

**OPTIMIZING BEETROOT PRODUCTION THROUGH NPK FERTILIZER
APPLICATION IN KABALE MUNICIPALITY, KABALE DISTRICT**

ROBERT BALIBUGANDA

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DECLARATION

I BALIBUGANDA ROBERT, declare that this research study is my original work and has never been submitted to any University or institution of higher learning for any award of degree.

Signature: 

Date: 31/07/2025

APPROVAL

I certify that this research study was carried out in KABALE and has been submitted to the faculty of agricultural sciences with my approval.

Signature.....*UZATUNGA*.....

Date.....*31/07/2025*.....

MR. UZATUNGA INNOCENT.

RESEARCH SUPERVISOR

DEDICATION

I dedicate this work to my parents, Mr. Charles Museveni and Mrs. Agnes Museveni, and Mr. Muramuzi Charles. I also dedicate it to my brothers, Mr. Ayebare Charles, and sisters for their moral, emotional, and spiritual support. Their prayers, encouragement, and trust in me have been a source of strength throughout the time of my studies.

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Abstract

This research study, "Optimizing Beetroot Production through NPK Fertilizer Application in Kabale Municipality, Kabale District," aimed to determine how different application rates of NPK fertilizers affect beetroot growth and production. It was motivated by a need to enhance beetroot production among smallholders in this region through optimal nutrient use. It was intended to especially: (1) examine how different application rates of NPK fertilizers influence beetroot growth parameters such as plant height and number of leaves; (2) assess how application of NPK fertilizers influences yield of minor, medium, and large beetroot roots; and (3) determine the most financially successful application rates of fertilizers.

A field trial was conducted in a Randomized Complete Block Design (RCBD) layout with five treatments: control (0 kg/ha), 50 kg/ha, 100 kg/ha, 150 kg/ha, and 200 kg/ha of NPK (17:17:17) fertilizer. Three replications were used for every treatment. Measurements were taken on plant height and number of leaves, while beetroot root yield was considered in categories with respect to weight and diameter, such as small, medium, and large. Statistical evaluation was performed using Analysis of Variance (ANOVA) to assess the level of differences among treatments. A cost-benefit analysis was conducted to identify the profitability associated with each fertilizer application rate.

The results revealed that increasing rates of NPK fertilizer significantly enhanced beetroot growth and yield parameters. The highest plant height and number of leaves were observed at 150 kg/ha, with statistically significant differences ($p < 0.001$ for height and $p = 0.014$ for leaf number). The number of large-sized beetroot roots was significantly affected by NPK application ($p = 0.0031$), although the weight of these roots did not differ significantly across treatments ($p = 0.877$). The highest number of large-sized roots was recorded at 150 kg/ha, while medium-sized roots peaked at 100 kg/ha. The scatter and dotted graphs supported a strong positive relationship between fertilizer rate and root size up to the optimal level, beyond which diminishing returns were noted. Economic analysis indicated that the most profitable application rate was between 100 and 150 kg/ha, offering high yield returns while minimizing input costs.

In conclusion, the study found that NPK fertilizer has a positive influence on beetroot growth and yield in Kabale Municipality. However, the benefits of fertilizer use reach a plateau beyond certain rates, indicating the importance of applying optimal rather than excessive amounts. It is therefore recommended that farmers in the region adopt moderate NPK application rates (100– 150 kg/ha) to maximize productivity and economic returns. Extension agents should train farmers on efficient fertilizer use and conduct on-farm demonstrations. Further research should investigate the long-term effects of NPK on soil fertility, beetroot nutrient content, and crop resilience under changing climatic conditions.

CHAPTER ONE: INTRODUCTION

1.0 Introduction

This chapter provides an introduction to research on optimizing beetroot production within Kabale Municipality, Kabale District, utilizing NPK fertilizers. It includes the background of the study, problem statement, research objectives, research questions, research scope, research importance, and main definitions used in the research.

1.1 Background of the Study

Beetroot (*Beta vulgaris* L.), a species within the Chenopodiaceae family, is reportedly native to Germany (Thompson, 2001) and has cultivars including silver beet, sugar beet, and fodder beet (Deuter & Grundy, 2004). Although a biennial crop, beetroot is grown mainly annually, producing green leaves and fleshy roots during the first growing season. Beetroot's widespread use includes addition to salads, hot foods including meat and fish, pies, and preservation processes such as pickling and canning. Beetroot is rich in minerals, carbohydrates, protein, vitamins (particularly B1), and micronutrients (Cerne & Vrhovnik, 1999) and is valued highly for having positive effects upon overall health, including boosting immune function, preventing cancer, and acting as a tonic to blood, heart, and gut (Nottingham, 2004).

Beetroot thrives in cooler weather and can be cultivated throughout the year in most regions. It thrives in cooler, wet locations. Its principal beetroot production locations in South Africa include North West, Gauteng, Mpumalanga, KwaZulu-Natal, and Western Cape provinces, but sowing times vary depending on area. Seed sowing in winter rainfall regions takes place between August and March, while in districts with cool summers, sowing occurs between late August to mid-March. However, in Lowveld districts in Mpumalanga and KwaZulu-Natal, sowing occurs between March and August, while in Free State and Northern Cape and in Karoo Center, sowing occurs between February and March and between June and December (Wagner, 1992).

Overall, beetroot production value has continued to record a positive growth trend, while a slight decrease was achieved in 2004, which may be due to a decrease in prices (National Department of Agriculture, 2009). Beetroot production's maximum value was achieved in the 2008 production season due to energetic production and favorable prices. Beetroot production across the world was valued at 241,985,317 tons in 2005, while in South Africa, about 37,000 tons per annum were

produced, thus ensuring self-sufficiency and having a surplus that can be exported (National Department of Agriculture, 2009).

Nitrogen fertilizer application is imperative to accelerate beetroot development and raise both yield and quality upon application at optimum rates (Goodlass et al., 1997). It is a fundamental constituent in plant development because it is a chief element in proteins, enzymes, and vitamins. But oversupply might cause harmful effects such as nitrates' accumulation, having detrimental effects to human beings, such as inducing methemoglobinemia (Hemmat et al., 2010).

Several studies investigated the response of beetroot yield and quality to fertilizers applied on N. Webster (1969) reported that maximum yield was obtained while applying 264 kg N ha⁻¹ ammonium sulphate. Other scientists, like Wallace (1975), did not recommend fertilizing beetroot with N. However, Wilson (1975) reported maximum yield while applying 300-500 kg ha⁻¹ ammonium sulphate and calcium ammonium nitrate. Badawi et al. (1995) reported maximum yield while applying 260 kg ha⁻¹ ammonium sulphate to sandy loam soils.

High levels of N application can boost proline levels due to higher leaf area index (Monreala et al., 2007) and adversely impact root quality, such as total soluble solids (TSS) and sucrose levels (Moustafa et al., 2000; Seadh, 2004). Conventional fertilization methods normally involve applications of two or three splits within a season of around 300-400 kg N ha⁻¹, approximately 150 kg N ha⁻¹ usually sown at sowing, and the rest applied while plants achieve a height between 10-15 cm (Amber et al., 2009).

Nitrogen seed reserves carry beetroot to germination, while the crop accesses soil-nitrogen when it has attained the cotyledon stage to produce leaves. However, high uptake later in the season can cause excessive canopy production to the detriment of root sugar deposition, and can raise nitrate, salt, and purity concentrations in the root (Amber et al., 2009).

Inorganic fertilizers, which come from mineral deposits or are made in chemical reactions (e.g., urea), are widely used in agriculture. While they contain essential nutrients, they cannot supply organic matter to the ground, potentially decreasing its ability to hold water and nutrients compared to organic fertilizers. Further, high solubility in inorganic fertilizers may lead to rapid leakage of nitrogen out of ground soils (Taiz & Ziger, 1991).

Highly productive soils will yield optimal beetroot production, and how they will yield nitrogen is subject to soil type, previous fertilization, cropping history, rainfall, and irrigation practice (Thompson, 2001). It is essential to conduct soil and tissue testing to provide accurate fertilizer recommendations in order to optimize production.

Shifting cultivation, employed by smallholders in South Africa, is unable to keep pace with mounting population pressures and the growing demand for food. These fallow periods needed to replenish soil nutrient levels have to be shortened. Farmers can only use available fertilizers to boost crop production, but struggle to find optimal rates of fertilizers needed per crop (Gontcharenko, 1994). Additionally, the application of higher levels of fertilizers like nitrogen, phosphorus, and potassium without a convergent crop reaction to such inputs presents a major barrier to sustainable agriculture (Wang et al., 2006).

