stage V5 (Table 17), but no significant difference was revealed. At R6, the highest number of branches (8.67) was recorded in M2× C2, while the lowest (4.67) occurred in M0×B2 (Table 17)

Table 15 : Main Effect of Manure on the Number of Branches at V5 and R6 Stage of Growth

Manure Treatment	**Mean number of branches (V5)**	**Mean number of branches (R6)**
M2	4.06[a]	8.11[a]
M1	3.83[a]	7.22[a]
NPK	3.78[a]	7.22[a]
M0	3.00[b]	5.61[b]
MSD(α=0.05)	0.6712	1.3745
CV (%)	20.60	21.97

Table 16: Interaction of Manure and Foliar Sprays on the Number of Branches at V5

Manure \ Foliar	**B1**	**B2**	**C1**	**C2**	**EG**	**F0**
M0	3.00[a]	3.00[a]	3.33[a]	2.33[a]	2.67[a]	3.67[a]
M1	3.67[a]	4.00[a]	4.00[a]	3.67[a]	4.33[a]	3.33[a]
M2	3.67[a]	4.00[a]	3.67[a]	4.33[a]	4.67[a]	4.00[a]
NPK	3.33[a]	4.00[a]	4.33[a]	3.33[a]	3.33[a]	4.33 [a]

Table 17: Interaction of Manure and Foliar Sprays on the Number of Branches at R6

Manure \ Foliar	**B1**	**B2**	**C1**	**C2**	**EG**	**F0**
M0	6.33[a]	4.67[a]	5.67[a]	4.67[a]	5.67[a]	6.67[a]
M1	7.00[a]	7.33[a]	7.33[a]	6.67[a]	8.33[a]	6.67[a]
M2	8.00[a]	8.33[a]	7.67[a]	8.67[a]	8.33[a]	7.67[a]
NPK	6.33[a]	7.00[a]	8.00[a]	7.00[a]	6.33[a]	8.67[a]

Means followed by the same letter in a column are not significantly different at $p<0.05$

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week.

4.2.3 Biomass

The main effects of both manure and foliar spray on the biomass of common bean were statistically significant ($p<0.05$) at flowering stage (R1) (Appendix G). The highest biomass (47.45 g) was observed in treatment M2 (Table 19). Treatment M1 and the untreated control (M0) had the lowest biomass of 36.83 g and 36.80g, respectively. Significantly, higher biomass was observed in treatments C1 and EG than C2 and B1 at $p<0.05$ for foliar sprays (Table 19). The effect of interaction between manure and foliar spray on biomass of common bean was significant ($p<0.05$) (Table 20).

Table 18: Main Effect of Manure and Foliar Spray on Biomass of Common Beans at R1 Stage of Growth(g)

Manure	Mean Biomass(g)	Foliar Spray	Mean Biomass(g)
M2	47.45^{a}	C1	45.01^{a}
NPK	42.55^{b}	EG	43.62^{a}
M1	36.83^{c}	B2	40.82^{ab}
M0	36.80^{c}	F0	40.53^{ab}
MSD(α=0.05)	3.73	C2	37.79^{b}
		B1	37.68^{b}
		MSD(α=0.05)	5.0955
CV (%): 10.26			

Means followed by the same letter in a column are not significantly different at *p*<0.05

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week.

Table 19: Interactive Effect of Manure and Foliar Spray on the Biomass of Common Beans

	Foliar spray					
Manure	F0	B1	B2	C1	C2	EG
M0	44.81^{abcd}	39.61^{cde}	31.98^{e}	38.49^{cde}	31.50^{e}	34.38^{de}
M1	30.83^{e}	27.29^{e}	41.41^{bcd}	46.01^{abc}	31.40^{e}	44.05^{abcd}
M2	41.46^{bcd}	45.13^{abc}	43.99^{abcd}	50.10^{ab}	49.24^{ab}	54.76^{a}
NPK	45.02^{abc}	38.70^{cde}	45.88^{abc}	45.46^{abcd}	39.00^{cde}	41.26^{bcd}

Means followed by the same letter in a column are not significantly different at *p*<0.05

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week

4.2.4 Days to 50% Flowering and Pods

The results showed no significant effects of manure, foliar spray, or their interaction on number of days to 50% flowering of common beans and days to 50% pods formed at $p<0.05$. In comparison to beans without manure (M0), which took an average of 46.06 days to reach 50% flowering, beans treated with NPK took longer (46.94 days). For foliar sprays, 46.75 days was the longest average number of days to

50% blooming under treatment B1, while 46.17 days for B2 was the shortest. In terms of interaction effects, NPK × B1 and NPK × C2 recorded the longest time to flowering (48.33 days), while the combination M0 × EG produced the shortest time to flowering (44.67 days). For pods, treatment M0 took the lowest mean days to develop 50 % pods (54.33 days), whereas M2 took more days (56.06). On the other hand, for foliar spray, treatment B1 had the lowest mean (55.00 days) and EG, the highest mean (56.3 days) to develop 50% of pods. For interaction, treatment M0×F0 developed 50% of pods earlier (53.33 days), whereas NPK× B1 took longer (58.33 days).

4.2.5 Number of Pods

Main effect of manure treatments on the average number of pods in common bean was significant ($p<0.05$). On the contrary, foliar spray treatments and the combination of manure and foliar spray did not have any significant effect on the number of pods at $p<0.05$. With mean of 14.39 pods per bean, M2 performed significantly better than all other treatments. Treatment NPK came in second with 12.61 pods, while treatment M1 came in third with 12.39 pods (Table 21). Treatment M0 produced the least pods (9.33). For foliar sprays, the number of pods per plant varied from EG spray which produced the most pods on average (13.25), followed by B1 (12.67) and F0 (12.33). In the B2 treatment, the fewest pods were found (10.67) but these differences were not statistically significant. Treatment combinations ranged from a low number of 6.00 pods observed under M0 × B2 to a high of 16.00 pods recorded in multiple treatments including M1 × EG, M2 × C2, and M2 × EG., although no significant difference was recorded (Table 22).

Table 20: Main Effect of Manure on the Number of Pods per Common Bean

Manure Treatment	Mean Pods/Plant
M2	14.39[a]
NPK	12.61[b]
M1	12.39[b]
M0	9.33[c]
MSD(α=0.05)	0.5308
CV (%)	16.87

Means followed by the same letter in a column are not significantly different at p<0.05

Table 21: Effect of Combining Cattle Manure and Foliar Sprays on the Number of Pods on Beans

Manure \ Foliar	B1	B2	C1	C2	EG	F0
M0	11.67[a]	6.00[a]	8.67[a]	8.33[a]	9.33[a]	12.00[a]
M1	12.00[a]	12.67[a]	12.00[a]	11.67[a]	16.00[a]	10.00[a]
M2	15.00[a]	12.33[a]	14.00[a]	16.00[a]	16.00[a]	13.00[a]
NPK	12.00[a]	11.67[a]	14.00[a]	12.00[a]	11.67[a]	14.33[a]

Means followed by the same letter in a column are not significantly different at *p*<0.05

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week

4.2.6 Leaf Area Index at V4 and R6 Growth Stage

Leaf Area Index (LAI) at V4 growing stage was significantly affected (p<0.05) by both foliar spray (Table 23) and the manure-foliar spray interaction (Table 24). The mean LAI values for manure ranged from 0.12 (M0) to 0.14 (M1). Although M1 treatment recorded the highest average LAI, followed by M2, NPK, and M0, the differences among them were not statistically significant at p<0.05. For foliar sprays, treatment C1 produced beans with high leaf area indexes and it was significantly different from treatment C2 and F0 (p<0.05) (Table 23). The combination effect of manure and foliar spray treatments was significant (p<0.05). The highest LAI (0.170) was observed under the M1 × C1 treatment. In contrast, the lowest LAI (0.090) was recorded in M0 × C2 and M1 × F0. Treatments involving M1 manure generally resulted in higher LAI values, particularly when combined with foliar sprays like C1 and EG (Table 24). At R6 growing stage, all levels (M0, M1, M2, and NPK) fell into the same statistical group; they had no discernible effect on leaf area index (LAI) at p<0.05. The range of LAI values for manure treatments was 0.15 for the control (M0) to 0.16 for treatment M1. For foliar spray treatments, though no statistical significance was revealed (p<0.05); C1 recorded the greatest LAI (0.15), while F0 recorded the lowest (0.11). For interaction, also there was no statistical significance, but M1 × C1 (0.190) and M1 × EG (0.1867) generated the highest LAI values while M0 × C2 (0.1233) and M1 × F0 (0.120) had the lowest LAI values.

Table 22: Main Effect of Foliar Spray on Leaf Area Index of Common Beans at V4 Growth Stage

Foliar Sprays	**Mean LAI (V4)**
C1	0.15^{a}
EG	0.14^{a}
B1	0.13^{a}
B2	0.13^{a}
C2	0.12^{b}
F0	0.11^{b}
MSD(α=0.05)	0.0326
CV (%)	20.65

Means followed by the same letter in a column are not significantly different at *p*<0.05

Table 23: Main Effect of Manure and Foliar Sprays Interaction on Leaf Area Index of Common Beans at V4 Growing Stage

Manure	B1	B2	C1	C2	EG	F0
M0	0.117^{bcde}	0.137^{abcd}	0.117^{bcde}	0.090^{e}	0.157^{abc}	0.130^{abcd}
M1	0.150^{abcd}	0.14^{3abcd}	0.170^{a}	0.137^{abcd}	0.160^{ab}	0.090^{e}
M2	0.140^{abcd}	0.113^{cde}	0.157^{abc}	0.120^{bcde}	0.100^{de}	0.140^{abcd}
NPK	0.117^{bcde}	0.123^{bcde}	0.147^{abcd}	0.133^{abcd}	0.143^{abcd}	0.093^{e}

Means followed by the same letter in a column are not significantly different at $p<0.05$

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week

4.3 Yield

4.3.1 Harvest Index (HI)

Both manure and foliar spray had significant main effects on harvest index HI ($p<0.05$), whereas the interaction effect (manure and foliar spra**y**) was not significant ($p<0.05$**).** The highest HI (0.40389) was found in M2, which was comparable to NPK and significantly different from M0 and M1(Table 25). Among foliar sprays, C2 and B1 showed significant different HI compared to EG and F0 (Table 25).

Table 24: Main Effect of Manure and Foliar Spray on the Harvest Index (HI) of Common Bean

Manure	Mean HI	Foliar spray	Mean HI
M0	0.32^{b}	C1	0.38^{abc}
M1	0.34^{b}	C2	0.40^{a}
M2	0.40^{a}	B1	0.40^{a}
NPK	0.39^{ab}	B2	0.39^{ab}
MSD(α=0.05)	0.0409	EG	0.34^{c}
		F0	0.31528^{bc}
		MSD(α=0.05)	0.0560
CV (%)		17.55	

Means followed by the same letter in a column are not significantly different at $p<0.05$

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week, HI: Harvest Index

4.3.2 Hundred Seed Weight (HSW)

The analysis of variance (ANOVA) results for a hundred seed weight (HSW) revealed significant main effects of both manure and foliar spray (p<0.05). The highest mean HSW in manure treatments was 45.51g (Table 26). The control (M0) had the lowest HSW, measuring 41.06 g and was significantly different from M2 and M1 (Table 26). For foliar spray, F0 had the lowest mean weight (40.45 g), while treatment C1, B2, and EG had higher HSW values (above 44 g) than the control (F0) (p<0.05) (Table 26). The effect of interaction of manure and foliar spray on HSW was not significant at p<0.05. The highest HSW were observed in M2 combined with B2 (47.95 g) and B1 (47.06 g) while the lowest weights were recorded in M0 with C2 (37.37 g) and F0 (38.93 g).

Table 25: Main Effect of Manure and Foliar Spray on Hundred Seed Weight (HSW) of Common Beans

Manure	Mean HSW (g)	Foliar Spray	Mean HSW (g)
M2	45.51[a]	C1	44.49[a]
M1	43.96[a]	B2	44.48[a]
NPK	43.35[a]	EG	44.39[a]
M0	41.06[b]	B1	43.90[a]
MSD(α=0.05)	2.6801	C2	43.11[a]
		F0	40.45[b]
CV (%): 8.67		MSD(α=0.05)	3.6613

Means followed by the same letter in a column are not significantly different at $p<0.05$

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1=Blackjack spray once a week, B2 =Blackjack spray twice a week, C1 = Comfrey spray once a week) EG =Easy grow, C2= Comfrey spray twice a week, HSW= Hundred Seed Weight

4.3.3 Yield per Hectare

The analysis of variance (ANOVA) showed that main effects of foliar sprays, manure, and their combination on the yield of common bean were significant at p<0.05. An excellent fit was indicated by the model's explanation of 86.37% of the total variation (R^2 = 0.8637) (Appendix K). All other manure treatments were greatly outperformed by the application of treatment M2, which produced the greatest mean yield (1652.31 kg ha^{-1}) and was significantly different from M1 (1334.89 kg ha^{-1}) and NPK (1380.90 kg ha^{-1}), which were both significantly higher than the control (M0) (1016.05 kg ha^{-1}). In comparison to all other foliar treatments, treatment C2, had the highest yield (1669.77 kg ha^{-1}) which was significantly different from treatment EG (1401.57 kg ha^{-1}), B2 (1348.65 kg $ha^{-1)}$, B1 (1333.04 kg ha^{-1}) and C1 (1282.16 kg ha^{-1}) and F0 (Table 27). With a yield of 1041.04 kg ha^{-1}, the treatment F0 was the least productive of all the foliar treatments. For interaction, M2× C2 and M2×B1 showed the maximum yield, while M0× F0, M1×F0, M0×C2, M0×B2 had lowest yield (Table 28).

