EFFECT OF INTEGRATED CATTLE MANURE AND PHOSPHATIC FERTILIZER APPLICATION ON ORANGE FLESHED SWEET POTATO YIELD AND QUALITY

STEPHEN KAHORA MWANGI

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CHUKA UNIVERSITY

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented for an award of diploma or conferment of degree in any University.

Signature: .... Date: 29th Oct. 2025

Mwangi Stephen Kahora
NM17/29283/17

Recommendation

This thesis has been examined, passed and submitted with our approval as University supervisors.

Signature: .... Date: 29/10/2025

Prof. Moses Mahugu Muraya, Ph.D.
Chuka University

Signature: .... Date: 29/10/2025

Prof. Shelmith Wanja Munyiri, Ph.D.
Chuka University

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DEDICATION

This thesis is dedicated to my beloved grandmother, Lucy Wangu, whose unwavering love, wisdom, and prayers have been a constant source of strength throughout my journey. Her enduring faith, kindness, and resilience have inspired me to overcome every obstacle and remain focused on my goals. Her presence in my life has been a guiding light, and her belief in me has propelled me to achieve this milestone. To my father James Mwangi, whose guidance and encouragement have shaped my academic and personal growth, and to my brothers, Arnold Ruvumba and Stephen Kahora and my sisters, Diana Wangu, Faith Wangui, and Marylyne Wangeshi, I encourage you all to never give up. May you always find motivation to set ambitious goals and strive to reach even greater heights. Lastly, I dedicate this thesis to my supervisor, Prof. Shelmith Munyiri, whose mentorship, wisdom, and constant encouragement have played an integral role in my academic success and in shaping this research. Her unwavering support, combined with her ability to challenge and inspire me, has been invaluable throughout this journey. She has consistently cheered me on, pushing me to persevere and aim higher, even in the face of difficulties.

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ABSTRACT

Sweet potato (*Ipomoea batatas L.*) is a highly nutritious and a resilient crop with significant potential to enhance food security and reduce poverty in Kenya. However, its production has declined in recent years due to poor agronomic practices, particularly inadequate soil fertility management. Phosphorus deficiency remains a major constraint, as most farmers rarely apply phosphatic fertilizers, and research on optimal combinations of fertilizer and manure application to maximize yield and quality is limited. The objective of this study was to evaluate the effects of combined application of different levels of cattle manure and phosphorus (P) fertilizer on the yield and quality of orange-fleshed sweet potato, variety Vita. The study was conducted at two sites, Wambugu Agricultural Training Farm in Nyeri County and Kibirigwi Irrigation Scheme in Kirinyaga County. A 3 × 3 factorial experiment laid out in a Randomized Complete Block Design with three replications was used. The treatments were; cattle manure at 0 t/ha, 1.5 t/ha, and 2.5 t/ha, and phosphorus-based inorganic fertilizer (TSP) at 0 kg/ha, 50 kg/ha, and 75 kg/ha. Treatments were applied at planting. Data were collected on vine length, number of branches per plant, number of leaves, days to 70% maturity, tuber diameter, length, weight, and proximate analyses for quality determinants including dry matter content, vitamin A, and ash content. The results revealed significant differences ($p < 0.05$) in vine length, vine girth, number of branches, and leaf area index across treatments. Growth parameters improved progressively with increasing manure and TSP application, with the combination of 2.5 t/ha manure + 75 kg/ha TSP (T3S3) consistently producing the most vigorous plants. Vine girth under T3S3 reached 4.823 cm by 112 DAS, significantly higher than 2.507 cm under the control (T1S1). In terms of yield performance, root yields ranged from 1.07–1.09 t/ha in the control to 3.00–3.10 t/ha under T3S3, representing nearly a threefold increase. Intermediate treatments, such as 1.5 t/ha manure + 50 kg/ha TSP, also showed substantial yield improvement, underscoring the synergistic effect between organic and inorganic nutrient sources. Across sites, yields were consistently higher under integrated treatments, with greater responsiveness observed at Kibirigwi (nutrient-deficient soils) compared to Wambugu (moderately fertile soils). Nutritional analysis indicated that integrated treatments enhanced root quality, with significant increases in β-carotene, vitamin C, and crude protein compared to the control. The highest β-carotene content (10.03 mg/100 g) was recorded under T3S3, compared to 3.47 mg/100 g under the control. Similarly, T3S3 produced the highest dry matter and vitamin C concentrations, demonstrating that nutrient supplementation not only enhances yield but also improves the nutritional value of OFSP, thereby contributing to food and nutrition security. These findings confirm that integrated nutrient management enhances both agronomic and economic outcomes. Integrated application of cattle manure and TSP significantly improved sweet potato growth, yield and nutritional quality. The combination of 2.5 t/ha manure and 75 kg/ha TSP (T3S3) proved most effective across both sites, validating the superiority of integrated over sole nutrient applications. Farmers are encouraged to adopt integrated use of cattle manure and TSP for sustainable sweet potato production. Extension programs should promote awareness of the agronomic, nutritional, and economic benefits of integrated nutrient management. Future studies should assess long-term impacts on soil health, as well as adaptability of the approach across diverse agro-ecological zones to refine site-specific recommendations.