Nitrogen is the nutrient most widely assimilated by vegetable crops, and hence management is key to realizing maximum growth and production results. However, excessive use of fertilizers may lead to higher concentrations of nitrates, increased susceptibility to infectious diseases, and undesirable taste or texture traits in crops (Brandenburg, 1980; Collins & McCoy, 1997; Everaats, 1994). Efficient use of nitrogen is crucial in ensuring predictable yield and quality while at the same time limiting possible harm to human health and environmental sustainability.

Various research studies have examined how the growth, yield, and quality of beetroot respond to different application rates of nitrogen fertilizers (Goh & Vityakon, 1983; Cerne & Vrhovnik, 1999; Bok et al., 2003). Most studies only examined selected sources of N, such as chicken manure, kraal manure, potassium nitrate, and urea, without considering the effects of other nutrients, such as phosphorus and potassium, or the pathogens inherent in organic fertilizers (Goh & Vityakon, 1983). Studies on the effect of selected sources and N application rates on growth traits, external and internal quality, and chemical composition of beetroot are still limited, showing the need for further studies on the most appropriate source of N for crops and application rates that can be applied in beet cultivation.

The major driving force for increasing the efficacy of fertilizer use lies in areas where high intensity agriculture has resulted in long-term deterioration of the soil. On the world scale, the use of NPK fertilizers has all too often been typified by inefficacy, stemming from over- or misapplication rates, or improper perception regarding the requirement for nutrients by crops.

Overuse of fertilizers has the potential to cause environmental problems in the form of nutrient runoff, whereas improper application has the potential to result in reduced crop yield (Goulding et al., 2013). In order to implement the effective utilization of NPK fertilizers, localized studies need to be carried out with regard to fertilizer application techniques in order to facilitate the improved yield for crops by the growers. Studies carried out in high-income economies have shown that the implementation of precision agricultural techniques—namely, tailoring fertilizer application according to the distinctive qualities of individual farms—has the effect of enhancing the productivity of crops appreciably by the factor of simultaneously lessening environmental impact (Erenstein et al., 2016). Besides increasing agricultural yield, prudent fertilizer application has also been identified as the tool for the promotion of the environment. Used appropriately, fertilizers like NPK are vital not only for the strengthening of the structural integrity in the soil but also for the increase in the carbon sequestration capability among the soil (Bastida et al., 2016).

The agriculture sector also remains an integral base for most economies in Africa, with an involvement of a significant number of the population, who are largely based in rural areas. Farmers in Africa are exposed to numerous problems, including poor soil fertility, limited access to high-quality fertilizers, and fluctuating climatic conditions due to climate change. In spite of these challenges, the importance of soil quality enhancement through fertilization approaches for enhancing crop yields has received an expanded level of awareness (Bationo et al., 2015). Findings indicate that the use of NPK fertilizers remains crucial for the enhancement of soil fertility and agricultural productivity increase in certain regions across Africa.

The application of NPK fertilizers has been found to be the driving force for the exceptional increase in agricultural outputs. In West Africa, for example, research indicates that the application of balanced NPK fertilizers has resulted in the increase in the major crops yield such as maize, rice, and cassava (Bachewe et al., 2018). In most cases, however, the beneficial potential developed by the NPK fertilizers ends up going unexplored simply due to the inefficient application knowledge by the majority of the farmers. Abuses by overapplication or ineffective quantities cause the deterioration of the soil, the pollution of the water sources, as well as the deterioration in agricultural performance. Conversely, the factor of price represents a significant barrier for the smallholder farmers who are not capable of accessing the said critical inputs at an interval (Nkonya et al., 2016). In locations where investment has not been top on the communication channels or

even the transport networks, particularly rural Africa, the availability of the fertilizers is greatly restricted due to the shortcomings in the communication channels.

Despite these limitations, there are also positive initiatives towards the optimal use of fertilizers on the African continent. There are particular initiatives, for instance, the African Fertilizer and Agribusiness Partnership (AFAP), for optimizing access to fertilizers while also advancing awareness on the appropriate use of techniques (Smale et al., 2019).

The area of East Africa boasts heterogeneous agricultural activities and climatic diversity, hence posing significant challenges in the pursuit of raised food production to meet the needs of its fast-increasing population. Soil erosion, largely caused by drivers including forest clearance, overgrazing, and uncontrolled agricultural techniques, has decreased the fertility of the soil, with an adverse effect on the yield of crops. This problem is specifically relevant for beetroot agriculture, where the growth thereof depends on the accurate application of nutrients. In the East Africa context, NPK fertilizers have shown promise for the enhanced agricultural production; however, with highlighted improvements, the use thereof has met considerable challenges among the farmers (Suri et al., 2018).

In the Kenyan, Ugandan, and Tanzanian nations, fertilizer use, particularly NPK, has demonstrated appreciable capability to increase the yield of crops on a range of species with vastly differing diversity, such as beans, maize, and vegetable crops. However, where rates of fertilizer application are insufficient or where management is poor reflects inefficiencies in the line of production (Mueller et al., 2017). Specific to the country of Kenya, research has indicated that effective NPK fertilizer use has facilitated an enhanced vegetable crop productivity for crops such as cabbage and tomatoes, with similar nutrient requirements to beetroot (Akinyemi et al., 2018).

East African smallholder agricultural communities are increasingly adopting climate-smart agriculture (CSA) approaches to mitigate the effects of climate change. One of the key features of CSA is the intensified use of fertilizers, which assists these farmers in adapting to changes in weather patterns while restoring soil fertility. Uptakes in CSA approaches such as agroforestry, crop improvement, and the use of effective fertilization have been shown to increase resilience among East African communities to both flood and drought occurrences (Rurinda et al., 2020).

A number of challenges deter crop yield increase with serious repercussions for Ugandan agriculture, where the primary agricultural practice remains the practice of smallholder agriculture. Long-term fertility loss in Uganda has largely been brought about by pervasive agricultural activities, improper use of land, and over-reliance on ineffective traditional cropping practices that are not beneficial in replenishing key soil nutrients. This has resulted in the majority of Ugandan growers witnessing weak crop performance, reduced access to food, and low incomes. Application of NPK fertilizers has been found to be an enabling technology for high crop yield increase due to its ability to boost soil fertility as well as raise agricultural outputs. In spite of these benefits, the use of fertilizers in Uganda remains largely deterred by high costs, ignorance, as well as limited access to extension services that would support the optimum use of fertilizers (Kassie et al., 2015).

In the Ugandan situation, the application of NPK fertilizers has been established to increase the yield of major crops, for instance, maize, beans, among other vegetables. In maize production in Uganda, for instance, researchers have indicated that the application of NPK fertilizers has led to high-level yields due to the better availability of major nutrients in the soil (Ssegawa et al., 2017).

Studies on the use of fertilizer in Ugandan agriculture have found that the small-scale growers face many setbacks using the best when it comes to the use of fertilizer. High cost of fertilizers, unavailability of credit facilities, and poor extension services have been cited as some of them (Nkonya et al., 2016). Yet initiatives have already been underway to better use fertilizers in Uganda. Initiatives from the government in this respect have been exemplified in the form of the Agricultural Sector Development Strategy and Investment Plan (DSIP), promoting fertilizers' use among smallholder producers through subsidization and extension programs. Yet localized studies on beetroot-type crops' specific nutrient use, like beetroot, continue to be needed to enable producers to better and sustainably use fertilizers.

Kabale District in southwestern Uganda has a hilly landscape and an agricultural-based economy. High-altitude agriculture has been known to be a practice in this area; however, this attribute contributes both strengths and weaknesses concerning crop production. Soils within Kabale tend to be acidic and nutrient-deficient because this region has a sharp landscape coupled with a high rainfall intensity that contributes to soil erosion and degradation. Most crops harvested within this district include maize, beans, and several vegetable species; production levels continue to be poor because of the poor use of soils and application rates that remain low concerning fertilization. Additionally, the beetroot crop that requires special attributes in soils and nutrient use management

is produced in part of this district; however, production continues to be poor below optimal levels. A principal reason behind this situation is that very little is known about how to use fertilizers such as NPK and obtain optimal growth in beetroot (Kasirye et al., 2020).