Table 26: Main Effect of Manure on the Yield of Common Beans ($kgha^{-1}$)

Manure	**Mean yield($kgha^{-1}$)**	**Foliar spray**	**Mean yield ($kgha^{-1}$)**
M2	1652.31^{a}	C2	1669.77^{a}
NPK	1380.90^{b}	EG	1401.57^{b}
M1	1334.89^{b}	B2	1348.65^{b}
M0	1016.05^{c}	B1	1333.04^{b}
MSD(α=0.05)	139.05	C1	1282.16^{b}
		F0	1041.04^{c}
CV: 6.43%		MSD(α=0.05)	189.96

Means followed the same letter in a column are not significantly different at $p<0.05$.

Table 27: Interactive Effect of Manure and Foliar Spray on Yield of Common Beans ($kgha^{1}$)

	Foliar spray					
Manure	B1	B2	C1	C2	EG	F0
M0	1137.65^{gh}	928.18^{ij}	1133.49^{gh}	934.07^{ij}	1063.81^{hi}	899.09^{j}
M1	1192.35^{fgh}	1405.50^{de}	1116.79^{gh}	1694.41^{bc}	1658.28^{bc}	942.02^{ij}
M2	1776.93^{ab}	1678.95^{bc}	1334.61^{ef}	2373.88^{a}	1462.49^{cd}	1287.01^{ef}
NPK	1225.23^{fg}	1381.95^{de}	1543.77^{cd}	1676.71^{bc}	1421.71^{de}	1036.04^{hi}

Means followed the same letter in a column are not significantly different at $p<0.05$.

Key: M0 = Control, M1 = 5t ha^{-1}, M2 =10t ha^{-1}, NPK =NPK (27-27-27), F0 =Control (nothing applied), B1= Black jack spray once a week, B2 =Black jack spray twice a week, C1 = Comfrey spray once a week, EG =Easy grow, C2= Comfrey spray twice a week

4.3.4 Protein in Seeds

The main effects of manure, foliar spray and their interaction at $p<0.05$ on protein content in seeds were non-significant for manure treatments, protein content ranged from 24.87% in M2 to 19.37% in M0 (Figure 5). For foliar sprays, mean values of 23.95% in B2 and 19.29% in F0 were observed (Figure 5). Although the manure and foliar spray interaction was not significant at $p <0.05$, the combination of treatment M2 with treatment EG or C2 foliar sprays produced higher protein contents 27.07% and 26.30%, respectively.

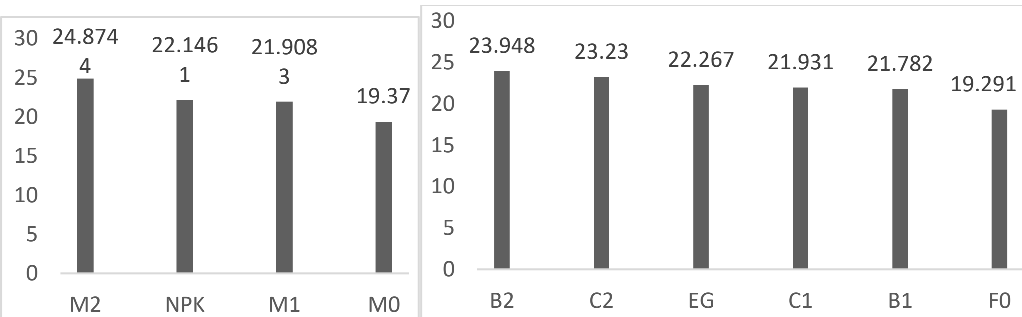


Figure 5: The Effect of Manure and Foliar Sprays on Protein Content of Bean Seeds

Table 28: Interactive Effect of Manure and Foliar Spray on Yield of Common Beans ($kgha^{-1}$)

Manure \ Foliar	B1	B2	C1	C2	EG	F0
M0	18.64^{a}	22.10^{a}	18.33^{a}	21.65^{a}	19.41^{a}	16.09^{a}
M1	21.12^{a}	24.31^{a}	22.82^{a}	23.26^{a}	20.78^{a}	19.16^{a}
M2	25.21^{a}	25.55^{a}	25.09^{a}	26.30^{a}	27.07^{a}	20.03^{a}
NPK	22.16^{a}	23.83^{a}	21.49^{a}	21.71^{a}	21.81^{a}	21.88^{a}
CV (%): 4.16						

CHAPTER FFIVE

DISCUSSIONS

5.1 Effect of Cattle Manure Combined with Foliar Sprays of Blackjack and Comfrey Leaf Extracts on Nitrogen, Phosphorus and Potassium Concentration in Common Beans at Flowering (R1) Stage

The results of this study confirmed that the significant improvement of nitrogen concentration in common beans tissues was due to the highest manure rate application M2 (10 t ha^{-1}), which compared well to treatment M1(5t ha^{-1}), and NPK fertilizer. The control (M0) treatment resulted in beans with lowest nitrogen concentration in tissues. This shows that beans require a noticeable amount of nitrogen when grown in acid soils. The pH of the soil was acidic (pH water:5.45-6.21). High manure levels greatly contributed to nitrogen accumulation in bean tissues. Manure expanded the total nitrogen pool in the soil and boosted the availability of ammonium and nitrate for root absorption (Nadeem *et al*., 2023). We are assuming that fixation was low in acid soils.

Foliar sprays of comfrey and blackjack, applied either weekly or biweekly, had similar effects on nitrogen concentration in common bean at R1 as the commercial easy grow (EG) foliar spray. Common bean in the control (no foliar applied) had lower values compared to biweekly foliar sprays of black jack and comfrey extracts. This aligns with the nutrient content of these amendments and the nitrogen demand of common beans. Foliar application likely provided readily absorbable nitrogen forms, unlike slower mineralization of organic manure nitrogen (Delgado *et al*., 2016; Schjoerring, 2023). A study by Basdemir *et al.* (2022b) showed that vermicompost sprayed on leaves had a more rapid but less long-lasting nutritional effect, promoting short-term vegetative growth but falling short of the long-term nitrogen buildup observed with soil-applied cattle manure. Therefore, combining 10t/ha SI units or 100g per hole of cattle manure application with foliar sprays of nutrient-rich plants like comfrey and blackjack twice a week (C2, B2) can optimize nitrogen availability, and nitrogen concentration in tissues which can boost common bean yield.

Both manure and foliar spray did not significantly affect the concentration of phosphorus and potassium in common bean tissues at R1. This may be attributed to slow mineralization of manure under natural conditions (Ramazanoglu *et al.* (2024). Additionally, due to the acidic soil conditions at the site (pH 5.45 to 6.21), phosphorus is likely to have been fixed by aluminum and iron, making it unavailable for plant uptake (Mitra *et al.*, 2022). Additionally, limiting its short-term impact phosphorus is less mobile and less efficiently absorbed through foliar application (Niu *et al.*, 2021). Similarly to potassium, the study conducted by Ishfaq *et al*. (2022) reported that potassium is also less mobile and is more effectively absorbed through roots than leaves; the study showed that while foliar-applied potassium improved plant growth and slightly increased total potassium uptake in wheat and maize, the majority of potassium was still absorbed through the roots, indicating that foliar application acts as a supplement rather than a replacement for root uptake. In addition, In acidic soils, cation competition may have further reduced potassium uptake and its overall effectiveness (Han *et al*., 2019) . While tailored soil testing is essential to identify phosphorus and potassium limitations; also, site-specific strategies such as targeted placement of phosphorus fertilizers or use of potassium-enriched composts may be necessary to overcome fixation and ensure adequate supply during critical growth stages like flowering and pod filling (Cropnuts Guide, 2024; Cobucci & Nascente, 2014).

5.2. The Effect of Cattle Manure Combined with Foliar Sprays of Blackjack and Comfrey Leaf Extracts on the Growth of Common Beans

In common bean production, plant height, number of branches, biomass, leaf area index (LAI) are vital indicators of growth. Plant height and branching reflect vegetative vigor while biomass and LAI indicates overall productivity and photosynthetic capacity. The results of this study demonstrated significant increases in common bean height at vegetative and reproductive stages (V3, V4, V5, and R6) after fertilizer application. The manure levels M2 (10 t ha^{-1}) M1 (5t ha^{-1}) and NPK (27-27-27) as positive control consistently produced tallest beans compared to no-manure control (M0). This can be attributed to nitrogen supply from manure mineralization and fertilizer. Nitrogen promotes leaves, stems, and other vegetative parts of plants and consequently helps in growth and development (Mazahar & Rainah, 2022). Similar results were shown in study conducted by Francine *et al*. (2021) who reported that the climbing beans treated with cattle manure produced highest average height (243.39cm) while the control treatments produced shortest beans (97.81cm). For foliar spray treatment, only at growing stage V4, was the effect was revealed where treatment C1(comfrey spray once a week), (EG: Easy grow, both vegetative and flower and fruits), B2 (Black jack twice a week) and F0 (without foliar spray) produced the tallest plants than B1 (black jack once a week) and C2 (comfrey twice a week) which had shortest plants.

When compared to other growth stages, the observed lower efficacy of treatment C1 and B2, specifically at the V4 growth stage, was probably due to important physiological traits of common bean plants at this stage. Rapid stem extension and the onset of lateral branches characterize the V4 stage, a crucial time in common bean vegetative growth (Mamo *et al*., 2023). The plant becomes less receptive to treatments that primarily encourage vegetative growth after the V4 stage as resource allocation starts to shift toward reproductive development (Costa *et al.*, 2013). The greater effect of foliar treatments at V4 compared to earlier stages may be explained by this physiological shift and at this stage, stomata are more opened to absorb more nutrient. The fact that treatment C1 (comfrey applied once weekly) worked better than treatment C2 (comfrey applied twice weekly) indicates that applying comfrey too frequently may have negative consequences, presumably because of phytotoxicity or foliar overload, which can cause symptoms like leaf burn as observed in our experiment. However, B2 (Blackjack sprayed twice a week) slightly outperformed B1 (Black Jack sprayed once a week) (no significantly different at $p<0.05$), suggesting that increasing the frequency of black jack spray boosted vegetative development, most likely as a result of better nutrient or bio stimulant delivery. It is interesting to note that the untreated control (F0) outperformed both B1 and C2, suggesting that some foliar spray applications can hinder rather than promote growth.

Branching was significantly enhanced by manure application at both V5 and R6 stages, with M2, M1, and NPK treatments yielding more branches than the control (M0). This is consistent with the findings of (Fekadu *et al*., 2018) who reported that the application of cattle manure increased the number of branches for common beans due to high nitrogen content of cattle manure and potassium which favored vegetative growth . Sharifi *et al*. (2024), also reported that 10 t ha^{-}1 of cattle manure improved the number of branches per plant comparing to the control with average of 26 branches per plant. The lack of significant effect from foliar sprays or their interaction with manure on branching shows that soil nutrient status is the primary determinant of branching in beans, with foliar nutrients playing a minor role unless soil deficiencies are present which implies that the soil was containing ample soil nutrients due to manure application (Kinrade, 2025).

Biomass production was significantly influenced by both manure and foliar spray treatments, as well as their interaction. The highest biomass was observed in M2 (10 t ha^{-1}), followed by NPK (27-27-27, 185kg ha^{-1}), while M1(5t ha^{-1}) and M0 (no manure) produced the lowest biomass. The study conducted by Ngakou *et al.* (2008) reported that cattle manure application resulted in high mean biomass (8.54g/plant) and was significantly different from the control that yielded low biomass beans (1.31g/plant). Among foliar sprays, comfrey applied once a week (C1) and Easy Grow (EG) resulted in the greatest biomass, suggesting that these treatments may enhance nutrient uptake or physiological efficiency under certain conditions. This agrees with the results of Byan (2014) who reported that the snap beans treated with licorice extract produced high dry and wet weight compared to the control. The combination of M2 and EG yielded the highest overall biomass, which supports the concept of integrated nutrient management as advocated by Agegnehu *et al*. (2016), who found that combining organic amendments with targeted foliar applications maximizes growth and yield in legumes. Neither manure nor foliar spray treatments, nor their interactions, had a significant effect on the number of days to 50% flowering and pods. This indicates that the timing of reproductive development in common beans is relatively insensitive to variations in nutrient supply from the tested amendments. This agrees with the findings of Wilczek *et al.*(2010) and Selvakumar *et al*. (2025) who noted that phenological events as well as development timing such as flowering are more strongly influenced by genetic and environmental factors than by moderate differences in nutrient availability. However, numerical tendencies were observed; plots without manure (M0) reached 50% flowering and pods development earliest while those with the highest manure rate (M2, 10 t ha^{-1}) took the longest.