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LIST OF ABBREVIATIONS AND ACRONYMS

AOAC	Association of Official Analytical Chemists
ASL	Above Sea Level
ASTM	American Society for Testing and Materials
EDTA	Ethylenediaminetetraacetic acid
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
ICP	Integrated Crop Pollination
OFSP	Orange Fleshed Sweet Potato
PUE	Phosphorus use Efficiency
TSP	Triple Superphosphate
USADA	United States Anti – Doping Agency

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Sweet potato (*Ipomoea batatas* L.) is the seventh most important food crop globally and ranks third among root and tuber crops after cassava and Irish potato (Ray & Ravi, 2005). Among sweet potato varieties, Orange-Fleshed Sweet Potato (OFSP) is particularly notable for its high nutritional value, especially its rich beta-carotene content, which significantly contributes to addressing vitamin A deficiency (Low *et al*., 2017). Globally, sweet potato is cultivated in 111 countries, predominantly across tropical and subtropical regions, with Asia leading production at approximately 52.7 million tonnes in 2022, primarily driven by China (FAOSTAT, 2023; Science Agriculture, 2023). Meanwhile, in Africa, the cultivation of OFSP has been gaining attention in countries such as Malawi, Tanzania, Nigeria, and Uganda due to its nutritional and economic potential (Low *et al*., 2020).

In Kenya, Orange-Fleshed Sweet Potato (OFSP) has become increasingly important as a staple crop for smallholder farmers due to its resilience to drought, adaptability to marginal soils, short maturity cycle, and enhanced nutritional profile compared to traditional sweet potato varieties (SciELO, 2015). Despite its potential, OFSP production in Kenya remains significantly below optimal levels, primarily due to phosphorus-deficient soils and limited access to fertilizers (Mucheru-Muna *et al*., 2014; Kamau *et al*., 2020; Muriuki *et al*., 2021). Smallholder farmers frequently face constraints such as high fertilizer costs, limited availability, and insufficient extension services, which restrict effective nutrient management practices (Mucheru-Muna *et al*., 2014; Muriuki *et al*., 2021).

In Kenya, the average yield of sweet potatoes is approximately 8.2 tons per hectare, which is significantly below the crop's potential yield of 50 tons per hectare (KIPPRA, 2025). This disparity is attributed to factors such as phosphorus-deficient soils, limited access to fertilizers, and inadequate extension services, which hinder effective nutrient management practices (Meru University of Science and Technology, 2022). To enhance productivity, smallholder farmers can adopt improved agronomic practices, utilize disease-resistant and high-yielding varieties, and implement better soil fertility management strategies. These measures can help bridge the gap between current and optimal yields, thereby improving food security and economic stability for rural communities (KIPPRA, 2025).