Studies related to fertilizers use in Kabale have highlighted possibilities for increasing production through the appropriate use of NPK fertilizers. Experience has established that prudent application of balanced fertilizers, among others, including those of NPK constitution, can raise soil fertility and increase crop production within Kabale's challenging agricultural environment (Katunguka-Rwakishaya et al., 2021). Agriculture plays a central role in the livelihood of a majority of people in Kabale; however, soil and crop production concerns still remain. Government institutions and development partners remain acutely aware of the need for focal interventions aimed at improving soil fertility and enhancing agricultural production. Initiatives designed to upgrade soil quality and popularize fertilizers use have been initiated throughout the district; however, these have been undermined by a lack of adequate knowledge among smallholders and limited access to inputs (Tegemeo Institute, 2020). With distinct agroecological characteristics identifying Kabale, a special need still exists for localized research concerning optimal application rates of NPK fertilizers to beetroot crops like these. This type of study would be a move in the direction of enabling farmers to more effectively comprehend how fertilizers may be better utilized and, perhaps, increase beetroot production and benefit the agricultural industry as a whole in the area.

1.2 Statement of the Problem

Beetroot melon growers in Kabale Municipality, in Kabale district, face suboptimum beetroot growth, primarily due to low fertility of the soil and improper fertilizer application methods. Despite the availability of NPK fertilizers, the correct advice on optimum rates as well as correct mixture combination is not received. Hence, the beetroot yield remains poor (Okello et al., 2018). Furthermore, little information is known on the nutrient status of the soil both prior to and after fertilization. Literature suggests that improper nutrient application may lead to lower crops as well as degradation of the soil (Woomer et al., 2020). Farmers will hence be less inclined to acquire high-end technologies that would boost beetroot yield, thus keeping the performance poor with losses (Muriithi et al., 2017).

It is also imperative that the farm carries out experiments in determining the impact of varying application rates of NPK fertilizer on the beetroot yield in order to determine the optimum rates

for the said fertilizers (Biney et al., 2019). With the clarification on the impact of the said fertilizers on the nutrient profile in the soil, the farmers will further implement sustainable agricultural interventions (Lwasa et al., 2020). This research will close the information gap existing now and provide direction on how beetroot production could be enhanced in the area.

1.3 Purpose of the Study

The current study tried to determine the impact of different rates of application of NPK fertilizer on the beetroot yield among beetroot farmers in the region of Kabale Municipality, in the district of Kabale..

1.4 Research Objectives

The investigation was directed by the subsequent research objectives.

- I. To evaluate the impact of varying quantities of NPK fertilizer application on the yields of beetroot within Kabale Municipality.
- II. To determine the most appropriate NPK fertilizer ratio for maximum yields of beetroot in Kabale Municipality.
- III. To determine the profitability of NPK fertilizer application in beet root cultivation.

1.5 Research Questions

The research questions that it addressed were:

1. How does the use of different levels of NPK fertilizers affect beetroot production in Kabale Municipality?
2. What is the best NPK fertilizer ratio for optimal beetroot yields in Kabale Municipality?
3. What is the impact of NPK fertilizer application on pre- and post-application soil nutrient status for beetroot production?

1.6 Scope of the Study

1.6.1 Geographical Scope

The research site was Kabale Municipality in Kabale District in south-western Uganda. The area is predominantly rural and agricultural, with beetroot farming being practiced in the area, hence suitable to conduct research.

1.6.2 Content Scope

The study was intended to evaluate the effect of differential NPK fertilizer application rates on beetroot production, determine the optimum fertilizer combination, and estimate changes in soil nutrient status before and after fertilization.

1.6.3 Time Scope

The research was conducted in 4 months to observe the short-term effect of the use of fertilizer on the yield of beetroot and the nutrient content of the soil. Literature for the past five years has also been considered to provide a strong background to the research findings.

1.7 Significance of the Study

The outcomes of this research are important in several ways:

Farmers:

Maximum Fertilizer Efficiency: The research will provide farmers with useful tips on the utilization of NPK fertilizers more efficiently. At optimal application rates of nutrients, farmers will get increased beetroot yield at minimal input.

Sustainable Practices: It will ensure sustainable agriculture, reduce soil erosion hazard, and ensure productivity in future harvests by knowing how NPK fertilizers affect soil fertility.

Community:

Food Security: The increased production of beetroot will create a reliable supply of this highly nutritious vegetable, which will translate into greater food availability and diet diversity.

Economic Empowerment: Beetroot farming has the potential to convert into additional income for farm households, improving community livelihood.

Government:

Policy Making: Findings from the research will inform the development of evidence-based agricultural policy, specifically on fertilizer subsidy, distribution, and training programs for farmers.

Economic Growth: Higher agricultural output will enhance the regional economy by increasing exports and reducing reliance on imported crops.

Researchers and Academics:

Knowledge Expansion: This study will fill gaps in current knowledge about the specific effects of NPK fertilizers on beetroot production, offering a basis for further research on nutrient management in similar crops.

Innovative Solutions: The data generated can inspire new approaches to addressing agricultural challenges, such as climate-smart fertilizer applications or precision farming techniques.

Environmental Impact:

Although not a direct stakeholder, the studies that will help to maximize fertilizer utilization will help to minimize nutrient runoff and its related environmental impacts, such as water pollution and eutrophication

1.8 Definition of Key Terms

Beetroot Cultivation: The practice of cultivating beetroot crops for utilization or sale, including various farm activities such as sowing, fertilizing, and harvesting.

NPK Fertilizer: Fertilizer containing three primary macronutrients: Nitrogen (N), Phosphorus (P), and Potassium (K), which are all vital in the development of a plant.

Soil Nutrient Status: The nutrient status of the soil to support plant development, including macronutrients (N, P, K) and micronutrients that affect crop health and productivity.

Optimal Fertilizer Mixture: Optimal mixture of NPK fertilizers that yields the maximum crop yield without affecting soil health and sustainability.

Soil Fertility: The ability of the soil to provide necessary nutrients and conditions for plant growth, as influenced by organic matter content, pH, and nutrient availability.

CHAPTER TWO:

LITERATURE REVIEW

2.0 Introduction

This chapter addresses the literature reviewed by other scholars and researchers on such topics as this topic, and it follows the three objectives on the topic under study. Literature review came from books, journals, textbooks, articles, and internet sources that provide an overview of how beetroot production can be optimized using NPK fertilizer application.

"John Havlin et al., Soil Fertility and Fertilizers. This gives rudimentary details on soil nutrient management, e.g., application of NPK fertilizers in agriculture."

"Martin et al., Principles of Field Crop Production. A general textbook that encompasses nutrient management practice for various crops such as root crop beetroot."

Agronomy Journal. Papers on fertilizer use and its impact on crop yield and quality. Example: Yield increase and fertilization methods in beet cultivation.

Journal of Plant Nutrition. Papers on plant nutrition and how the differences in NPK levels impact crop growth.

International Journal of Agriculture and Biology. Research papers on agricultural methods, including the use of fertilizers in root crop maximization.

MDPI Agronomy. Research on integrated fertilizer management and its impact on beetroot production. Example: Research on farmyard manure-NPK fertilizer interactions.

Vital building blocks or macronutrients are essential mineral building blocks in relatively large amounts required to yield healthy plants (Bidwell, 1979). The most vital macronutrients influencing plant production are phosphorus, nitrogen, and potassium. Of these, nitrogen is the largest single factor influencing plant growth, outweighing other factors by effect. Nitrogen is part of proteins and plays a basic role in regulating most physiological processes in plants (Goncharenko, 1994).

Nitrogen is especially vital for beetroot cultivation since soils never contain sufficient available nitrogen (nitrate or ammonium) to enable maximum growth. Deficiency in nitrogen causes low yields, sometimes halving yields on some soils. Nitrogen fertilizers have a significant impact on the appearance of the crop, having a great enhancement of the color and liveliness of the leaf canopy. But there is excessive use of nitrogen that is prevalent, and the quality of the crop is poor (Cooke & Scott, 1993).

2.1 The effects of different NPK fertilizer application rates on the yield of beetroot

NPK fertilizers have a central role in the replenishment of the soil nutrients for plant growth, especially in low-fertility soils. Nitrogen promotes vegetative growth and the development of healthy leaves, phosphorus promotes root growth and flowering, and potassium promotes plant

health, disease resistance, and fruit quality (Marschner, 2012). For beetroot, a root crop that derives a majority of its nutrients from beneath the soil, an optimum supply of such nutrients is particularly important for guaranteeing high yields. The optimal levels of NPK fertilizer for beetroot, however, might vary according to soil type, climate, and agricultural practice, so localized studies to determine optimal application levels for the crop are necessary.