In contrast, the number of pods per plant was significantly influenced by manure application ($p < 0.05$). The highest pod number was achieved with the application of 10 t ha^{-1} of cattle manure (M2, 14.39 pods/plant), which was significantly greater than the control (M0, 9.33 pods/plant). NPK and M1 (5 t ha^{-1} manure) produced also high number of pods (12.61 and 12.39 pods/plant, respectively) compared to the control. Foliar sprays did not significantly affect pod number, with all treatments statistically similar, although EG and B1 had numerically higher pod counts. The interaction between manure and foliar sprays was also not significant for pod number. This highlights the primary importance of soil fertility, particularly organic amendments, in supporting reproductive output in beans.

Leaf area index (LAI) at the V4 stage was significantly affected by foliar spray and the interaction between manure and foliar spray ($p < 0.05$), but not by manure alone. The highest LAI was observed in C1 (Comfrey, once a week, 0.1475), while treatment C2 (comfrey spray twice a week) and F0 (without foliar spray) recorded low LAI. The study conducted by Jeevaa *et al.*(2025), showed that foliar spray fertilizers may boost growth including leaf area index by supplying nutrients directly to leaves, promoting faster growth and expansion. This can lead to larger, more efficient leaf development during key growth stages compared to manure applied fertilizers. For combinations, M1×C1 recorded high LAI while M0×C2 and M1×F0 produced low LAI, which implies that high frequency of applying comfrey can cause various harmful effects including toxicity and leaf burn as observed on leaves of the treated beans. Treatment without foliar spray produced beans with low LAI, which implies the inadequacy of nutrients for vegetative growth since manure nutrient release is very slow. At the R6 stage, treatment effects were not significant, although C1 and EG maintained the highest LAI. These results suggest that foliar sprays, especially comfrey applied once a week may enhance early canopy development, but this effect does not necessarily persist to later stages.

5.3 The Effect of Cattle Manure Combined with Foliar Sprays of Blackjack and Comfrey Leaf Extracts on Yield and Protein of Common Beans

For harvest index, significant effects of both manure and foliar spray treatments were observed. The harvest index measures how efficiently the plant converts biomass into grain yield. For manure, the best results were found in the highest rate (M2, 0.40389) while for foliar sprays, in C2 (Comfrey, twice a week) and B1 (Blackjack, once a week). Manure derived organic matter enhances soil health, nutrient availability, and water retention, all of which can have a good impact on grain yield and biomass production, potentially raising HI (Mahmood *et al*., 2017). The capability of foliar sprays to advance the HI, shows that foliar extracts can boost the effectiveness of resource allocation to economic yield (Gulmezoglu & Kinaci, 2007). Though interaction was not significant, the highest HI values were seen when M2 was paired with either B1 or C2. This suggest that both organic manure and targeted foliar nutrition can improve the efficiency of biomass partitioning into grain.

Hundred Seed Weight (HSW) was also significantly affected by both manure and foliar spray treatments. HSW reflects seed size, yield quality and market value. The highest HSW was recorded for M2 (45.51 g), followed by M1 (43.96 g) and NPK (43.35 g), while the control (M0) had the lowest (41.06 g). Among foliar sprays, C1, B2, and EG all exceeded 44 g, while the unsprayed control (F0) was lowest at 40.45 g. Although the interaction was not significant, the combination of M2 and B2 produced the highest HSW (47.95 g), suggesting that optimal seed filling occurs under high soil and foliar nutrient availability. According to Tadesse *et al.* (2022), farmyard manure (FYM) improved soil health and nutrient availability, which led to a considerable rise in hundred seed weight. They reported that FYM levels of 2.5–5 t/ha increased seed weight because of enhanced nutrient uptake and root development. Additionally, by encouraging microbial activity, this organic input improved plant development and produced heavier seeds.

Most notably, yield per hectare was highly responsive to all factors and their interaction ($R^2 = 0.8831$). The highest yield was achieved with treatment M2 (1652.31 kg ha^{-1}), significantly outperforming all other manure treatments. This goes in the line with Agronomiques *et al*., 2020), who reported that common beans treated with manure produced high yield (838.58 kg ha^{-1}) comparing to the control (651.72 kg ha^{-1}). Amongst foliar sprays, C2 (Comfrey, twice a week) produced the highest yield (1669.77 kg ha^{-1}). The interaction between manure and foliar spray was also significant. The combination of M2 and C2 resulted in the maximum yield (2373.88 kg ha^{-1}), though the combination of no manure and no foliar spray (M0 × F0) formed the lower yield (899.09 kg ha^{-1}). This validates a strong complementary effect when high rates of manure are combined with frequent foliar application of Comfrey.

For the effect of treatments on the protein contents of common beans seeds, no main or interaction significant effects were revealed. The highest protein content was in M2 with the average of 24.87% while M0 had the lowest protein content of 19.37%, that ranges with the normal protein content in common beans which is 16-33%. A study by Munyiri *et al*. (2019), on the effect of fertilizer inputs on climbing bean production in Mbeere north subcounty, showed that organic fertilizers at least under the conditions of the study, did not lead to any noticeable changes in the protein levels of the beans. The findings draw attention to the fact that although fertilizer can help boost bean yield, it may not always raise the protein content of the beans.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The broad objective of the study was to contribute to to food and nutritional security in Kenya though increasing nutrient uptake, growth, yield and nutritional quality of common beans (*Phaseolus vulgaris* L.) by applying cattle manure and foliar spray derived from comfrey (*Symphytum officinale* L.) and blackjack (*Bidens pilosa* L.) leaf extracts.

Based on the results of this study, the following conclusions are drawn:

i. Compared to NPK fertilizer and lesser manure rates, cattle manure applied at 10 t ha^{-1} (M2) considerably raises the nitrogen concentration in bean tissues (24.87%). No significant rises in phosphorus and potassium concentrations in bean tissues were observed from the treatments, possibly due to nutrient fixation in acidic soils and dilution effects in foliar extracts.

ii. The maximum common bean yield (2373.88 kg/ha) are obtained by combining high-rate cattle manure (10 t/ha, M2) with twice-weekly comfrey foliar spray (C2), demonstrating the synergistic advantages of integrating soil and foliar nitrogen sources. This integrated strategy confirmed its worth in enhancing productivity by improving biomass, seed weight, and harvest index.

6.2 Recommendations

In areas with similar conditions as the study area,

i. Application of at 10 t ha^{-1} cattle manure is recommended for improving nitrogen concentration in common bean.

ii. Combining 10 tha^{-1} cattle manure with twice-weekly comfrey foliar spray is recommended for increasing common bean yield.

6.3 Areas of Further Studies

i. Integrated approaches used in this study can be tested in acid soils with lime application and the effect on phosphorus and potassium uptake by common bean evaluated.

ii. Further research can be done on the effect of various manure types combined with foliar sprays of comfrey and blackjack extracts on common bean yield.

REFERENCES

Adedapo, A., Jimoh, F., & Afolayan, A. (2011). Comparison of the nutrient value and biological activities of the acetone, methanol and water extracts of the leaves of *Bidens pilosa* and *Chenopodiumalbum*. *ActaPol.Pharm, 68* (1),83-92. https://www.ptfarm.pl/pub/File/acta_pol_2011/1.2011/083-092.pdf

Agegnehu, G., Nelson, P. N., & Bird, M. I. (2016). Plant yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. *Soil and Tillage Research, 160*, 1–13.https://doi.org/10.1016/j.still.2016.02.003

Agronomiques (INERA), R. U. N. pour l'Etude et la R., Nioka, Kinshasa 1, et al. (2020a). Improve Common Bean (*Phaseolus vulgaris* L.) Yield through Cattle Manure in Nioka Region, Ituri Province, DRC. *Open Access Library Journal, 07(09)*, Article 09. Published September 2020. https://doi.org/10.4236/oalib.1106610

Agutaa, A. A. (2015). *Effect of plant rotation pattern on soil bacterial wilt (Ralstonia solanacearum) population and potato (Solanum tuberosum L.) yield in Njoro, Kenya* [Master's thesis or Ph.D. Dissertation, Egerton University]

Alcázar-Valle, M., Lugo-Cervantes, E., Mojica, L., Morales-Hernández, N., Reyes-Ramírez, H., Enríquez-Vara, J. N., & García-Morales, S. (2020). Bioactive compounds, antioxidant activity, and antinutritional content of legumes: a comparison between four Phaseolusspecies. *Molecules*, *25*(15), 3528. https://www.mdpi.com/1420-3049/25/15/3528

Alshaal, T., & El-Ramady, H. (2017). Foliar Application: From Plant Nutrition to Biofortification. *Environment, Biodiversity and Soil Security*, *1(2017)*, 71–83. https://doi.org/10.21608/jenvbs.2017.1089.1006

Amann, A., Herrnegger, M., Karungi, J., Komakech, A. J., Mwanake, H., Schneider, L., Schürz, C., Stecher, G., Turinawe, A., Zessner, M., & Lederer, J. (2021). Can local nutrient-circularity and erosion control increase yields of resource-constraint smallholder farmers? A case study in Kenya and Uganda. *Journal of Cleaner Production, 318*, 128510. Published November 2021. https://doi.org/10.1016/j.jclepro.2021.128510

Amy. (2014, March 31). *Comfrey Fertilizer: Does it Really Improve Soil?* Tenth Acre Farm. Retrieved November 2, 2025, from https://www.tenthacrefarm.com/does-comfrey-really-improve-soil/

Aserse, A. A., Markos, D., Getachew, G., Yli-Halla, M., & Lindström, K. (2020). Rhizobial inoculation improves drought tolerance, biomass and grain yields of common bean (*Phaseolus vulgaris* L.) and soybean (*Glycine max* L.) at Halaba and Boricha in Southern

Ethiopia. *Archives of Agronomy and Soil Science, 66(4)*, 488–501. Published April 2020. https://doi.org/10.1080/03650340.2019.1624724

Banti, M., & Bajo, W. (2020). Review on nutritional importance and anti-nutritional factors of legumes. *Int. J. Food Sci. Nutr*, *9*(13), 8-49. https://doi.org/10.11648/j.ijnfs.20200906.11

Basdemir, F., Ipekesen, S., Tunc, M., Elis, S., & Bicer, B. T. (2022). Effects of Cow manure and liquid vermicompost applications on growth and seed yield of dry beans. *Journal of Elementology,27(4)*.Published December2022.https://doi.org/10.5601/jelem.2022.27.3.2305
Basdemir, F., Ipekesen, S., Tunc, M., Elis, S., & Bicer, B. T. (2022). Effects of Cow manure and liquid vermicompost applications on growth and seed yield of dry beans. *Journal of Elementology,27(4)*.Published December2022.https://doi.org/10.5601/jelem.2022.27.3.2305
Bazargan, K., Marzi, M., Hasheminasab, K. S., Shahbazi, K., & Zare, A. A. (2022). Optimizing ammonium acetate procedure for determining available potassium in Iranian calcareous soils, testing the concentration and contact time. *Journal of Soil Science Society of Iran, 1(1)*, 125–136. Published March 2022. https://doi.org/10.47176/jsssi.01.01.1024

Ben-Gal, A., Tal, A., & Tel-Zur, N. (2006). The sustainability of arid agriculture: Trends and challenges. *Annals of Arid Zone*, *45*(3/4), 227.

Bhattacharjee, S., Paul, K., Sinha, D., & Jha, U. C. (2024). Common Bean (Phaseolus vulgaris) Plant Wild Relatives: Their Role in Improving Climate-Resilient Common Bean. In *Legume Plant Wild Relatives*. CRC Press. Published January 2024.

Bhattacharyya, T., Chandran, P., Ray, S. K., Mandal, C., Tiwary, P., Pal, D. K., Maurya, U. K., Nimkar, A. M., Kuchankar, H., Sheikh, S., Telpande, B. A., & Kolhe, A. (2015). Walkley-Black Recovery Factor to Reassess Soil Organic Matter: Indo-Gangetic Plains and Black Soil Region of India Case Studies. *Communications in Soil Science and Plant Analysis, 46(20)*, 26282648.PublishedNovember2015.https://doi.org/10.1080/00103624.2015.1089265

Bhunia, S., Bhowmik, A., Mallick, R., & Mukherjee, J. (2021). Agronomic efficiency of animal-derived organic fertilizers and their effects on biology and fertility of soil: A review. *Agronomy*, *11*(5), Article 5. https://doi.org/10.3390/agronomy11050823

Bishnoi, S. W., Rozell, C. J., Levin, C. S., Gheith, M. K., Johnson, B. R., Johnson, D. H., & Halas, N. J. (2006). All-Optical Nanoscale pH Meter. *Nano Letters, 6(8)*, 1687–1692. Published August2006.https://doi.org/10.1021/nl060865w

Bitocchi, E., Nanni, L., Bellucci, E., Rossi, M., Giardini, A., Zeuli, P. S., Logozzo, G., Stougaard, J., McClean, P., Attene, G., & Papa, R. (2012). Mesoamerican origin of the common bean (*Phaseolus vulgaris* L.) is revealed by sequence data. *Proceedings of the National Academy of Sciences*, *109*(14), E788–E796. https://doi.org/10.1073/pnas.1108973109

Bolcer, B. E. (2020). *Plant medicine: The use of medicinal plants as green manures in the treatment of Streptomyces scabies infection and potato scab disease* [Master's thesis, Northern Michigan University]

Brummerloh, A., & Kuka, K. (2023). The Effects of Manure Application and Herbivore Excreta on Plant and Soil Properties of Temperate Grasslands—A Review. *Agronomy, 13(12),* Article 12. Published December 2023.https://doi.org/10.3390/agronomy13123010

Byan, U. A. (2014). Effect of foliar spraying by some natural extracts for improving snap bean production. *Egypt J Hort*, *41,* 109-119.