Phosphorus plays a crucial role in root development, crop vigour, and productivity of OFSP. However, many regions in Kenya have soils inherently deficient in phosphorus, negatively affecting OFSP yields (Mukhongo *et al.*, 2017). Studies from neighbouring Uganda highlight that integrating phosphorus fertilizers with organic amendments such as cattle manure significantly enhances OFSP yields, increasing production from around 4.5 tonnes/ha to over 30 tonnes/ha (Mukhongo *et al.*, 2017). Despite these promising results, similar integrated approaches have not been extensively explored or optimized for local conditions in Kenya, presenting a critical knowledge gap for farmers cultivating OFSP. Current studies in Kenya predominantly addresses varietal improvements and disease resistance, often neglecting comprehensive nutrient management strategies (Mbinda *et al*., 2021). Consequently, there is limited data on optimal application rates and combinations of cattle manure and phosphatic fertilizers tailored specifically for OFSP production (Thume *et al.*, 2013). Farmers thus remain unaware of effective integrated nutrient management practices, leading to suboptimal yields and compromised nutritional outcomes.

Integrated soil fertility management (ISFM), which combines organic and inorganic nutrient sources, has been shown to enhance crop yields, improve tuber quality, and increase nutrient use efficiency (Mutisya *et al*., 2022). While several studies document these benefits, adoption rates of ISFM practices remain low in Kenya, constrained by inadequate knowledge dissemination, limited extension services, high fertilizer costs, and the widespread use of suboptimal agronomic practices, such as improper planting densities, inadequate soil nutrient management, and poor weeding regimes, which collectively limit OFSP productivity and tuber quality (Otieno, 2021; Mugai *et al*., 2022). Moreover, there is limited research on the specific effects of combined cattle manure and phosphatic fertilizer on both the yield and quality of OFSP tubers, leaving a critical knowledge gap for smallholder farmers seeking cost-effective production strategies.

The application of organic and inorganic fertilizers, particularly cattle manure and phosphatic fertilizers, plays a crucial role in improving soil fertility, enhancing nutrient availability, and boosting crop performance. Cattle manure contributes essential macro- and micronutrients, improves soil structure, and increases water-holding capacity, while phosphatic fertilizers supply readily available phosphorus, a key nutrient for root development, tuber bulking, and overall crop vigor (Munyasi *et al*., 2020; Onyango *et al*., 2021). Studies from East Africa indicate that integrating these nutrient sources can synergistically enhance sweet potato yields, improve tuber quality attributes such as dry matter content and beta-carotene concentration, and increase resilience to soil nutrient limitations (Boru *et al*., 2017; Mukhongo *et al*., 2017; Njiru *et al*., 2020). For instance, research in Kenya demonstrated that combining cattle manure with phosphatic fertilizers significantly increased yields and improved tuber quality compared to the use of either fertilizer alone (Kipkorir *et al*., 2018).

However, the specific effects of different application rates and combinations of manure and phosphatic fertilizers on sweet potato yield and quality under Kenyan smallholder conditions remain poorly documented. Understanding these interactions is therefore critical for developing practical, cost-effective recommendations that optimize sweet potato productivity, improve nutritional outcomes, and increase farmers' economic returns (Munyasi *et al*., 2020; Kamau *et al*., 2020). Further research is needed to tailor fertilizer application rates to local conditions and identify the most effective combinations for smallholder farmers (Muriuki *et al*., 2021).

The integration of cattle manure and phosphatic fertilizers in sweet potato production presents a cost-effective strategy for smallholder farmers, particularly in regions with phosphorus-deficient soils. Previous research indicates that applying 15 tonnes per hectare of farmyard manure combined with 69 kg per hectare of phosphorus fertilizer can yield up to 23.65 tonnes per hectare of marketable tubers, resulting in a net benefit of 55,000 Kenyan Shillings per hectare (Mwangi *et al*., 2019). This combination not only enhances yield but also improves tuber quality attributes such as dry matter content and beta-carotene concentration, which are crucial for nutritional outcomes.

However, despite these promising findings, the adoption of integrated nutrient management practices may be limited by the high labor and transportation costs associated with sourcing and applying manure, as well as the financial constraints of smallholder farmers (Ndeleko-Barasa, 2021). While the research has provided clear answers to the low yield problem, the underlying challenge lies in translating these benefits into practice. The existing literature predominantly addresses the effects of individual fertilizers or their basic combinations, but there is limited investigation into the specific effects of different application rates and combinations of cattle manure and phosphatic fertilizers tailored to the unique needs of Kenyan smallholder farmers.