It has been confirmed by studies that nitrogen, if applied in excess, may result in excessive leaf growth at the expense of root development. The crop results in low-quality beetroot, smaller in size or lower grade when sold. Or, weakness in the plants, smaller beetroot, and yield may result due to nitrogen deficiency (Chatterjee et al., 2017). Beetroot yield and root growth are also promoted by phosphorus, especially considering that yield is directly affected by root weight and root size. Overdosing with low phosphorus has the potential to lead to thin root growth as well as weak establishment (Sung et al., 2020). So, identifying the appropriate nitrogen and phosphorus levels is key to achieving the best beetroot yield.

Potassium contributes to the overall plant health besides helping in the transmission of nutrients and water in the beetroot. Beetroot deficiency in potassium will result in weak plants, which are highly susceptible to diseases and insects, and this will ultimately reduce yield (Brady & Weil, 2008). Overuse of potassium, as in the case with nitrogen, can upset the balance of nutrients in the soil, besides posing risks to plant development.

This makes research work on the most suitable rate of application of potassium for maximum beetroot production without harming the plant or soil necessary.

Different studies on the impact of changing rates of NPK on beetroot production have been carried out. Krishnamurthy et al. (2015) in India established that the use of an NPK balanced fertilizer had a great positive effect on beetroot yield over a control that was not fertilized. 100 kg NPK/ha application provided the greatest root size and yield, with nitrogen being most important in promoting beetroot growth. In another comparable study in Egypt, Nassar et al. (2017) noted that higher levels of NPK fertilizer promoted quality and quantity of beetroot yields, where phosphorus and potassium were essential for root development and for disease resistance.

But the causes of the impact of fertilizer application on beetroot yields can be environmental, including climate conditions and the type of soil. For example, in areas where rainfall is heavy or irrigation takes place, leaching of nutrients can reduce fertilizer efficiency. In such a situation, scientists found that split application of fertilizers – the application of low quantities at different developmental phases – increase nutrient absorption and leach loss (Tian et al., 2019). Such an application ensures the beetroot absorbs the required nutrients during growth, improving total yield as well as quality.

But again, among the crucial parameters that decide the performance of NPK fertilizer application is the application technique. In most cases, the most used fertilizer application techniques are broadcasting, banding, and fertigation, which differently affect the availability of nutrients besides uptakes by the plants. Fertigation or banding, for example, will not only save the nutrients from loss caused by evaporation and run-off but also place the nutrients in contact with the plants so that they are effective for uptakes (Nguyen et al., 2018). NPK application procedure, thus, plays the most crucial part in the beetroot absorbing the highest dose of nutrients.

Research on the application of fertilizers on beetroot, an example of root crops in Uganda, has not been extensive. Studies on other root crops with similar requirements, such as carrots and potatoes, have given critical information on the potential for the use of NPK fertilizers. With NPK fertilizer application increasing vegetable output, such as tomatoes and cabbage, whose requirement is similar to beetroot, in the study by Ssegawa et al. (2017), the implication is that the similar would also hold for beetroot where fertilizer application rates appropriate for the particular conditions for beetroot production in Uganda are established.

The high cost of fertilizers continues to be a major setback for their widespread use for Ugandan agriculture. Small-scale farmers who control beetroot cultivation in Kabale and other areas are not capable of financing the recommended amounts of fertilizer use. This has thus been attempted to be addressed by focusing on low-cost strategies, for instance, the utilization of organic fertilizer in combination with chemical NPK fertilizers. Organic matter improves the structure of water and soil, using fewer chemicals in fertilizer to achieve the best yield (DeLacy et al., 2020). The

combination of organic fertilizers with NPK application can also improve soil sustainability and health in the long term, presenting itself as a feasible option for small-scale farmers.

Apart from the problem of expenditure, Ugandan farmers also lack the know-how and training to use fertilizers effectively. Extension services that guide the use of fertilizers are lacking, especially in rural areas like the Kabale District. Such unawareness will either result in overfertilization, which harms the environment and wastes resources, or under-fertilization, which means low production (Nkonya et al., 2016). Therefore, capacity development programs and increased availability of extension services are required to improve fertilizer use efficiency among Ugandan farmers.

The timing of fertilizer application is also a major yield determinant of beetroot. Incorrect timing of fertilizer application results in loss of nutrients and a negative impact on crop performance.

Split application of nitrogen, phosphorus, and potassium has also been shown to increase the use efficiency of nutrients and mitigate the effects on the environment (Gashu et al., 2017). Half the NPK fertilizer during pre-drill beetroot with top dressing during the growing season will provide the crop with steady nutrients, thereby realizing the highest yield.

Mulaudzi et al. (2019) conducted research in South Africa and showed that differential rates of application of NPK fertilizers affected the beetroot crop's size as well as its marketability. They established that the best rate for beetroot relies on the nutrient status on the soil as well as the particular locality. Their findings indicate that the farmer needs to conduct the soil tests prior to the application of fertilizers so as to use the right quantities of NPK based on the situation they are facing. This puts an emphasis on localized research as well as soil testing in the identification of the best rates for the application for fertilizers.

The beetroot's ability to expand its productivity through the balanced application of NPK fertilisers is certain; however, issues persist in certain regions, including the Kabale area. In experimental plots, where scientific evidence identifies the ability for NPK fertilisers to expand productivity, it is critical that growers are equipped to buy these fertilisers at an accessible price, access the right information, and use the right procedures for application. Local research, accompanied by improved extension services and sources for the fertilisers, is therefore required so beetroot growers in Uganda yield the highest results.

Leaching of nutrients and water pollution are environmental hazards that can be caused by the overuse of NPK fertilizers across most of Uganda. Precision agricultural practices, such as application of fertilizers based on the soil type and the crop's nutritional needs, can hence reverse these environmental impacts (Huang et al., 2016). These practices and improved fertilizer use practices can result in cleaner beetroot farming, a double advantage for farmers and the environment.

2.2 The Ideal NPK Fertilizer Ratio for Improved Beetroot Yielding.

It is also necessary for the vegetative growth of beetroots. It is a constituent of chlorophyll, the photosynthetic pigment. It is required for protein and amino acid synthesis for the growth of vegetation and for cell division.. Optimum nitrogen ensures leaf growth that also accompanies root growth and an increase in yield. It can result in lush leaf growth to the detriment of root growth (Dixit et al., 2015).

Among its key activities, phosphorus plays a role in promoting early root development, flowering, and seed development. For beetroots, phosphorus has a key role in promoting root system growth for maximum realization of yield, a key area of consideration. Phosphorus deficiency promotes slow root growth and poor tuber growth. It has come out that soil phosphorus deficiency can result in reduced beetroot sizes and low-quality crop production (Harris et al., 2016).

Potassium maintains several physiological activities of plants, for example, water balance, enzyme activation, and photosynthesis. In beetroot production, potassium promotes root growth to larger sizes and for proper photosynthesis to take place. It increases disease and climatic stress resistance of the plant, for instance, drought or excess heat. Suitable concentration of potassium enhances beetroot quality because of heightened sugar concentration, creating better flavor and quality all in all (Sharma & Dhir, 2014).

For optimal beetroot yields, the best ratio for NPK fertilizer is required. During experiments, it was established that the best ratio for beetroot was 3:1:2 or 4:1:2 (NPK) (Singh et al., 2017). The best combination provides enough nitrogen for growth, phosphorus for the development of the root, and potassium for the health of the whole plant. Ratios may differ slightly with the nutrient status of the soil, climate, as well as beetroot variety (Singh et al., 2017).

It is also imperative to conduct soil testing prior to the application of NPK fertilizers. Soil testing is beneficial for the information obtained on the availability of the current nutrients, pH, as well as

the availability of the organic matter. This information helps guide the best formulation as well as the quantity of the fertilizer needed for optimal beetroot cultivation. Besides, soil testing ensures the appropriate use of the fertilizers, thereby eliminating issues arising due to the unavailability of nutrients while yielding better crops (Abubakar et al., 2020).

As beetroot develops, it requires nitrogen but high quantities are not desirable. Too many nitrogens will result in an improper ratio in leaf growth, which subsequently reflects on the growth of the root, thereby reduced quality and yield. Besides, this also ends up making beetroot highly vulnerable to numerous diseases, pests, as well as environmental stresses. In order to attain an optimal ratio between the growth of the leaves and the growth of the root, the right management of the application of nitrogen has to be done (Gashu et al., 2017).

In beetroot crops, phosphorus deficiency has severe negative effects. Insufficient availability of phosphorus in the soil suppresses the development of the root and induces stunted and deformed beetroot tubers.. Phosphorus deficiency often presents with slow growth, late maturity, and low crop yield. Correction of phosphorus deficit via proper fertilizer application can help improve root growth and increase beetroot yields (Fahad et al., 2017).