Carbas, B., Machado, N., Oppolzer, D., Ferreira, L., Queiroz, M., Brites, C., Rosa, E. A., & Barros, A. I. (2020a). Nutrients, Antinutrients, Phenolic Composition, and Antioxidant Activity of Common Bean Cultivars and their Potential for Food Applications. *Antioxidants, 9(2),* Article 2. Published February 2020.https://doi.org/10.3390/antiox9020186

Carbas, B., Machado, N., Oppolzer, D., Ferreira, L., Queiroz, M., Brites, C., Rosa, E. A., & Barros, A. I. (2020b). Nutrients, Antinutrients, Phenolic Composition, and Antioxidant Activity of Common Bean Cultivars and their Potential for Food Applications. *Antioxidants, 9(2),* Article 2. Published February 2020. https://doi.org/10.3390/antiox9020186

Carbas, B., Machado, N., Pathania, S., Brites, C., Rosa, E. A., & Barros, A. I. (2023). Potential of Legumes: Nutritional Value, Bioactive Properties, Innovative Food Products, and Application of Eco-friendly Tools for Their Assessment. *Food Reviews International, 39(1),* 160–188. Published January 2023.https://doi.org/10.1080/87559129.2021.1901292

Catarino, S., Brilhante, M., Essoh, A. P., Charrua, A. B., Rangel, J., Roxo, G., ... & Romeiras, M. M. (2021). Exploring physicochemical and cytogenomic diversity of African cowpea and common bean. *Scientific reports*, *11*(1), 12838. https://www.nature.com/articles/s41598-021-91929-2

Chekanai, V., Chikowo, R., & Vanlauwe, B. (2018). Response of common bean (Phaseolus vulgaris L.) to nitrogen, phosphorus and rhizobia inoculation across variable soils in

Zimbabwe. *Agriculture, cosystems&Environment,266*,167. PublishedOctober2018.https://doi.org/10.1016/j.agee.2018.08.010

Costa, D. S. D., Barbosa, R. M., & Sá, M. E. D. (2013). Weed management and its relation to yield and seed physiological potential in common bean cultivars. *Pesquisa Agropecuária Tropical, 43(2),* 147–154. Published April/June 2013.https://doi.org/10.1590/S1983-40632013000200010

Cresswell, J. (2019, May 31). *How to… Make Comfrey 'Extract.'* Brighton and Hove Organic GardeningGroup.Retrieved November 2, 2025, from https://bhorganicgardeninggroup.org/2019/05/31/how-to-make-comfrey-extract/

Crop Nutrition Laboratory Services (Cropnuts). (2024). *Cropnuts Guide 2024*

De Ron, A. M., González, A. M., Paula Rodiño, A., Santalla, M., Godoy, L., & Papa, R. (2016). History of the common bean plant: Its evolution beyond its areas of origin and domestication. *Arbor,192(779),* a317.PublishedDecember2016.https://doi.org/10.3989/arbor.2016.779n3007

De Ron, A. M., Papa, R., Bitocchi, E., González, A. M., Debouck, D. G., Brick, M. A., Fourie, D., Marsolais, F., Beaver, J., Geffroy, V., McClean, P., Santalla, M., Lozano, R., Yuste-Lisbona, F. J., & Casquero, P. A. (2015). Common Bean. In A. M. De Ron (Ed.), *Grain Legumes* (pp. 1–36). Springer. Published 2015.https://doi.org/10.1007/978-1-4939-2797-5_1

Deba, F., Xuan, T. D., Yasuda, M., & Tawata, S. (2007). Herbicidal and fungicidal activities and identification of potential phytotoxins from Bidens pilosa L. var. Radiata Scherff. *Weed Biology and Management, 7(2),* 77–83. Published June 2007.https://doi.org/10.1111/j.1445-6664.2007.00239.x

Delgado, A., Quemada, M., & Villalobos, F. J. (2016). Fertilizers. In F. J. Villalobos & E. Fereres (Eds.), *Principles of Agronomy for Sustainable Agriculture* (pp. 321–339). Springer International Publishing. Published 2016.https://doi.org/10.1007/978-3-319-46116-8_23

Diaz, L. M., Ricaurte, J., Tovar, E., Cajiao, C., Terán, H., Grajales, M., Polanía, J., Rao, I., Beebe, S., & Raatz, B. (2018). QTL analyses for tolerance to abiotic stresses in a common bean (*Phaseolusvulgaris* L.)population. *PLoSONE,13*(8), e0202342. https://doi.org/10.1371/journal.pone.0202342

Dimka Haytova, D. (2013). A review of foliar fertilization of some vegetable's plants. *Annual Research & Review in Biology, 3*(4), Article 4

Duku, C., Groot, A., Demissie, T. D., Muhwanga, J., Nzoka, O., & Recha, J. W. M. (2020).

Common beans Kenya: Climate risk assessment. *Published 2020*. https://hdl.handle.net/10568/107723

Eckhardt, D. P., Redin, M., Jacques, R. J. S., Lorensini, F., Santos, M. L. D., Weiler, D. A., & Antoniolli, Z. I. (2016). Mineralization and efficiency index of nitrogen in cattle manure fertilizers on the soil. *Ciência Rural*, *46,* 472-77.https://www.scielo.br/j/cr/a/NNrF7KY6sYvjwCStr7QCLMC/?lang=en

Elzaawely, A. A., Ahmed, M. E., Maswada, H. F., & Xuan, T. D. (2017). Enhancing growth, yield, biochemical, and hormonal contents of snap bean (*Phaseolus vulgaris* L.) sprayed with moringa leaf extract. *Archives of Agronomy and Soil Science*, *63*(5), 687–699.https://doi.org/10.1080/03650340.2016.1234042

Enang, R. K., Yerima, B. P. K., Kome, G. K., & Van Ranst, E. (2018). Assessing the Effectiveness of the Walkley-Black Method for Soil Organic Carbon Determination in Tephra Soils of Cameroon. *Communications in Soil Science and Plant Analysis*, *49*(19), 2379–2386. https://doi.org/10.1080/00103624.2018.1510948

Fekadu, E., Kibret, K., Melese, A., & Bedadi, B. (2018). Yield of faba bean (*Vicia faba* L.) as affected by lime, mineral P, farmyard manure, compost and rhizobium in acid soil of Lay Gayint District, northwestern highlands of Ethiopia. *Agriculture & Food Security*, *7*(1), 16. https://doi.org/10.1186/s40066-018-0168-2

Food and Agriculture Organization of the United Nations. (2023). FAOSTAT statistical database, https://www.fao.org/faostat/en/#home

Francine, SB, Géant, CB, Ndeko, AB, Thierry, C., Kanyege, AL, & Gustave, MN (2021). Towards management of South Kivu ferral soils by the contribution of different types of fertilizers: their influence on the biofortified climbing bean behavior. *World*, *9* (2), 65-72. https://www.sciepub.com/wjar/abstract/13362

Freyer, B., & Bingen, J. (2021). Resetting the African Smallholder Farming System: Potentials to Cope with Climate Change. In *African Handbook of Climate Change Adaptation* (pp. 1441–1467). Cham: Springer International Publishing.

Fryd. (2023). Comfrey manure. *Accessed May 17, 2024*. https://fryd.app/en/magazine/comfrey-manure

Furber, J. D. (1982). Nutrition, Diet, and Supplements for Peak Physical & Mental Performance.

Garcia, P. L., Sermarini, R. A., & Trivelin, P. C. O. (2020). Nitrogen Fertilization Management with Blendsof Controlled-Release and Conventional Urea Affects Common Bean Growth and YieldduringMildWintersinBrazil. *Agronomy,10*(12), Article2. https://doi.org/10.3390/agronomy10121935

Ghosh, PK, Ramesh, P., Bandyopadhyay, KK, Tripathi, AK, Hati, KM, Misra, AK, & Acharya, CL (2004). Comparative effectiveness of cattle manure, poultry manure, phosphocompost and fertilizer-NPK on three cropping systems in vertisols of semi-arid tropics. I. Crop yields and system performance. *Bioresourcetechnology, 95* (1),7783. https://www.sciencedirect.com/science/article/abs/pii/S0960852404000410

Girma, F., Fininsa, C., Terefe, H., & Amsalu, B. (2022). Distribution of common bacterial blight and anthracnose diseases and factors influencing epidemic development in major common bean growing areas in Ethiopia. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, *72*(1),685699**.**
https://www.tandfonline.com/doi/full/10.1080/09064710.2022.2063168Godlewska,
K.,Biesiada, A., Michalak, I., & Pacyga, P. (2019). The Effect of Plant-Derived Biostimulants on White Head Cabbage Seedlings Grown under Controlled Conditions. *Sustainability, 11*(19), Article 19.https://doi.org/10.3390/su11195317

Godlewska, K., Biesiada, A., Michalak, I., & Pacyga, P. (2019). The effect of plant-derived biostimulants on white head cabbage seedlings grown under controlled conditions. *Sustainability, 11*(19), Article 5317. https://doi.org/10.3390/su11195317

Godongo, M. (2022). *Factors affecting adoption of agricultural innovations amongst small holder farmers: A case of Nyota Beans Technology in Bungoma County* [Doctoral dissertation, University of Nairobi]

Gondar, E. (2021). Analysis the economic efficiency of common beans production among smallholder farmers: in case of Burji district, Southern Nation National People's Region, Ethiopia. *Archives of Agriculture and Environmental Science*, *6*(3), 315–323. https://doi.org/10.26832/24566632.2021.060303

González, A. M., Pesqueira, A. M., García, L., & Santalla, M. (2023). Effects of photoperiod and drought on flowering and growth development of protein-rich legumes under Atlantic environments. *Agronomy, 13*(4), Article 1025. https://doi.org/10.3390/agronomy13041025

Gou, X., Reich, P. B., Qiu, L., Shao, M., Wei, G., Wang, J., & Wei, X. (2023). Leguminous plants significantly increase soil nitrogen cycling across global climates and ecosystem types. *Global Change Biology, 29*(14), 4028–4043. https://doi.org/10.1111/gcb.16742

Govere, S., Madziwa, B., & Mahlatini, P. (2011). The nutrient content of organic liquid fertilizers in Zimbabwe. *International Journal of Modern Engineering Research*, *1*(1), 17–18

Han, T., Cai, A., Liu, K., Huang, J., Wang, B., Li, D., Qaswar, M., Feng, G., & Zhang, H. (2019).

The links between potassium availability and soil exchangeable calcium, magnesium, and aluminum are mediated by lime in acidic soil. *Journal of Soils and Sediments*, *19*(3), 1382–1392. https://doi.org/10.1007/s11368-018-2145-6

He, Z., Honeycutt, C. W., & Griffin, T. S. (2003). Comparative Investigation of Sequentially Extracted Phosphorus Fractions in a Sandy Loam Soil and a Swine Manure. *Communications in Soil Science and Plant Analysis, 34*(11–12), 1729–1742. https://doi.org/10.1081/CSS-120021308

Hills, L. D. (2011). *Comfrey: Past, Present and Future* (pp. 7–19). Faber & Faber.