This study aims to fill this gap by evaluating the combined impact of various rates and combinations of cattle manure and phosphatic fertilizers on the yield, tuber quality, and profitability of Orange-Fleshed Sweet Potato (OFSP) production in Kenya. Understanding these interactions will provide practical, cost-effective recommendations that optimize sweet potato productivity, improve nutritional outcomes, and increase farmers' economic returns. Therefore, while previous studies have outlined the potential of integrated nutrient management, this research offers valuable insights into how smallholder farmers in Kenya can effectively implement these practices, considering the local socio-economic and environmental conditions.

The study therefore investigates the integrated application of cattle manure and phosphorus fertilizers on OFSP, focusing on optimizing yield, tuber quality, and economic returns. By evaluating the effects of different application rates and combinations, the study aims to provide smallholder farmers with evidence-based, cost-effective recommendations that enhance production efficiency, improve the nutritional and market value of OFSP tubers, and increase profitability. Ultimately, these findings are expected to support the adoption of sustainable nutrient management practices, contributing to improved food security, better nutritional outcomes, and enhanced livelihoods for Kenyan smallholder farmers. .

1.2 Statement of the Problem

Continuous cropping without adequate soil fertility management has led to significant nutrient depletion, adversely affecting both the productivity and nutritional quality of

Orange-Fleshed Sweet Potato (OFSP) in Kenya. Although OFSP has high potential to address food insecurity, poverty, and vitamin A deficiency, yields under smallholder farming conditions rarely exceed 8.2 tonnes per hectare, compared to the 50 tonnes per hectare achievable under optimal conditions. This substantial yield gap is largely driven by insufficient adoption of integrated nutrient management practices, particularly the limited and suboptimal use of phosphorus fertilizers in combination with organic amendments such as cattle manure. Moreover, there is a critical lack of locally adapted information on optimal application rates and combinations of these nutrient sources, restricting farmers' ability to maximize both yield and tuber quality. Consequently, there is an urgent need to generate evidence-based recommendations on integrated manure and phosphatic fertilizer use that can enhance OFSP productivity, improve nutritional outcomes, and promote sustainable farming practices among Kenyan smallholder farmers.

1.3 Objectives of the Study

1.3.1 General Objective

To contribute towards improved yield and quality of orange fleshed sweet potato through application of combined cattle manure and phosphatic fertilizer.

1.3.2 Specific Objectives

The specific objectives of this study were:

i. To determine the effects of combined cattle manure and phosphatic fertilizer application rates on the growth performance of orange-fleshed sweet potato
ii. To determine the effects of combined cattle manure and phosphatic fertilizer application rates on the tuber yield of orange-fleshed sweet potato.
iii. To determine the effects of combined cattle manure and phosphatic fertilizer application rates on the quality attributes of orange-fleshed sweet potato tubers.

1.4 Hypotheses

The hypothesis of this study were:

$H0_1$: There is no significant effect of combined application of cattle manure and phosphatic fertilizer rates on the growth performance of orange-fleshed sweet potato.

$H0_2$: There is no statistically significant effect combined cattle manure and phosphatic fertilizer application rates on the tuber yield of orange fleshed sweet potatoes.

$H0_3$: There is no statistically significant effect of combined cattle manure and phosphatic fertilizer rates on the quality of orange fleshed sweet potato tubers.

1.5 Justification of the Study

This research is crucial in addressing persistent food insecurity and poor nutrition in Kenya by unlocking the potential of orange-fleshed sweet potato (OFSP) as a resilient, high yielding, nutrient-rich crop that thrives in resource-constrained farming systems. Orange-fleshed sweet potato is particularly rich in beta-carotene, a precursor of vitamin A, which is essential for reducing micronutrient deficiencies among vulnerable populations, especially children and pregnant women (Low *et al.*, 2017). By improving the adoption and yield performance of OFSP in regions like Kirinyaga and Nyeri counties, this study directly contributes to enhance household food diversity and dietary quality.