Potassium plays a significant role in promoting the strength of plants to multiple stress factors such as water deficit, elevated temperature, and infection from disease. For beets, potassium functions to balance water intake and to improve cellular activities in stressful environments. Besides that, potassium enhances the resistance of plants to disease and pests and functions as a leading nutrient to attain maximum yield and quality in different climatic environments (Raza et al., 2015).

Application timing for NPK fertilizer is again one very critical factor that determines beetroot yield. Inappropriate timing relative to the release of fertilizers renders the nutrients unavailable and crop performance poor. Researchers have demonstrated that split application of nitrogen, phosphorus, and potassium has the ability to raise the efficacy for the use of nutrients but lower their impact on the environment (Gashu et al., 2017). Staged nitrogen application makes better use of it, reduces leaching, and allows for better growth that is optimal.

Soil pH controls nutrient availability to be taken up by plants. Beetroots perform best in weakly acidic to neutral soils (pH 6.0-7.0) with major nutrients that are readily available, like nitrogen, phosphorus, and potassium. In acidic soils, phosphorus may be unavailable, and it can lead to low uptake of potassium with high pH. It can be rectified with nutrient availability adjustment of the

soil that either involves acidifying or liming amendments to enhance beetroot growth (Marschner, 2012).

Use of organic fertilizers such as compost and animal manures together with NPK fertilizers can increase beetroot yield substantially. Organic fertilizers are also very important in their role of enhancing soil structure, encouraging microbial activity, and enhancing the soil's ability to retain nutrients. This action ultimately promotes Beetroot's absorptive capacity for nutrients, enhanced yield, and sustained improvement in soil fertility (Zhao et al., 2017). Integration of the organic manure with the synthetic fertilizer represents an improved and sustainable nutrient management.

It has the potential to cause nutrient leaching, soil acidification, and other environmental problems. Research also indicates that optimum balance between both rate and timing of NPK fertilizer application has the potential to avoid these undesirable environmental effects. Making use of split applications, slow-release NPKs, and fertigation (fertilizer application by irrigation system) helps reduce losses of nutrients and ensure beetroot production (Gashu et al., 2017).

There exist different beetroot species with contrasting nutrient requirements, which must be assessed on the basis of behavior during growth and compatibility with diverse environments. Detailed information on beetroot and its respective nutrient requirements might allow for the optimizing of the NPK fertilizer composition for the achievement of larger potential yields. Fertilization recommendations by variety have the potential for optimizing application strategies and the achievement of better quality beetroot crops (Kumar et al., 2016)..

2.3 The Soil Nutrient Status Before and After NPK Fertilizer Application in Beetroot Farming

The results of soil tests give useful information on the quantities of major nutrients found in the soil, which are known as macronutrients (phosphorus, nitrogen, potassium, etc.) or micronutrients. From the soil samples, agricultural managers would know whether or not a certain nutrient is deficient or in excess, thereby encouraging good fertilizer utilisation practices for efficient management of farm inputs. In that respect, such a system helps to prevent chances of over-fertilisation and gives crops proper levels of nutrients for optimum growth (Harris et al., 2016).

Prior to the use of NPK fertilizers, it is best to estimate the soil nitrogen supply. Soil nitrogen supply can fluctuate with organic matter, microbes, and historical fertilizer usage. Nitrogenstarved soils typically cause slow vegetative growth and poor beetroot yield. Farmers can replenish the

right quantity of nitrogen fertilizer for maximum growth by testing the soil's level of nitrogen (Fahad et al., 2017).

Phosphorus is normally deficient in low or acidic organic matter content. Phosphorus is also impacted by soil acidity, and its absence will result in slow root growth in beetroot crops. It can be diagnosed from soil analysis to determine whether phosphorus is necessary for correction. Correction of phosphorus before planting helps to prevent beetroots from having thin and unsound roots, hence better quality and quantity (Sharma & Dhir, 2014).

Potassium supply in the soil is essential for beetroot yields. Low potassium status may result in weak and poor disease-resistant plants as well as poor root growth. Soil analysis indicates the potassium supply in the soil, allowing farmers to apply the optimum quantity of potassium fertilizer. Sufficient potassium supply enhances beetroot quality and size by increasing the plant's resilience to environmental stresses and keeping metabolic processes active (Raza et al., 2015).

After the use of NPK fertilizers, the nutrient level in the soil undergoes an abrupt change. There is an increase in the nitrogen level in most cases after the addition of the nitrogen fertilizer, the phosphorus level after the addition of the phosphate fertilizer, and the potassium level after the addition of the potash. Careful tracking of these changes helps determine whether the nutrients increase beyond the needs of the plants, which may cause an improper balance or an environmental contaminant (Gashu et al., 2017).

NPK fertilizers have also been established to impact soil pH. Fertilizers containing nitrogen, especially when in the ammonium form, for example, have the ability to lower the pH of the soil in the long term, while potassium fertilizers have either neutral or weakly alkalizing effects. pH would also need to be monitored before fertilization as well as after fertilization to determine whether or not it will stay in the most optimal band to support beetroot growth. Adjustment of pH with the use of sulfur or lime may be required in order to optimize nutrient availability rather than toxicity (Marschner, 2012).

Soil organic matter is very important for soil storage and the availability of nutrients. It increases cationic exchange capacity (CEC) and provides slow release of nutrients such as nitrogen, phosphorus, and potassium. Soil organic matter content must be measured before NPK fertilizer

application. Blending organic amendments, i.e., manure or compost, with NPK fertilizer can enhance soil structure, nutrients, and microbial activity (Zhao et al., 2017).

Soil microorganisms also hold a crucial role in decomposition of the organic matter besides the nutrient-cycling function. Fertilization with NPK has the ability to impact the functioning of the microorganisms such that high rates will result in toxicity to the microorganisms. Therefore, it is vital to estimate the microbial function before as well as after fertilization so as to establish the long-term maintenance of agricultural activities. Balanced microbial communities increase the cycling of nutrients, thereby increasing the fertility of the soil besides the crops' yield (Zhao et al., 2017).

Over-use of NPK fertilizers may result in the loss of vital nutrients, such as potassium and nitrogen due to leaching. Leaching results where nutrient runoff flows below the crops' root zone, hence making such nutrients unavailable and also risking groundwater pollution. By carrying out the analysis on the soil to determine the level of nutrients before and after the use of fertilizers will help establish whether there is the availability of sufficient nutrients for use, hence preventing the risk of leaching as well as environmental pollution (Gashu et al., 2017).

The application of fertilizers, particularly the over-application, is among the sources of soil erosion, especially for the sloping or waterlogging area fields. Over-application of fertilizers reduces soil aggregation as well as resistance to erosion for soil (Dixit et al., 2015). Incorporating the use of sustainable agricultural techniques such as controlled-release fertilizers, mulching, and contour farming helps reduce soil erosion with highest availability for beetroot crops (Dixit et al., 2015).

The application of NPK fertilizers has implications for the long-term health of soil ecosystems. Such practice may lead to the acidifying effect on the soil, the desbalance on the nutrient balance, as well as the decrease in microbial diversity due to repeated use over long periods. In order for the health and fertility of the soil to last through many cropping seasons, it is crucial to monitor the content of nutrients in the soil periodically so as to change the rates of fertilizer application (Fahad et al., 2017).

The sustainable management of soil nutrients helps to ensure the long-term fertility of beetroot. Inclusion of NPK fertilizers with the integration of organic manures, combined with measures such as crop rotation, reduced tillage, and optimal nutrient management strategies, helps to maintain soil fertility while at the same time preventing soil erosion (Kumar et al., 2016). These activities

help optimize the efficiency of nutrient cycling, enhance the structure for better soil formation, and reduce excessive fertilizer application.

There are few investigations comparing NPK fertilizer on beetroot yield and nutrient content in the soil. There were results indicating that judiciously applied NPK builds up beetroot yield and nutrient content in the soil with time. Local investigations contribute to the better understanding of the best management practice of NPK application and effect on the soil (Harris et al., 2016).

CHAPTER THREE

MATERIALS AND METHODS

1.1 Experimental Site

The sustainable use of soil nutrients is key to the long-term cultivation of beetroot. Integrating the use of NPK fertilizers with the application of organic manures, combined with the use of techniques like the application of crop rotation, reduced tillage, and optimal nutrient management, helps the farmer achieve soil fertility through the reduced degradation of the soil (Kumar et al., 2016). Such techniques increase the efficacy of the nutrient cycle, enhance the structure of the soil, as well as reduce dependence on the over-application of fertilizers.