Hinke, T. (2022, April 27). *Compost extract brewing like a pro: The ingredients, the recipe, the process.* Urban Worm Company. Retrieved November 2, 2025, from https://urbanwormcompany.com/compost-extract-brewing-ingredients-recipe-process/

Hoque, M., Emon, K., Malo, P. C., Hossain, M. H., Tannu, S. I., & Roshed, M. M. (2023). Comprehensive guide to vitamin and mineral sources with their requirements. *Indiana Journal of Agriculture and Life Sciences*, *3*(6), 23-31. https://zenodo.org/records/10284736

Hoyle, F. C., & Murphy, D. (2018). *Soil Quality: 3 Soil Organic Matter.* Retrieved November 2, 2025,fromhttps://books.apple.com/au/book/soil-quality-3-soil-organic-matter/id1444338744

Intergovernmental Panel on Climate Change. (2019). *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.* Cambridge University Press / IPCC. Retrieved November 2, 2025, from https://www.ipcc.ch/srccl/download/

International Seed Testing Association. (2023). *International rules for seed testing 2023*. International Seed Testing Association. Retrieved November 2, 2025, from https://www.seedtest.org

Ishfaq, M., Kiran, A., Wakeel, A., Tayyab, M., & Li, X. (2022). Foliar-applied potassium triggers soil potassium uptake by improving growth and photosynthetic activity of wheat and maize. *Ecology,Environment&Conservation*,*28*(4),1723–1732. https://doi.org/10.6084/m9.figshare.21786690.v1

Jeevaa, G., Rajadurai, K. R., Sellamuthu, K. M., Beaulah, A., Venkatesan, K., & Udithyan, B. (2025). Foliar fertilization: A key strategy for enhancing growth and bio productivity in flower plants. *Plant Science Today, 12*(2), Article 2. https://doi.org/10.14719/pst.7531

Jepleting, N., Sila, D. N., & Orina, I. N. (2022). Nutritional Composition and Antinutrient to

Mineral Molar Ratios of Selected Improved Common Beans Grown in Kenya. *Current Research in Nutrition and Food Science Journal, 10*(3), 1230–1239.

Joe, V., Rock, C., & McLain, J. (2017). *Compost tea 101: What every organic gardener should know* (AZ1739). University of Arizona Cooperative Extension. Retrieved November 2, 2025, from https://extension.arizona.edu/sites/default/files/2024-08/az1739-2017.pdf

Jones, R. A. C. (2021). Global plant virus disease pandemics and epidemics. *Plants*, *10*(2), Article 233. https://doi.org/10.3390/plants10020233

Kan, L., Nie, S., Hu, J., Wang, S., Bai, Z., Wang, J., Zhou, Y., Jiang, J., Zeng, Q., & Song, K. (2018). Comparative study on the chemical composition, anthocyanins, tocopherols and carotenoids of selected legumes. *Food Chemistry, 260*, 317–326. https://doi.org/10.1016/j.foodchem.2018.03.148

Kan, L., Nie, S., Hu, J., Wang, S., Cui, SW, Li, Y., ... & Xie, M. (2017). Nutrients, phytochemicals and antioxidant activities of 26 kidney bean cultivars. *Food and Chemical Toxicology*, *108*, 467-477. https://www.sciencedirect.com/science/article/abs/pii/S0278691516303210

Karavidas, I., Ntatsi, G., Vougeleka, V., Karkanis, A., Ntanasi, T., Saitanis, C., Agathokleous, E., Ropokis, A., Sabatino, L., Tran, F., Iannetta, P. P. M., & Savvas, D. (2022). Agronomic practices to increase the yield and quality of common bean (*Phaseolus vulgaris* L.): A systematic review. *Agronomy, 12*(2), Article 271. https://doi.org/10.3390/agronomy12020271

Karavidas, I., Ntatsi, G., Vougeleka, V., Karkanis, A., Ntanasi, T., Saitanis, C., Agathokleous, E., Ropokis, A., Sabatino, L., Tran, F., Iannetta, P. P. M., & Savvas, D. (2022). Agronomic practices to increase the yield and quality of common bean (*Phaseolus vulgaris* L.): A systematic review. *Agronomy, 12*(2), Article 271. https://doi.org/10.3390/agronomy12020271

Kavoi, J., Wambua, S., Gichangi, A., Mutua, M., Birachi, E., & Chege, C. (2022). Household income determinants of crop sales: The case of Common Bean production and marketing in selected bean corridors in Kenya. *African Journal of Rural Development*, *7*(3), 400–412. Retrieved November 2, 2025, from https://afjrdev.org/index.php/jos/article/view/351

Keller, B., Ariza-Suarez, D., de la Hoz, J., Aparicio, J. S., Portilla-Benavides, A. E., Buendia, H. F., Mayor, V. M., Studer, B., & Raatz, B. (2020). Genomic prediction of agronomic traits in common bean (*Phaseolus vulgaris* L.) under environmental stress. *Frontiers in Plant Science, 11*, Article 1001. https://doi.org/10.3389/fpls.2020.01001

Kemanian, A. R., Stöckle, C. O., Huggins, D. R., & Viega, L. M. (2007). A simple method to estimate harvest index in grain plants. *Field Plants Research, 103*(3), 208–216. https://doi.org/10.1016/j.fcr.2007.06.007

Kenya National Bureau of Statistics. (2023). *2023 Economic Survey*. https://www.knbs.or.ke/wp-content/uploads/2023/09/2023-Economic-Survey.pdf

Kenya National Bureau of Statistics. (2024). *Stats Kenya 2024*. Retrieved November 2, 2025, from https://www.knbs.or.ke/reports_category/2024/

Kenya National Bureau of Statistics. (2024, May). *2024 Kenya facts & figures*. Retrieved November 2, 2025, from https://www.knbs.or.ke/reports/2024-kenya-facts-figures/

Keskin, S. O., Ali, T. M., Ahmed, J., Shaikh, M., Siddiq, M., & Uebersax, M. A. (2022). Physico-chemical and functional properties of legume protein, starch, and dietary fiber—A review. *Legume Science, 4*(1), e117. https://doi.org/10.1002/leg3.117

Khasabulli, B. D., Musyimi, D. M., George, O., & Gichuhi, M. N. (2018). Allelopathic Effect of *Bidens pilosa* on Seed Germination and Growth of *Amaranthus dubius*. *Journal of Asian Scientific Research*, *8*(3), 103–112**.** https://doi.org/10.18488/journal.2.2018.83.103.112

Kinaci, E., & Gulmezoglu, N. (2007). Grain yield and yield components of triticale upon application of different foliar fertilizers. *Interciencia*, *32*(9), 624–628.

King, E. J. (1932). The colorimetric determination of phosphorus. *Biochemical Journal*, *26*(2), 292–297.

Kinrade, T. (2025, February 6). Practice Guide: Foliar Applications. Soils for Life. https://soilsforlife.org.au/practice-guide-foliar-applications/

Leigh, R. A., & Wyn Jones, R. G. (1984). A hypothesis relating critical potassium concentrations for growth to the distribution and functions of this ion in the plant cell. *New Phytologist, 97*(1), 1–13. https://doi.org/10.1111/j.1469-8137.1984.tb04103.x

Lithourgidis, A. S., Matsi, T., Barbayiannis, N., & Dordas, C. A. (2007). Effect of Liquid Cattle Manure on Corn Yield, Composition, and Soil Properties. *Agronomy Journal*, *99*(4), 1041–1047. https://doi.org/10.2134/agronj2006.0332

Ljubojević, S., & Eliseev, V. I. (2016). Influence of special herbal preparation on growth and development of cucumber, pepper and tomato. *Agricultural Engineering*, *7*(26), 264-270.

Ljubojević, S., & Eliseev, V. I. (2016). Influence of special herbal preparation on growth and development of cucumber, pepper and tomato. *Proceedings of the 51st Croatian and 11th International Symposium on Agriculture* (pp. 29–33). Retrieved November 2, 2025, from https://www.cabidigitallibrary.org/doi/pdf/10.5555/20173053882

Loko, L. E. Y., Toffa, J., Adjatin, A., Akpo, A. J., Orobiyi, A., & Dansi, A. (2018). Folk taxonomy and traditional uses of common bean (Phaseolus vulgaris L.) landraces by the sociolinguistic groups in the central region of the Republic of Benin. *Journal of ethnobiology and ethnomedicine*, *14*(1), 52. https://www.cabidigitallibrary.org/doi/full/10.5555/20203421228

Lone, A. A., Khan, M. N., Gul, A., Dar, Z. A., Iqbal, A. M., Lone, B. A., ... & Nisar, F. (2021). Common beans and abiotic stress challenges. *Curr J Appl Sci Technol*, *40*(14), 41-53.ade

Lum, M. R., & Hirsch, A. M. (2002). Roots and Their Symbiotic Microbes: Strategies to Obtain Nitrogen and Phosphorus in a Nutrient-Limiting Environment. *Journal of Plant Growth Regulation*, *21*(4), 368–382. https://doi.org/10.1007/s00344-003-0003-1

Luo, Z., Li, Y., Pei, X., Woon, K. S., Liu, M., Lin, X., Hu, Z., Li, Y., & Zhang, Z. (2024). A potential slow-release fertilizer based on biogas residue biochar: Nutrient release patterns and synergistic mechanism for improving soil fertility. *Environmental Research*, *252*, 119076. https://doi.org/10.1016/j.envres.2024.119076

Mahmood, F., Khan, I., Ashraf, U., Shahzad, T., Hussain, S., Shahid, M., Abid, M., & Ullah, S. (2017). Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *Journal of Soil Science and Plant Nutrition*, *17*(1), 22–32. https://doi.org/10.4067/S0718-95162017005000002

Mamo, T., Singh, A., Singh, A., Mahama, A. A., & Suza, W. (2023). Common bean breeding. In *Plant Improvement: An Introduction*. Iowa State University Digital Press / Pressbooks. Retrieved November 2, 2025, from https://iastate.pressbooks.pub/plantimprovement/chapter/common-bean-breeding/

Mashamaite, C. V., Ngcobo, B. L., Manyevere, A., Bertling, I., & Fawole, O. A. (2022). Assessing the usefulness of *Moringa oleifera* leaf extract as a biostimulant to supplement synthetic fertilizers: A review. *Plants*, *11*(17), Article 2214. https://doi.org/10.3390/plants11172214

Mboya, R. M. (2018). *The nutritional and health potential of blackjack—Bidens pilosa L.—A review*.Retrieve May 19, 2024, from https://www.researchgate.net/publication/329322368_Mboya_RM_2018_The_Nutritional_and_health_potential_of_blackjack-_Bidens_pilosa_L-_Areview_Promoting_the_use_of_blackjack_for_food

Mekbib, F. (2003). Yield stability in common bean (*Phaseolus vulgaris* L.) genotypes. *Euphytica*, *130*(2), 147–153

Messina, V. (2014). Nutritional and health benefits of dried beans123. *The American journal of clinical nutrition*, *100*, 437S-442S. https://pubmed.ncbi.nlm.nih.gov/24871476/

Mitra, R., Yadav, P., Usha, K., & Singh, B. (2022). Regulatory role of organic acids and phytochelators in influencing the rhizospheric availability of phosphorus and iron and their uptake by plants. *Plant Physiology Reports, 27*(2), 193–206. https://doi.org/10.1007/s40502-022-00650-3

Moreira, M. M. R., Seabra, J. E. A., Lynd, L. R., Arantes, S. M., Cunha, M. P., & Guilhoto, J. J. M. (2020). Socio-environmental and land-use impacts of double-plantped maize ethanol in Brazil. *Nature Sustainability, 3*(3), 209–216. https://doi.org/10.1038/s41893-019-0456-2

Mozaffari, H., Moosavi, A. A., Baghernejad, M., & Cornelis, W. (2024). Revisiting soil texture analysis: Introducing a rapid single-reading hydrometer approach. *Measurement*, *228,* Article 114330. https://doi.org/10.1016/j.measurement.2024.114330

Mtenga, D. V., & Ripanda, A. S. (2022). A review on the potential of underutilized Blackjack (*Biden pilosa*) naturally occurring in sub-Saharan Africa. *Heliyon, 8*(6), e09586. https://doi.org/10.1016/j.heliyon.2022.e09586

Munyiri, L. M., Gachoki, P. K., & Mueni, P. W. (2019). An experimental analysis on the effect of fertilizer inputs on climbing bean production in Mbeere North Subcounty. *Global Scientific Journals*,*7*(6),828–833. https://www.globalscientificjournal.com/researchpaper/an_experimental_analysis_on_the_effect_of_fertilizer_inputs_on_climbing_bean_production_in_mbeere_north_subcounty.pdf

Muoki, P., & Goldstein, P. (2022, June 7). *Nyota iron bean is Kenya's "shining star" for better nutrition*.HarvestPlus.Retrieved November 2, 2025, from https://www.harvestplus.org/nyota-iron-bean-is-kenyas-shining-star-for-better-nutrition/

Muoki, P., & Goldstein, P. (2022, June 7). *Nyota iron bean is Kenya's "shining star" for better nutrition*.HarvestPlus.Retrieved November 2, 2025, from https://www.harvestplus.org/nyota-iron-bean-is-kenyas-shining-star-for-better-nutrition/

Musaninkindi, N. (2013). *Effect of cattle manure, mineral fertilizer and rhizobium inoculation on climbing beans production and soil properties in Burera district, Rwanda* [Master's thesis, Kenyatta University].