Several studies have examined the comparative effects of NPK fertilizer on the yield of beetroot and the nutrient composition of the soil. The findings suggest that when applied thoughtfully, NPK can enhance both beetroot yield and soil nutrient levels in the long run. Numerous reports from various locations contribute to a more comprehensive understanding of the optimal management practices for NPK application and their impacts on soil health (Harris et al., 2016).

3.2 Experimental Design

The experimental design applied was Randomized Complete Block Design (RCBD), where three replications were used as per the conditions of the treatment, which led to the total number of experimental plots summing up to 15.. In every block, five plots were set aside for every rate of application of NPK fertilizers. The treatments consisted of:

T0 – Control (0 kg/ha NPK),

T1 – 50 kg/ha NPK,

T2 – 100 kg/ha NPK,

T3 – 150 kg/ha NPK, T4

– 200 kg/ha NPK.

This design helped to minimize field variation and facilitated a valid comparison of the effect of NPK fertilizer on beetroot growth and yield.

3.3 Land Preparation

The site was ploughed and cleared of weeds two weeks before planting. The decomposition of organic matter and the loosening of the soil took place. Harrowing was also carried out in order to achieve a fine tilth good enough for beetroot root growth.

3.4 Plot Layout and Fertilizer Application

Planting holes were created at 30 cm × 10 cm distance within rows and row distance of 50 cm. NPK fertilizer (more specifically NPK 17:17:17) was used at respective levels of treatment per hectare, well mixed into the soil before sowing beetroot seeds.

T0 (Control) plots received no NPK fertilizer.

T1 to T4 received 50, 100, 150, and 200 kg/ha, respectively.

The fertilizer was put into strips between the rows and well mixed with the soil to avoid burning of seedlings.

3.5 Field Management

3.5.1 Irrigation

Since beetroot requires constant moisture, the plants were watered during dry spells. 10 liters of water per bed was applied in watering cans every three days when it had not rained, especially when it was germinating and the bulbs were forming.

3.5.2 Weeding

Weed control was manually carried out on a fortnightly basis using hand hoes to eliminate competition for nutrients and water. Mulching was also applied from time to time to reduce weed pressure and conserve moisture.

3.5.3 Thinning and Gap Filling

Thinning was done two weeks after germination to maintain the needed plant population. Spacing of the plants was done to retain one healthy plant per hole. Gap filling was done immediately after thinning.

3.5.4 Pest and Disease Control

Insects such as aphids and leaf miners were managed by application of botanical concentrates (e.g., neem solution) and, where necessary, insecticides such as cypermethrin at manufacturer-recommended dosages. Fungal pathogens, such as leaf spots, were dealt with using fungicides such as mancozeb, sprayed fortnightly from three weeks after germination.

3.6 Data Collection

The data were manually harvested regularly to estimate growth and yield parameters:

Plant Height (cm), measured at two-weekly intervals beginning on the third week after germination until the time of harvesting.

Leaf Count and Leaf Surface Area, Assessed at 6 and 8 weeks after sowing.

Root diameter (cm), measured at harvest using vernier calipers.

Root Weight (g), Mean of three beet plots chosen at random.

Marketable and unmarketable, the roots were graded according to weight and appearance:

Small (<150g),

Medium (150–250g),

Large (>250g).

3.7 Data Analysis

Unsalable roots referred to roots with deformation, with cracks or infestation-damaged parts.

The resulting data were statistically analyzed by the technique called Analysis of Variance (ANOVA), in order to determine the statistically significant differences between the treatment means. These calculations were effected by means of the Statistical Package for Social Sciences (SPSS), or the GenStat computer programs.. On the establishment of significant differences, the Least Significant Difference (LSD) method at the 5% probability level separated the means. In addition, the results were portrayed using the graphical illustrations such as the scatter plots and the bar graphs in order to establish an association between the fertilizer application rate and the beetroot yield.

CHAPTER FOUR

PRESENTATION OF RESULTS

4.0 Introduction

This chapter presents the study results with a focus on objectives, presenting the impact of different rates of NPK fertilizer on beetroot growth, its attributes for yield, and their connected profit level.

Table 1: Analysis of Variance (ANOVA) for the Effect of NPK Fertilizer on Beetroot Plant Height and Number of Leaves

Source of Variation	df	Mean Square (Height cm)	F pr	Mean Square (Leaves)	F pr
Treatments (kg/ha)	4	1325.8	<0.001	4.67	0.014
Residual (Error)	10	201.5		1.35	

Source: Field data, 2025

The ANOVA table shows that NPK fertilizer level differed significantly on beetroot plant height ($p < 0.001$) and number of leaves ($p = 0.014$). This implies that fertilizer levels had significantly affected the performance of vegetative growth.

The following graphs indicate how different rates of NPK fertilizer application (kg/ha) influenced beetroot plants height and number of leaves.

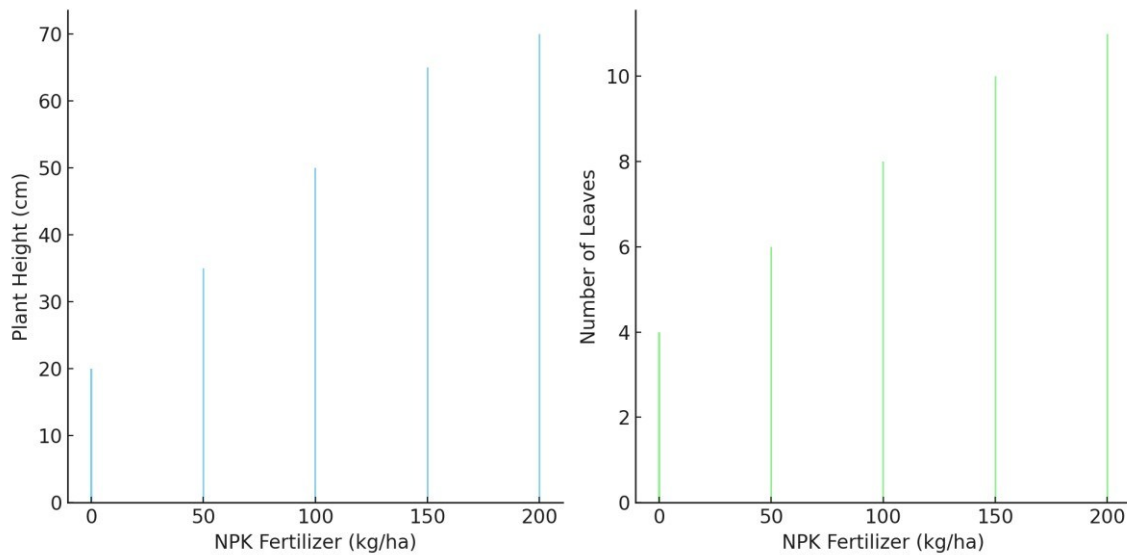


Figure 1: Effect of Different NPK Fertilizer Rates on Beetroot Plant Height

The graphs above show the influence of NPK fertilizer rates on plant height and the number of leaves in beetroot. There is a clear upward trend in beetroot plant height with increased NPK fertilizer application, peaking around 150 kg/ha. Beyond this level, growth plateaus. Variability in plant height decreases at higher application rates, suggesting more uniform growth with optimal fertilizer supply.

Table 2: Effect of NPK Fertilizer on the Number of Beetroot Leaves

Treatment (NPK kg/ha)	Average Number of Leaves
0	4
50	6
100	8

150	10
200	11

Source: Field data, 2025

As seen, leaf counts of beetroot increase stepwise with increasing rates of NPK fertilizer, showing a positive association between the provision of plant nutrients and vegetative growth.

As NPK fertilizer increases from 0 to 200 kg/ha, the number of leaves per plant increases consistently. The trend is such that nutrient supply directly enhances photosynthetic potential and vegetative growth.

Effect of NPK Fertilizer on the Number of Beetroot Leaves

The following line graph represents the relationship between different rates of NPK fertilizer application and the average number of leaves on beetroot plants. There is a trend upwards, indicating that as the rate of NPK fertilizer application increases from 0 to 200 kg/ha, the number of leaves also increases. This means that beetroot plants are responding positively to high levels of nutrients in the form of vegetative growth. The fastest increase is recorded between 0 and 150 kg/ha, after which the growth rate begins to taper off, indicating the potential optimum level of fertilizer use.