Muteti, K., Wambua, S., Gichangi, A., & Mutua, M. (2022). The Household Income Determinants Crop Sales: The Case of Common Bean Production and Marketing in Selected Bean Corridors in Kenya. *African Journal of Rural Development*, *7* (3), 399-411.https://afjrdev.org/index.php/jos/article/view/351

Mutungi, C., Tungu, J., Amri, J., Gaspar, A., & Abass, A. (2022). Nutritional benefits of improved post-harvest handling practices for maize and common beans in Northern Tanzania: A quantitative farm-level assessment. *Journal of Stored Products Research, 95*, 101918. https://doi.org/10.1016/j.jspr.2021.101918

Nadeem, M. A., Yeken, M. Z., Shahid, M. Q., Habyarimana, E., Yılmaz, H., Alsaleh, A., Hatipoğlu, R., Çilesiz, Y., Khawar, K. M., Ludidi, N., Ercişli, S., Aasim, M., Karaköy, T., & Baloch, F. S. (2021). Common bean as a potential plant for future food security: An overview of past, current and future contributions in genomics, transcriptomics, transgenics and proteomics. *Biotechnology & Biotechnological Equipment, 35*(1), 759–787. https://doi.org/10.1080/13102818.2021.1920462

Nadeem, M., Li, J., Yahya, M., Sher, A., Ma, C., Wang, X., & Qiu, L. (2019). Research progress and perspective on drought stress in legumes: A review. *International Journal of Molecular Sciences*, *20*(10), Article 2541. https://doi.org/10.3390/ijms20102541

Nadeem, M., Yahya, M., Tong, J., Shah, L., Khan, S. U., Ali, A., Sher, A., Ullah, N., & Waheed, A. (2023). Improving Nitrogen Acquisition and Utilization Through Root Architecture Remodelling: Insight from Legumes. *Journal of Plant Growth Regulation, 42*(9), 5295–5310. https://doi.org/10.1007/s00344-023-10938-9

Nascente, A. S., Carvalho, M. da C. S., Melo, L. C., & Rosa, P. H. (2017). Nitrogen management effects on soil mineral nitrogen, plant nutrition and yield of super early cycle common bean genotypes. *Acta Scientiarum. Agronomy, 39*(3), 369–378.

Nascente, A. S., Cobucci, T., Sousa, D. D., & Lima, D. D. P. (2014). Yield of common beans affected by soil phosphorus sources with or without calcium application. *Revista Ceres*, *61*(4), 459–464. https://doi.org/10.1590/0034-737X201461040008

Ngakou, A., Megueni, C., Noubissie, E., & Tchuenteu, T. L. (2008). Evaluation of the physico–chemical properties of cattle and kitchen manures derived composts and their effects on field grown Phaseolus vulgaris L. *Int. J. Sustain. Crop Prod*, *3*(5), 13-22. http://ggfjournals.com/assets/uploads/4.13-22_.doc_.pdf

Niu, J., Liu, C., Huang, M., Liu, K., & Yan, D. (2021). Effects of Foliar Fertilization: A Review of Current Status and Future Perspectives. *Journal of Soil Science and Plant Nutrition, 21*(1), 104–118.

Ogunlela, V. B., Masarirambi, M. T., & Makuza, S. M. (2005). Effect of cattle manure application on pod yield and yield indices of okra (*Abelmoschus esculentus* L. Moench) in a semi-arid sub-tropical environment. *J. Food Agric. Environ, 3*(1), 125-129.

Okumu, O. O., Muthomi, J., Ojiem, J., Narla, R., & Nderitu, J. (2018). Effect of Lablab Green Manure on Population of Soil Microorganisms and Establishment of Common Bean

(*Phaseolus vulgaris* L.). *American Journal of Agricultural Science*, *5*(3), 44–54

Onwonga, R. N., Lelei, J. J., Freyer, B., Friedel, J. K., Mwonga, S. M., & Wandhawa, P. (2008). Low cost technologies for enhancing N and P availability and maize (Zea mays L.) performance on acid soils. *World Journal of Agricultural Sciences*, *4*(5), 862-73.

Osanyinpeju, K. L., & Dada, P. O. O. (2018). Soil porosity and water infiltration as influenced by tillage practices on Federal University of Agriculture Abeokuta, Ogun State, Nigeria Soil. *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, *7*(4), 245–252.

Oster, M., Reyer, H., Keiler, J., Ball, E., Mulvenna, C., Ponsuksili, S., & Wimmers, K. (2021). Comfrey (*Symphytum* spp.) as a feed supplement in pig nutrition contributes to regional resource cycles. *The Science of the Total Environment, 796*, 148988. https://doi.org/10.1016/j.scitotenv.2021.148988

Ozbek, N., & Ak, S. (2016). Method development for the determination of calcium, copper, magnesium, manganese, iron, potassium, phosphorus and zinc in different types of breads by microwave induced plasma-atomic emission spectrometry. *Food Chemistry*, *200*, 245–248. https://doi.org/10.1016/j.foodchem.2016.01.043

Pasley, H. R., Cairns, J. E., Camberato, J. J., & Vyn, T. J. (2019). Nitrogen fertilizer rate increases plant uptake and soil availability of essential nutrients in continuous maize production in Kenya and Zimbabwe. *Nutrient Cycling in Agroecosystems*, *115*(3), 373–389. https://doi.org/10.1007/s10705-019-10016-1

Patel, A., Devraja, H.C., Sharma, P., & Singh, RRB (2019). *Food technology II*.

Patil, B. (2018). Foliar fertilization of nutrients. *Marumegh*, *3*(1), 49–53.

Pavlis, R. (2016, September 18). *Comfrey—Is it a dynamic accumulator?* Gardenmyths.Com. Retrieved November 3, 2025, from https://www.gardenmyths.com/comfrey-dynamic-accumulator/

Raina, R., & Mazahar, S. (2022). Nitrogen: A key macronutrient for the plant world. In *Advances in Plant Nitrogen Metabolism* (pp. 19-27). CRC Press.

Ramabulana, A.-T., Steenkamp, P. A., Madala, N. E., & Dubery, I. A. (2020). Profiling of altered metabolomic states in *Bidens pilosa* leaves in response to treatment by methyl jasmonate and methyl salicylate. *Plants*, *9*(10), Article 1275. https://doi.org/10.3390/plants9101275

Ramazanoglu, E., Beyyavas, V., Cevheri, C. I., Sakin, E., & Yilmaz, S. N. (2024). Effects of farmyard manure and chemical fertilizer application rates on soil biology, cotton and fiber yield. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *52*(3), 13838-13838.

Ramírez-Jiménez, A. K., Gaytán-Martínez, M., Morales-Sánchez, E., & Loarca-Piña, G. (2018).

Functional properties and sensory value of snack bars added with common bean flour as a source of bioactive compounds. *LWT, 89*,674–680. https://doi.org/10.1016/j.lwt.2017.11.043

Rana, M. S., Sun, X., Imran, M., Ali, S., Shaaban, M., Moussa, M. G., Khan, Z., Afzal, J., Binyamin, R., Bhantana, P., Alam, M., Din, I. U., Younas, M., & Hu, C. (2020). Molybdenum-induced effects on leaf ultra-structure and rhizosphere phosphorus transformation in *Triticum aestivum* L. *Plant Physiology and Biochemistry, 153*, 20–29. https://doi.org/10.1016/j.plaphy.2020.05.010

Recha, C. W. (2018). *Local and regional variations in conditions for agriculture and food security in Kenya.* Swedish University of Agricultural Sciences, SLU Global

Reyes-Ardila, W. L., Rugeles-Silva, P. A., Duque-Zapata, J. D., Vélez-Martínez, G. A., Tarazona Pulido, L., Cardona Tobar, K. M., ... & López-Alvarez, D. (2024). Exploring genomics and microbial ecology: Analysis of *Bidens pilosa* L. genetic structure and soil microbiome diversity by RAD-Seq and metabarcoding. *Plants*, *13*(2), 221.

Pedreira, A. M. de, González Fernández, A. M., Rodiño Míguez, A. P., Santalla Ferradás, M., Godoy Montiel, L. A., & Papa, R. (2016). History of the common bean plant: Its evolution beyond its areas of origin and domestication. *Arbor*, *192*(779), Article a317. https://doi.org/10.3989/arbor.2016.779n3007

Ross, D. J. (1989). Estimation of soil microbial C by A fumigation-extraction procedure: Influence of soil moisture content. *Soil Biology and Biochemistry*, *21*(6), 767–772. https://doi.org/10.1016/0038-0717(89)90168-5

Rozie. (2022, June 29). Comfrey: Its History, Uses & Benefits. Permaculture.https://www.permaculture.co.uk/articles/comfrey-its-history-uses-benefits/

Sáez-Plaza, P., Michałowski, T., Navas, M. J., Asuero, A. G., & Wybraniec, S. (2013). An Overview of the Kjeldahl Method of Nitrogen Determination. Part I. Early History, Chemistry of the Procedure, and Titrimetric Finish. *Critical Reviews in Analytical Chemistry, 43*(4), 178–223. https://doi.org/10.1080/10408347.2012.751786

Salehi, B., Sharopov, F., Boyunegmez Tumer, T., Ozleyen, A., Rodríguez-Pérez, C., M. Ezzat, S., Azzini, E., Hosseinabadi, T., Butnariu, M., Sarac, I., Bostan, C., Acharya, K., Sen, S., Nur Kasapoglu, K., Daşkaya-Dikmen, C., Özçelik, B., Baghalpour, N., Sharifi-Rad, J., Valere Tsouh Fokou, P., & Martins, N. (2019). *Symphytum* species: A comprehensive review on chemical composition, food applications and phytopharmacology. *Molecules*, *24*(12), Article 2272. https://doi.org/10.3390/molecules24122272

Santos, E., Marques, G., & Lino-Neto, T. (2020). *Phaseolus vulgaris* L. as a functional food for aging protection. In V. R. Preedy & V. B. Patel (Eds.), *Aging* (Second Edition) (pp. 289–295). Academic Press. https://doi.org/10.1016/B978-0-12-818698-5.00029-8

Savita. (2023). Production Technology of Underutilized Vegetables of Leguminosae Family. In Savita, M. Rawat, & V. Vimal (Eds.), *Production Technology of Underutilized Vegetable Plants* (pp. 25–99). Springer International Publishing. https://doi.org/10.1007/978-3-031-15385-3_3

Scheuerell, S., & Mahaffee, W. (2002). Compost Extract: Principles and Prospects for Plant Disease Control. *Compost Science & Utilization, 10*(4), 313–338. https://doi.org/10.1080/1065657X.2002.10702095

Schjoerring, J. K. (2023). Knowledge synthesis on foliar nitrogen and phosphorus fertilization. *University of Copenhagen, Department of Plant and Environmental Sciences, Frederiksberg C, Denmark*. 75 pp. Released August 2023.

Selvakumar, S., Ragavan, T., Gurusamy, A., Prabhaharan, J., Gunasekaran, M., Sivakumar, T., Subramanian, E., Rani, S., Arthirani, B., Sathishkumar, A., & Hussainy, S. A. H. (2025). Impact of different nutrient management strategies on growth, yield components and yield of coloured cotton (*Gossypium hirsutum* L.) cv. Vaidehi 1. *Frontiers in Sustainable Food Systems*, *9*, Article 1544696. https://doi.org/10.3389/fsufs.2025.1544696

Shahrajabian, M. H., Sun, W., & Cheng, Q. (2022). Foliar application of nutrients on medicinal and aromatic plants, the sustainable approaches for higher and better production. *Beni-Suef University Journal of Basic and Applied Sciences*, *11*(1), Article 26. https://doi.org/10.1186/s43088-022-00210-6

Sharifi, M. A., Nowrozi, A., Rostazada, M. D., & Ali, J. (2024). Effect of different doses of animal manure on growth and yield of common bean. *Engineering and Technology Quarterly Reviews*, *7*(2), 33–36. https://doi.org/10.5281/zenodo.11324329

Singh, B., Singh, J. P., Kaur, A., & Singh, N. (2017). Phenolic composition and antioxidant potential of grain legume seeds: A review. *Food Research International, 101*, 1–16.https://doi.org/10.1016/j.foodres.2017.09.026

Snapp, S. (2017). Chapter 5 - Designing for the Long-term: Sustainable Agriculture. In S. Snapp & B. Pound (Eds.), *Agricultural Systems* (Second Edition) (pp. 123–167). Academic Press. https://doi.org/10.1016/B978-0-12-802070-8.00005-0

Sharifi, M. A., Nowrozi, A., Rostazada, M. D., & Ali, J. (2024). Effect of different doses of animal manure on growth and yield of common bean. *Engineering and Technology Quarterly Reviews*, *7*(2), 33–36. https://doi.org/10.5281/zenodo.11324329

Tadele, Z. (2017). Raising plant productivity in Africa through intensification. *Agronomy*, *7*(1), Article 22. https://doi.org/10.3390/agronomy7010022

Tadesse, A., Shanka, D., & Laekemariam, F. (2022). Short-Term Integrated Application of Nitrogen, Phosphorus, Sulfur, and Boron Fertilizer and the Farmyard Manure Effect on the Yield and Yield Components of Common Bean (*Phaseolus vulgaris* L.) at Alle Special Woreda, Southern Ethiopia. *Applied and Environmental Soil Science, 2022*(1), 2919409. https://doi.org/10.1155/2022/2919409

Taiy, R. J. (2017). *Climate change challenges and knowledge gaps in smallholder potato production: The case of Mauche Ward in Nakuru County, Kenya* [Thesis, Egerton University].RetrievedNovember3,2025,from http://41.89.96.81:8080/xmlui/handle/123456789/2555