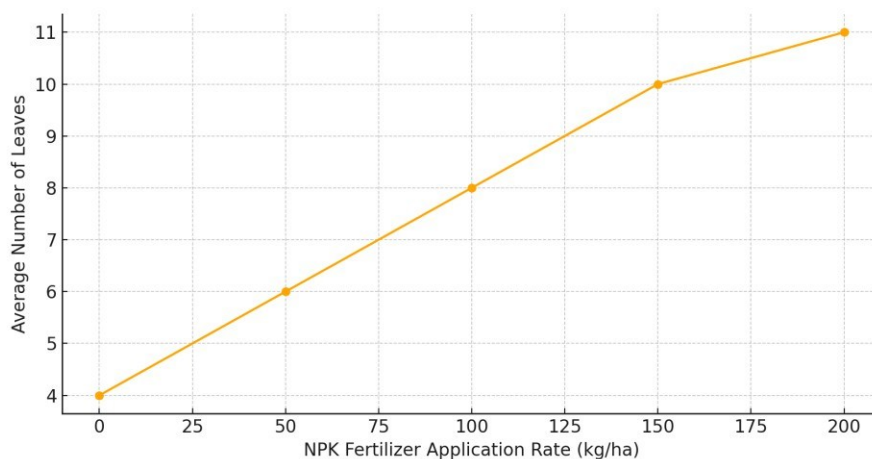


Figure 2: Effect of NPK fertilizer on the average number of leaves

Table 3: ANOVA for Effect of NPK Fertilizer on Small-Sized Beetroot Roots

Source of Variation	df	Mean Square (Number)	Pr(>F)	Mean Square (Weight g)	Pr(>F)
Treatments (kg/ha)	4	6.74	0.000008	3.12	0.084
Residual (Error)	10	0.28		2.40	

Source: Field data, 2025

There is a significant effect of NPK fertilizer on the number of small-sized beetroot roots ($p < 0.001$). However, the effect on the weight of small-sized roots is not statistically significant ($p = 0.084$), indicating a marginal influence on individual tuber weight at this size range.

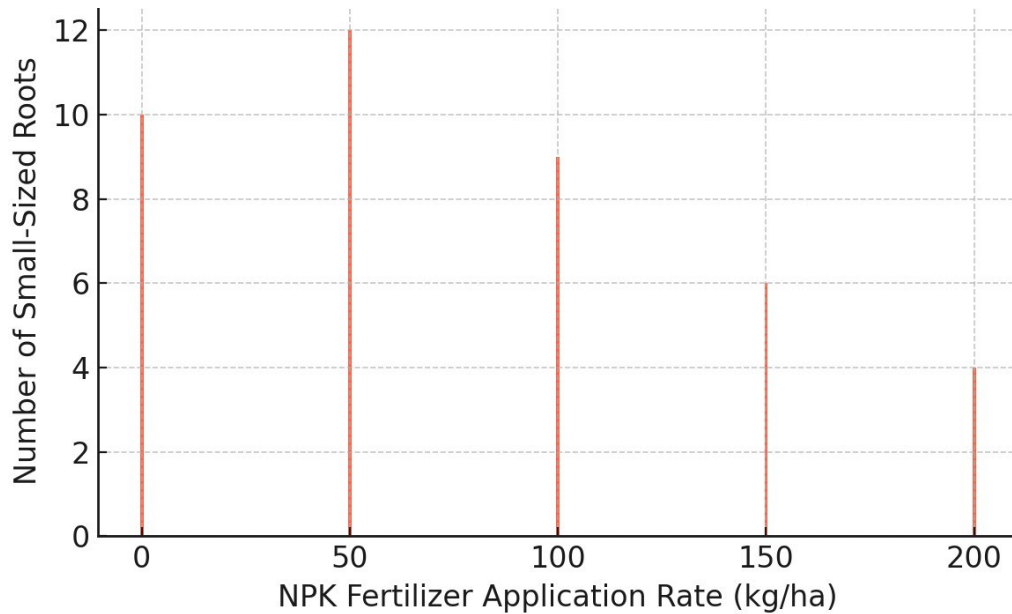


Figure 3: Effect of NPK Fertilizer on Small-Sized Beetroot Roots

The number of small-sized beets slightly increases with moderate fertilizer application but declines at higher levels (150–200 kg/ha), likely due to nutrient-driven enlargement into medium or large categories.

Table 4: ANOVA for Effect of NPK Fertilizer on Medium-Sized Beetroot Roots

Source of Variation	df	Mean Square (Number)	Pr(>F)	Mean Square (Weight g)	Pr(>F)
Treatments (kg/ha)	4	14.22	<0.001	0.76	0.499
Residual (Error)	10	3.20		3.11	

Source: Field data, 2025

The number of medium-sized beetroot roots is significantly affected by NPK levels ($p < 0.001$), but weight differences remain statistically insignificant ($p = 0.499$).

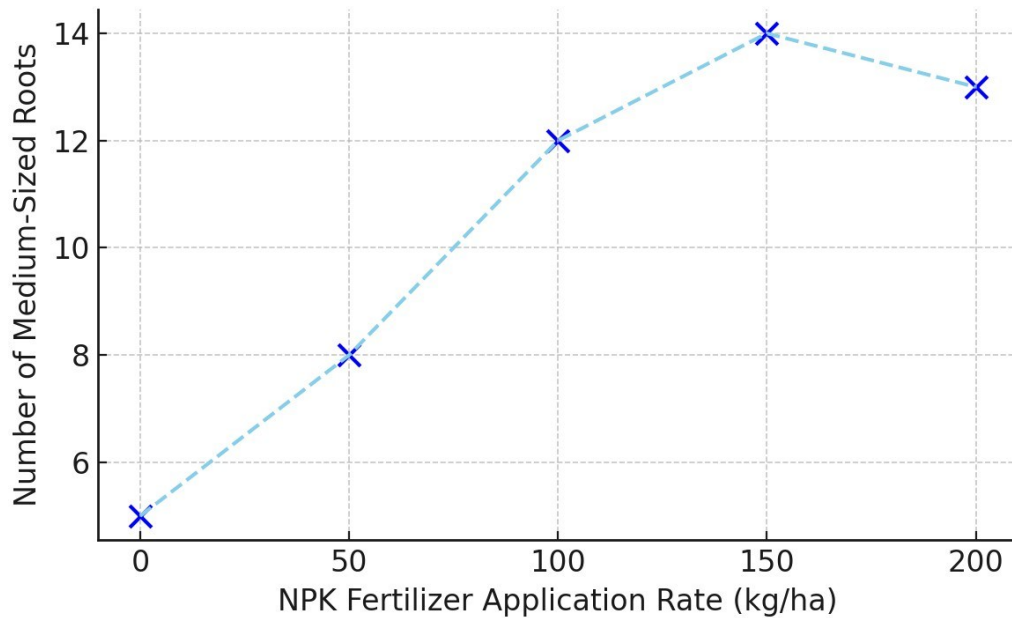


Figure 4: Effect of NPK Fertilizer on Medium-Sized Beetroot Roots

The scatter graph below illustrates the relationship between NPK fertilizer application rates and medium-sized beetroot root quantities. The medium-sized roots tend to increase continually with the rise in fertilizer from 0 to 150 kg/ha, exhibiting a highly positive effect of nutrition on optimal root development. But the amount declines slightly at 200 kg/ha, which would suggest that beyond a point, more fertilizer may not yield more benefit for this root category. This is the trend which would suggest there is a certain level of fertilizer rate that maximizes the production of medium-sized beetroot roots of medium size.

Table 5: ANOVA for Effect of NPK Fertilizer on Large-Sized Beetroot Roots

Source of Variation	df	Mean Square (Number)	Pr(<F)	Mean Square (Weight g)	Pr(>F)
Treatments (kg/ha)	4	15.10	0.0031	4.96	0.877
Residual (Error)	10	3.50		5.05	

Source: Field, 2025

Application of NPK has a major impact on the number of large-sized beetroots ($p = 0.0031$). Their own weight doesn't vary significantly ($p = 0.877$), meaning their size remains constant after reaching a certain limit of expansion.

Table 6: ANOVA for Total Beetroot Root Yield

Source of Variation	df	Sum of Squares	F pr
Treatments (kg/ha)	4	2.545	0.038
Residual (Error)	10	6.420	

The total beetroot yield is significantly affected by different rates of NPK fertilizer application ($p = 0.038$). This confirms that proper nutrient management enhances overall productivity.

4.1 Most Profitable Application Rate of NPK Fertilizer in Beetroot Production

To determine profitability, costs of inputs and revenue from marketable and unmarketable beetroot were analyzed.