Teschke, R., Vongdala, N., Quan, N. V., Quy, T. N., & Xuan, T. D. (2021). Metabolic toxification of 1,2-unsaturated pyrrolizidine alkaloids causes human hepatic sinusoidal obstruction syndrome: The update. *International Journal of Molecular Sciences*, *22*(19), Article 10419. https://doi.org/10.3390/ijms221910419

Tiwari, A. K., & Pal, D. B. (2022). Chapter 11—Nutrients contamination and eutrophication in the river ecosystem. In S. Madhav, S. Kanhaiya, A. Srivastav, V. Singh, & P. Singh (Eds.), *EcologicalSignificancofRiverEcosystems* (pp.203–216). Elsevier. https://doi.org/10.1016/B978-0-323-85045-2.00001-7

Upenji, R. (2020). Improve common bean (Phaseolus vulgaris L.) yield through cattle manure in Nioka region, Ituri Province, DRC. *Open Access Library Journal*, *7* (09), 1. https://www.scirp.org/journal/paperinforcitation?paperid=102905

Upenji, R., Umirambe, E., Lobo, E., Abineno, E., Zamukulu, P., Mushagalusa, P., & Dieudonne, K. (2020). Improve common bean (*Phaseolus vulgaris* L.) yield through cattle manure in Nioka Region, Ituri Province, DRC. *OALib Journal*, *7*(4), Article e1106610. https://doi.org/10.4236/oalib.1106610

Valiño, A., Pardo-Muras, M., Puig, C. G., López-Periago, J. E., & Pedrol, N. (2023). Biomass from allelopathic agroforestry and invasive plant species as soil amendments for weed control—Areview.*Agronomy*,*13*(12), Article2880. https://doi.org/10.3390/agronomy13122880

Vanderziel, A., Anthony, J. C., Barondess, D., Kerver, J. M., & Alshaarawy, O. (2025). Estimating the effects of prenatal cannabis exposure on birth outcomes. *The American Journal on Addictions*, *34*(1), 21–29. https://doi.org/10.1111/ajad.13650

Waddington, E. (2019, August 22). *How to make comfrey liquid fertilizer*. Rural Sprout. Retrieved November 3, 2025, from https://www.ruralsprout.com/comfrey-liquid-fertilizer/

Wilczek, A. M., Burghardt, L. T., Cobb, A. R., Cooper, M. D., Welch, S. M., & Schmitt, J. (2010). Genetic and physiological bases for phenological responses to current and predicted climates. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1555), 3129–3147. https://doi.org/10.1098/rstb.2010.0128

APPENDICES

Appendix A: Data for Height

Manure	Foliar	Block	V3(cm)	V4(cm)	V5(cm)	R6(cm)
M0	F0	1	8.49	13.30	15.33	21.68
M1	F0	1	9.68	13.87	19.44	23.27
M2	F0	1	11.47	16.09	21.70	26.29
NPK	F0	1	12.32	17.74	24.60	30.70
M0	B1	1	8.69	14.17	21.05	23.63
M1	B1	1	9.97	14.10	18.65	22.37
M2	B1	1	10.52	16.17	23.28	28.19
NPK	B1	1	10.44	15.07	18.32	27.42
M0	B2	1	7.75	11.18	14.24	17.17
M1	B2	1	11.05	16.95	22.25	27.00
M2	B2	1	10.17	15.67	18.00	25.90
NPK	B2	1	11.14	15.30	21.20	29.15
M0	C1	1	9.35	13.62	17.72	19.52
M1	C1	1	10.57	16.13	19.82	27.07
M2	C1	1	11.72	15.72	20.89	26.27
NPK	C1	1	9.94	14.95	19.40	24.00
M0	C2	1	6.97	9.69	12.82	18.25
M1	C2	1	10.15	14.50	20.05	25.39
M2	C2	1	11.45	16.54	22.34	27.32
NPK	C2	1	9.58	14.52	20.49	23.09
M0	EG	1	7.90	11.29	15.80	17.27
M1	EG	1	11.22	16.87	21.04	26.82
M2	EG	1	11.77	17.59	19.95	25.92
NPK	EG	1	10.42	15.23	17.94	23.54
M0	F0	2	9.30	13.89	18.00	22.10
M1	F0	2	9.42	15.19	19.60	25.20
M2	F0	2	10.60	15.04	21.22	25.05
NPK	F0	2	8.53	14.42	20.69	23.14
M0	B1	2	8.05	13.27	17.24	24.27
M1	B1	2	9.77	14.68	20.74	28.49

M2	B1	2	9.47	13.42	20.83	25.88
NPK	B1	2	8.13	11.70	17.07	19.99
M0	B2	2	7.95	11.60	13.97	16.12
M1	B2	2	8.53	14.48	18.62	21.33
M2	B2	2	10.54	17.24	23.08	26.45
NPK	B2	2	8.78	14.40	20.67	24.32
M0	C1	2	10.62	15.65	20.33	23.22
M1	C1	2	11.69	18.42	23.83	28.29
M2	C1	2	11.95	17.22	21.82	27.10
NPK	C1	2	10.77	16.60	22.22	26.45
M0	C2	2	7.17	11.10	12.52	17.70
M1	C2	2	9.64	15.15	20.10	24.67
M2	C2	2	11.13	15.65	21.39	27.49
NPK	C2	2	10.54	14.39	18.07	23.47
M0	EG	2	9.43	13.62	17.20	22.17
M1	EG	2	9.82	16.27	23.00	27.49
M2	EG	2	11.40	17.02	21.47	28.92
NPK	EG	2	11.04	16.04	21.52	26.45
M0	F0	3	8.82	14.12	18.13	22.64
M1	F0	3	9.70	14.27	16.62	21.40
M2	F0	3	10.08	14.95	17.62	22.03
NPK	F0	3	8.82	14.32	17.44	25.97
M0	B1	3	8.35	12.67	15.34	20.47
M1	B1	3	10.04	15.15	18.80	23.12
M2	B1	3	10.77	14.92	21.14	28.97
NPK	B1	3	7.45	11.87	19.02	22.45
M0	B2	3	7.19	11.74	13.80	13.97
M1	B2	3	10.94	16.47	18.62	24.80
M2	B2	3	9.89	14.09	19.04	22.18
NPK	B2	3	8.32	13.00	18.04	20.80
M0	C1	3	7.40	10.20	11.60	15.67
M1	C1	3	9.55	14.68	17.38	24.30
M2	C1	3	10.55	16.10	20.35	25.87

NPK	C1	3	9.89	15.97	20.39	25.43
M0	C2	3	7.49	11.12	15.95	17.89
M1	C2	3	8.62	12.99	15.75	23.87
M2	C2	3	10.27	15.65	19.58	26.09
NPK	C2	3	9.99	15.24	18.29	25.40
M0	EG	3	7.55	12.64	15.08	19.70
M1	EG	3	10.95	15.79	18.72	25.17
M2	EG	3	9.94	16.22	19.37	26.62
NPK	EG	3	9.25	14.10	16.62	24.23

Appendix B: Data for Number of Branches

Manure	Foliar	Block	V5	R6
M0	F0	1	3	6
M1	F0	1	5	8
M2	F0	1	4	8
NPK	F0	1	5	10
M0	B1	1	3	6
M1	B1	1	4	6
M2	B1	1	3	7
NPK	B1	1	3	7
M0	B2	1	3	5
M1	B2	1	5	9
M2	B2	1	4	8
NPK	B2	1	5	10
M0	C1	1	4	6
M1	C1	1	3	7
M2	C1	1	4	9
NPK	C1	1	4	7
M0	C2	1	2	3
M1	C2	1	4	7
M2	C2	1	4	8
NPK	C2	1	3	7
M0	EG	1	2	4

M1	EG	1	4	7
M2	EG	1	5	9
NPK	EG	1	3	4
M0	F0	2	4	7
M1	F0	2	3	7
M2	F0	2	4	8
NPK	F0	2	4	8
M0	B1	2	3	6
M1	B1	2	4	9
M2	B1	2	4	7
NPK	B1	2	3	6
M0	B2	2	2	4
M1	B2	2	3	5
M2	B2	2	5	10
NPK	B2	2	4	7
M0	C1	2	4	8
M1	C1	2	5	9
M2	C1	2	4	8
NPK	C1	2	5	9
M0	C2	2	2	5
M1	C2	2	4	7
M2	C2	2	5	9
NPK	C2	2	3	5
M0	EG	2	3	6
M1	EG	2	5	10
M2	EG	2	4	7
NPK	EG	2	4	8
M0	F0	3	4	7
M1	F0	3	2	5
M2	F0	3	4	7
NPK	F0	3	4	8
M0	B1	3	3	7
M1	B1	3	3	6

M2	B1	3	4	10
NPK	B1	3	4	6
M0	B2	3	4	5
M1	B2	3	4	8
M2	B2	3	3	7
NPK	B2	3	3	4
M0	C1	3	2	3
M1	C1	3	4	6
M2	C1	3	3	6
NPK	C1	3	4	8
M0	C2	3	3	6
M1	C2	3	3	6
M2	C2	3	4	9
NPK	C2	3	4	9
M0	EG	3	3	7
M1	EG	3	4	8
M2	EG	3	5	9
NPK	EG	3	3	7

Appendix C: Data for Biomass

Manure	Foliar	Block	Biomass(g)
M0	F0	1	49.33
M1	F0	1	30.54
M2	F0	1	41.06
NPK	F0	1	45.15
M0	B1	1	45.43
M1	B1	1	21.84
M2	B1	1	52.72
NPK	B1	1	37.62
M0	B2	1	34.02
M1	B2	1	41.93
M2	B2	1	50.05
NPK	B2	1	40.14

M0	C1	1	41.59
M1	C1	1	44.15
M2	C1	1	51.59
NPK	C1	1	43.05
M0	C2	1	31.94
M1	C2	1	31.63
M2	C2	1	50.17
NPK	C2	1	37.44
M0	EG	1	29.43
M1	EG	1	51.55
M2	EG	1	60.46
NPK	EG	1	41.78
M0	F0	2	48.00
M1	F0	2	31.99
M2	F0	2	44.54
NPK	F0	2	47.49
M0	B1	2	42.35
M1	B1	2	35.68
M2	B1	2	44.09
NPK	B1	2	40.93
M0	B2	2	31.49
M1	B2	2	41.15
M2	B2	2	42.70
NPK	B2	2	50.62
M0	C1	2	39.95
M1	C1	2	48.55
M2	C1	2	55.59
NPK	C1	2	52.66
M0	C2	2	33.61
M1	C2	2	33.34
M2	C2	2	48.56
NPK	C2	2	43.93
M0	EG	2	36.09

M1	EG	2	45.71
M2	EG	2	59.18
NPK	EG	2	50.34
M0	F0	3	37.10
M1	F0	3	29.97
M2	F0	3	38.78
NPK	F0	3	42.41
M0	B1	3	31.05
M1	B1	3	24.36
M2	B1	3	38.58
NPK	B1	3	37.55
M0	B2	3	30.43
M1	B2	3	41.15
M2	B2	3	39.22
NPK	B2	3	46.88
M0	C1	3	33.93
M1	C1	3	45.32
M2	C1	3	43.13
NPK	C1	3	40.66
M0	C2	3	28.95
M1	C2	3	29.24
M2	C2	3	49.00
NPK	C2	3	35.62
M0	EG	3	37.63
M1	EG	3	34.90
M2	EG	3	44.64
NPK	EG	3	31.67

Appendix D: Data for Harvest Index

Manure	**Foliar**	**Block**	**HI**
M0	F0	1	0.34
M1	F0	1	0.37
M2	F0	1	0.42

NPK	F0	1	0.36
M0	B1	1	0.38
M1	B1	1	0.46
M2	B1	1	0.49
NPK	B1	1	0.37
M0	B2	1	0.36
M1	B2	1	0.41
M2	B2	1	0.42
NPK	B2	1	0.53
M0	C1	1	0.33
M1	C1	1	0.37
M2	C1	1	0.42
NPK	C1	1	0.39
M0	C2	1	0.35
M1	C2	1	0.4
M2	C2	1	0.47
NPK	C2	1	0.44
M0	EG	1	0.34
M1	EG	1	0.34
M2	EG	1	0.32
NPK	EG	1	0.36
M0	F0	2	0.35
M1	F0	2	0.28
M2	F0	2	0.4
NPK	F0	2	0.32
M0	B1	2	0.39
M1	B1	2	0.34
M2	B1	2	0.45
NPK	B1	2	0.38
M0	B2	2	0.33
M1	B2	2	0.29
M2	B2	2	0.3
NPK	B2	2	0.42