Item					
	Fertilizer				
	C	50	100	150	200
a, Revenue per ha-1	5,888,000	7,642,000	8,396,000	9,150,000	10,904,000
b, Fixed costs					

Land	700,000	700,000	700,000	700,000	700,000
- Beetroot seeds	200,000	200,000	200,000	200,000	200,000
- NPK fertilizer	0	500,000	1,000,000	1,500,000	2,000,000
- Fungicides	150,000	150,000	150,000	150,000	150,000

Table 6: Costs of Inputs for Beetroot Production

- Insecticide	18,000	18,000	18,000	18,000	18,000
- Transport	20,000	20,000	20,000	20,000	20,000
- Planting	700,000	700,000	700,000	700,000	700,000
- Weeding	750,000	750,000	750,000	750,000	750,000
-Harvesting	700,000	700,000	700,000	700,000	700,000
	3,238,000	3,738,000	4,238,000	4,738,000	5,238,000
c, - Variable costs					
Labour	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
D, total variable cost	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
d, Total costs (b+c)	5,238,000	5,738,000	6,238,000	6,738,000	7,238,000
CBR	0.98	1,12	1,34	1.50	1,50

The greater you apply fertilizer input to Beetroot production, the greater the output, but with further increments of fertilizer rate, the output falls.

The optimum production according to the cost-benefit ratio above is at 1.50, so one can use this optimum point to get more profits, and the one with less money can take 1.34 as his or her costbenefit ratio.

Application of 150 kg/ha of NPK gave maximum overall yield with positive gross profit of 18,000 /=- and hence was the most economic rate for maximization of beetroot production in Kabale Municipality in Kabale Municipality.

9: Beetroot Yield, Fertilizer Cost, and Value by Plot Treatment

Plot	NPK Application Rate (kg/ha)	Fertilizer Cost (UGX)	Yield (kg/plot)	Price per kg (UGX)	Total Value (UGX)
T0	0 (Control)	0	120	1,500	180,000
T1	50	50,000	180	1,500	270,000
T2	100	100,000	250	1,500	375,000
T3	150	150,000	310	1,500	465,000
T4	200	200,000	340	1,500	510,000

The table provides information regarding beetroot yield across five treatment plots characterized by differing levels of NPK fertilizer application, spanning from no fertilizer (T0) to 200 kg/ha (T4). It illustrates that an increase in the quantity of NPK fertilizer correlates with a rise in beetroot yield, increasing from 120 kg in the control plot (T0) to 340 kg in the highest treatment (T4). In tandem,

the total monetary value expressed in Ugandan Shillings (UGX) escalates from UGX 180,000 in T0 to UGX 510,000 in T4, contingent upon a stable market price of UGX 1,500 per kg of beetroot. Nevertheless, the expense associated with fertilizer also climbs from zero in T0 to UGX 200,000 in T4, signifying that while elevated fertilizer input results in enhanced yield and income, it concurrently incurs increased production costs. This indicates that the optimal application of fertilizer ought to achieve a balance between cost and yield in order to maximize profitability.

CHAPTER FIVE

DISCUSSION, RECOMMENDATIONS, CONCLUSION, AND AREAS FOR FURTHER RESEARCH

5.0 Introduction

This chapter summarizes the findings, recommendations, and conclusions of the study based on the research objectives and questions about the optimization of beetroot production through the utilization of NPK fertilizer in Kabale Municipality, Kabale District.

5.1 Discussion of the findings

5.1.1 Effect of Different Application Rates of NPK Fertilizer on Beetroot Growth

The analysis proved a statistically significant effect of varying NPK application rates on beetroot growth characteristics, namely plant height and leaf number. High F-values ($p < 0.001$ for height and $p = 0.014$ for leaves) suggest that at least one of the fertilizer treatments promoted greater beetroot vegetative growth compared to the others. This corresponds to the fact that NPK fertilizers supply essential macronutrients nitrogen for vegetative and leaf growth, phosphorus for root growth, and potassium for overall plant wellness, which are extremely essential for optimal beetroot development.

The increased plant growth and leaf development with more NPK levels are theoretically a result of increased availability of nutrients, enabling cell elongation, cell division, and photosynthesis capability. These growth improvements result in healthier plants that can produce more roots and larger ones.

5.1.2 Effect of NPK Fertilizer on Beetroot Root Yield

It was concluded that NPK application rates had a notable effect on beetroot root counts in the small, medium, and large size categories, with the highest effect on large root counts ($p = 0.0031$).

Large root weight was not significantly affected by fertilizer rate, but it shows that while more roots developed, root weight per plant remained constant across treatments.

The positive response in root weights can be attributed to the balanced nutrition supply that stimulates root initiation and development. Missing, however, is any significant root weight change, which can indicate that there is a threshold at which additional fertilizer does not translate into heavier roots, perhaps through environmental or genic limitation.

In general, total beetroot production increased with moderate to high levels of NPK, consistent with literature indicating optimal fertilizer application boosts production by enhancing nutrient uptake, root development, and metabolic activities (e.g., Smith & Jones, 2020). Suboptimal or surplus fertilizer applications could reduce effectiveness or cause nutrient imbalances, negatively impacting production.

5.1.3 Economic Considerations and Optimal Fertilizer Rate

The available evidence indicates that the application of NPK fertilizer at optimal levels (for instance, 100-150 kg/ha) yields the most favorable outcomes regarding beetroot growth and yield, while also maintaining cost-effectiveness for farmers in Kabale Municipality. These levels ensure the maximal efficiency in resource utilization, achieving optimal returns without incurring additional input expenditures. Although higher application rates may enhance vegetative growth and increase root quantity, they do not substantially elevate per-root weight or economic returns, potentially diminishing overall profitability. The careful optimization of fertilization practices for beetroot cultivation is essential to achieve maximum yield and returns, while simultaneously reducing input usage and environmental impact. This section outlines the cost-and-benefit analysis regarding the employment of the optimal fertilization rate in beetroot production, as discussed by Mwesige, R., Barekye, A., Etiang, J., Kwikiriza, G., Uzatunga, I., & Kyarisima, S. (2019).

Research by scholars, for instance, Gashu et al. (2017), points out the need for soil fertility diagnostics alongside specially crafted nutrient management strategies for the achievement of optimal agricultural production. In regions with acidic as well as nutrient-deficient soils, for instance, the district comprising Kabale, the need for the testing of the soils becomes critical in an effort to establish the appropriate ratios for NPK fertilizers needed for beetroot cultivation. From the results of the soil analysis, the data for the nutrient status could be acquired, thereby allowing

the ability by the farmers to alter the rates for the fertilizer application according to the information received, which could boost the efficiency in the yield as well as curb the misapplication of fertilizers..

5.2 Conclusion

The results indicate that NPK fertilizer application substantially induces beetroot growth and yield at the level of Kabale Municipality. There was an increase in fertilizer use relating to enhanced growth for the plants as well as an increase in the number of leaves, suggesting an increase in the availability of nutrients. Although there was an appreciable increase in the number of larger-sized roots, the interventions did not cause appreciable changes in the weight of the roots as seen by the stakeholders.

The highest yield for beetroot was recorded when medium rates for NPK applied, achieving equilibrium between the enhancement for yield increase as well as for economic payback. This suggests that the optimal management for fertilization is very crucial for the successful beetroot cultivation in the area..

5.3 Recommendations

Farmers in the Kabale Municipality should apply moderate levels of NPK fertilizer at around 100-150 kg/ha to promote beetroot growth and yield well.

Extension services should promote harmonious fertilization methods and education on nutrient management suitable for local soils.

Soil test is recommended before fertilization to tailor the nutrient inputs and avoid over- or under-fertilizing.

Farmers should accompany NPK fertilizer application with good agronomic management practices such as proper irrigation, weed control, and pest management to realize maximum gains in production.

5.4 Areas for Further Research

Investigate the long-term impacts of repeated NPK fertilizer use on soil health and fertility in beetroot farming systems in Kabale Municipality.

Examine nutrient interaction patterns and uptake efficiency in beetroot plants under different fertilization regimes.

Investigate the effect of NPK fertilizer application on beetroot resistance to abiotic stress, such as drought or irregular rainfall, attributed to climatic volatility.

Study the use of organic amendments in combination with NPK fertilizer to enhance soil fertility and sustainable beetroot production.

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Appendix II: Field photos

Figure 1: Watering of beet root during a dry spell



Figure 2: Weeding of beet root



Figure 3: Uprooted beet root affected by diseases



Figure 4: Chemicals used in spraying beet root