M0	C1	2	0.37
M1	C1	2	0.27
M2	C1	2	0.29
NPK	C1	2	0.37
M0	C2	2	0.32
M1	C2	2	0.52
M2	C2	2	0.41
NPK	C2	2	0.48
M0	EG	2	0.31
M1	EG	2	0.3
M2	EG	2	0.36
NPK	EG	2	0.35
M0	F0	3	0.3
M1	F0	3	0.32
M2	F0	3	0.38
NPK	F0	3	0.31
M0	B1	3	0.34
M1	B1	3	0.4
M2	B1	3	0.44
NPK	B1	3	0.4
M0	B2	3	0.35
M1	B2	3	0.36
M2	B2	3	0.53
NPK	B2	3	0.39
M0	C1	3	0.39
M1	C1	3	0.36
M2	C1	3	0.4
NPK	C1	3	0.31
M0	C2	3	0.36
M1	C2	3	0.4
M2	C2	3	0.44
NPK	C2	3	0.32
M0	EG	3	0.28

M1	EG	3	0.3
M2	EG	3	0.33
NPK	EG	3	0.34

Appendix E: Data for Hundred Seed Weight

Manure	Foliar	Block	Weight
M0	F0	1	38.02
M1	F0	1	39.52
M2	F0	1	40.13
NPK	F0	1	41.19
M0	B1	1	41.27
M1	B1	1	45.13
M2	B1	1	49.51
NPK	B1	1	43.01
M0	B2	1	43.64
M1	B2	1	50.59
M2	B2	1	52.08
NPK	B2	1	46.4
M0	C1	1	42.8
M1	C1	1	47.77
M2	C1	1	49.41
NPK	C1	1	42.65
M0	C2	1	41.4
M1	C2	1	44.03
M2	C2	1	46.08
NPK	C2	1	43.22
M0	EG	1	41.25
M1	EG	1	44.46
M2	EG	1	45.44
NPK	EG	1	47.92
M0	F0	2	39.05
M1	F0	2	39.96
M2	F0	2	40.81

NPK	F0	2	40.77
M0	B1	2	42.53
M1	B1	2	41.35
M2	B1	2	43.26
NPK	B1	2	46.04
M0	B2	2	40.6
M1	B2	2	36.33
M2	B2	2	41.18
NPK	B2	2	43.9
M0	C1	2	46.77
M1	C1	2	43.88
M2	C1	2	42.71
NPK	C1	2	44.89
M0	C2	2	30.44
M1	C2	2	44.9
M2	C2	2	43.68
NPK	C2	2	43.66
M0	EG	2	47.98
M1	EG	2	44.71
M2	EG	2	39.76
NPK	EG	2	42.57
M0	F0	3	39.71
M1	F0	3	42.15
M2	F0	3	42.3
NPK	F0	3	41.81
M0	B1	3	40.07
M1	B1	3	44.48
M2	B1	3	48.42
NPK	B1	3	41.7
M0	B2	3	40.99
M1	B2	3	45.19
M2	B2	3	50.59
NPK	B2	3	42.21

M0	C1	3	41.45
M1	C1	3	43.75
M2	C1	3	45.58
NPK	C1	3	42.2
M0	C2	3	40.27
M1	C2	3	47.56
M2	C2	3	48.43
NPK	C2	3	43.64
M0	EG	3	40.85
M1	EG	3	45.52
M2	EG	3	49.78
NPK	EG	3	42.43

Appendix F: Data for Yield

Manure	**Foliar**	**Block**	**Yield(Kg ha^{-1})**
M0	F0	1	842.76
M1	F0	1	1084.28
M2	F0	1	1212.65
NPK	F0	1	1148.71
M0	B1	1	1193.56
M1	B1	1	1377.75
M2	B1	1	1664.61
NPK	B1	1	1234.04
M0	B2	1	914.06
M1	B2	1	1541.85
M2	B2	1	1710.03
NPK	B2	1	1394.02
M0	C1	1	1120.41
M1	C1	1	1310.76
M2	C1	1	1638.58
NPK	C1	1	1645.17
M0	C2	1	943.41

M1	C2	1	1907.84
M2	C2	1	2342.48
NPK	C2	1	1672.93
M0	EG	1	1087.53
M1	EG	1	1581.45
M2	EG	1	1481.54
NPK	EG	1	1367.16
M0	F0	2	1014.99
M1	F0	2	734.47
M2	F0	2	1477.09
NPK	F0	2	927.75
M0	B1	2	1203.78
M1	B1	2	1111.78
M2	B1	2	1525.94
NPK	B1	2	1193.25
M0	B2	2	743.71
M1	B2	2	1331.41
M2	B2	2	1441.39
NPK	B2	2	1433.12
M0	C1	2	1329.95
M1	C1	2	1001.59
M2	C1	2	1193.15
NPK	C1	2	1563.41
M0	C2	2	909.8
M1	C2	2	1827.54
M2	C2	2	2354.04
NPK	C2	2	1672.93
M0	EG	2	1015.37
M1	EG	2	1843.89
M2	EG	2	1437.65
NPK	EG	2	1479.05
M0	F0	3	839.53
M1	F0	3	1007.3

M2	F0	3	1171.29
NPK	F0	3	1031.67
M0	B1	3	1015.62
M1	B1	3	1087.53
M2	B1	3	2140.24
NPK	B1	3	1248.4
M0	B2	3	1126.76
M1	B2	3	1343.25
M2	B2	3	1885.44
NPK	B2	3	1318.71
M0	C1	3	950.1
M1	C1	3	1038.03
M2	C1	3	1172.09
NPK	C1	3	1422.73
M0	C2	3	949.01
M1	C2	3	1347.86
M2	C2	3	2425.12
NPK	C2	3	1684.27
M0	EG	3	1088.52
M1	EG	3	1549.51
M2	EG	3	1468.28
NPK	EG	3	1418.91

Appendix G: Analysis of Variance for Nitrogen

Source	DF	SS	Mean Square	F Value	Pr > F
Block	2	0.15560278	0.07780139	14.97	<.0001
Manure	3	0.22140417	0.07380139	14.20	<.0001
Foliar	5	0.28747361	0.05749472	11.06	<.0001
Manure*Foliar	15	0.10282083	0.00685472	1.32	0.2301

Appendix H: Analysis of Variance for Height

At stage V3

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Block	2	9.21947500	4.60973750	6.12	0.0044
Manure	3	60.70819444	20.23606481	26.85	<.0001
Foliar	5	10.68071667	2.13614333	2.83	0.0259
Manure*Foliar	15	9.69723889	0.64648259	0.86	0.6122

At stage V4

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Block	2	9.0910583	4.5455292	3.47	0.0396
Manure	3	117.90850	39.3028347	29.98	<.0001
Foliar	5	25.815729	5.1631458	3.94	0.0047
Manure*Foliar	15	36.241720	2.4161147	1.84	0.0570

At Stage V5

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Block	2	65.8296028	32.9148014	9.76	0.0003
Manure	3	239.2105153	79.7368384	23.65	<.0001
Foliar	5	19.2382069	3.8476414	1.14	0.3524
Manure*Foliar	15	62.1492097	4.1432806	1.23	0.2858

At R6 stage

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Block	2	39.0138250	19.5069125	4.27	0.0199
Manure	3	462.6698597	154.2232866	33.77	<.0001
Foliar	5	43.6285292	8.7257058	1.91	0.1108
Manure*Foliar	15	128.6435653	8.5762377	1.88	0.0517

Appendix I: Analysis of Variance for Biomass at Stage R1

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Block	2	542.002436	271.001218	15.38	<.0001
Manure	3	1421.770778	473.923593	26.89	<.0001
Foliar	5	533.836594	106.767319	6.06	0.0002
Manure*Foliar	15	1318.508272	87.900551	4.99	<.0001

Appendix J: Analysis of Variance for Harvest Index

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Block	2	5.94945899	2.97472950	5.06	0.0103
Manure	3	9.67548075	3.22516025	5.49	0.0026
Foliar	5	18.1006948	3.62013898	6.16	0.0002
Manure*Foliar	15	8.98765743	0.59917716	1.02	0.4531

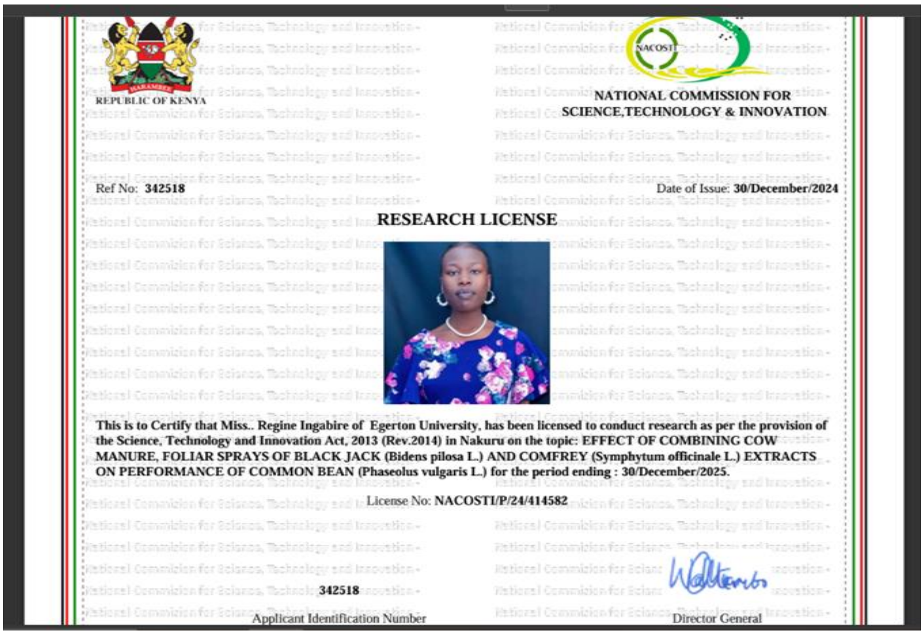
Appendix K: Analysis of Variance for Hundred Seed Weight

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Block	2	4.35935321	2.17967661	3.35	0.0438
Manure	3	14.25951423	4.75317141	7.31	0.0004
Foliar	5	16.02240774	3.20448155	4.93	0.0011
Manure*Foliar	15	6.06887622	0.40459175	0.62	0.8413

Appendix L: Analysis of Variance for Yield

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Block	2	0.86382940	0.43191470	2.06	0.1389
Manure	3	28.27765411	9.42588470	44.99	<.0001
Foliar	5	17.23036602	3.44607320	16.45	<.0001
Manure*Foliar	15	14.72329532	0.98155302	4.68	<.0001

Appendix M: Nacosti Permit



REPUBLIC OF KENYA

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RESEARCH LICENSE

This is to Certify that Miss.. Regine Ingabire of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nakuru on the topic: EFFECT OF COMBINING COW MANURE, FOLIAR SPRAYS OF BLACK JACK (Bidens pilosa L.) AND COMFREY (Symphytum officinale L.) EXTRACTS ON PERFORMANCE OF COMMON BEAN (Phaseolus vulgaris L.) for the period ending : 30/December/2025.

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Appendix N: Published Paper

ISRG Journal of Agriculture and Veterinary Sciences (ISRGJAVS)

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The effect of cow manure combined with foliar sprays of black jack (*Bidens pilosa* L.) and comfrey (*Symphytum officinale* L.) leaf extracts on the growth, yield and nutritional quality of common bean (*Phaseolus Vulgalis* L.)

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Abstract

Common bean (Phaseolus vulgaris L.) is important legume crop for nutritional and food security in Kenya. Declining soil fertility in small holder farms, as a result of limited or non-application of inorganic fertilizer, because of rising costs, has resulted in low production. The aim of the study was to investigate the effect of cow manure combined with foliar sprays of black jack (Bidens pilosa L.) and comfrey (Symphytum officinale L.) extracts on growth, yield and nutritional quality of common bean. A 4 x 6 factorial experiment in a randomized complete block design (RCBD) with 3 replicates was conducted in Egerton University's research Field 7 for two cropping seasons. Four fertilizer levels were 0, 5, 10 t ha^{-1} of cow manure and 148.15 kg ha^{-1} NPK (27-27-27) fertilizer, as a positive control. In addition, six foliar spray treatments; no spray (control), comfrey spray applied once(C1) or twice weekly(C2), black jack spray applied once(B1) or twice (B2) weekly and commercial Easy Grow spray (EG) (positive control), applied every 14 days at the rate of 3 kg ha^{-1} were used. Soil samples were collected before the experiment set up for analysis of initial chemical and physical properties. Data on yield parameters, including harvest index, hundred seed weight, yield per ha^{-1}, and protein content in seeds were collected at harvest. The Shapiro-Wilk test was used to ascertain the normality of data and analysis of variance was performed using Proc GLM in Statistical Analysis Software (SAS). Tukey's Honestly Significant Difference was used to compare the means at P<0.05. Compared to lesser manure rates, treatment M2 (10 t ha^{-1}) of cow manure performed better than other manures and control, it produced taller plants, more branches, higher biomass, great pod number, high seed weight, and yield than the control and lower manure rates. The effects of foliar spraying varied by stage; at the V4 stage, comfrey once a week (C1) and Black Jack sprayed twice a week (B2) increased plant height and the leaf area index, while C2 (comfrey twice a week) produced the most grain. The combination of M2 and C2 produced the maximum yield (2373.88 kg ha^{-1}), which can be recommended for beans production.

***Keywords:** Common beans, Cow manure, Foliar spray*