Furthermore, OFSP cultivation provides a reliable income stream for smallholder farmers due to its short growth cycle, tolerance to drought, and suitability for intercropping systems. These attributes are increasingly relevant under climate change conditions where prolonged dry periods have rendered cereal crops less dependable (Kaguongo *et al.*, 2021). Promoting OFSP is an opportunity to reduce rural poverty and improving nutritional food security. In addition to its human nutritional benefits, OFSP also offers livestock feed potential. Given the rising cost and scarcity of cereal-based feeds, sweet potato vines and tuber by-products can substitute conventional ingredients, reducing pressure on the cereal milling industry and stabilizing feed costs (Omondi *et al.*, 2022). This dual-purpose role of OFSP both as a food and feed crop positions it as a key solution to Kenya's intertwined food and livestock productivity challenges.

While the average yield of sweet potato in Kenya remains low at 8.2 tonnes/ha compared to the achievable 50 tonnes/ha under optimal management (FAOSTAT, 2023), this study aims to bridge that gap by evaluating soil fertility management and improved genotypes. In particular, nitisols prevalent in Kirinyaga and Nyeri are known for phosphorus fixation, necessitating targeted phosphate management strategies to unlock yield potential (Jaetzold *et al.*, 2009). This study results informs the actionable recommendations for phosphorus use, boosting productivity and supporting food sovereignty. The results of this research have the potential to transform livelihoods, contribute to national food and nutrition goals, and align with Kenya's Vision 2030 agricultural development agenda.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview on Sweet Potato Production, its Nutritive Value and Key Constraints in Kenya

2.1.1 Overview on Sweet Potato Production

Sweet potato (*Ipomoea batatas*) is a vital crop for food security and nutrition in Kenya and sub-Saharan Africa. Its high nutritional content including beta-carotene, vitamin C, iron, potassium, and various antioxidants makes it valuable for addressing both hunger and micronutrient deficiencies (Low *et al*., 2017). Despite its potential, sweet potato production in Kenya remains below its agronomic capacity. The national average yield was only 6.7 tonnes/ha in 2020, compared to potential yields of over 30 tonnes/ha under optimal conditions (FAOSTAT, 2023). This discrepancy is largely due to a combination of biotic and abiotic stresses, with soil fertility particularly phosphorus (P) deficiency emerging as a central abiotic constraint (Muriuki *et al*., 2020; Mutisya *et al*., 2022). Kenyan soils, especially in areas like Western Kenya and parts of the Rift Valley, are increasingly showing phosphorus limitations due to prolonged cultivation without replenishment and low organic matter (Njoroge *et al*., 2017). Recent agronomic studies show that application of P fertilizer (at rates of 30 - 60 kg P_2O_5 /ha) can significantly increase sweet potato yield and enhance storage root quality (Ndolo *et al*., 2019; Mutisya *et al*., 2022). Yet, adoption remains low due to high fertilizer costs, limited access, and low farmer awareness (Kamau *et al*., 2020).

In response to the high cost of fertilizers, the Kenyan government launched the National Fertilizer Subsidy Program (NFSP) in 2023. The program offers subsidized fertilizer at half the price of commercial fertilizer to smallholder farmers. With a subsidy outlay of 3.55 billion shillings ($23 million), the program is intended to bolster Kenya's agricultural sector and help stabilize food prices. By June 30, 2024, about 175,060 metric tonnes of subsidized fertilizer had been distributed in 41 of the country's 47 counties (Tegemeo Institute, 2024). This initiative has led to increased fertilizer adoption and improved crop yields, making fertilizers more accessible to farmers in rural regions (IFPRI, 2023).

Despite these efforts, challenges persist in ensuring equitable access to subsidized fertilizers and addressing the underlying issues of soil fertility management. The cost of fertilizers remains a significant barrier for many smallholder farmers, especially those with limited financial resources (Njagi *et al*., 2023). Further research and targeted interventions are needed to optimize fertilizer use and enhance sweet potato productivity in Kenya. Additionally, strategies such as soil testing, farmer education on efficient fertilizer use, and further refinement of the subsidy program will be essential to overcoming these challenges and closing the yield gap.

2.1.2 Nutritive Value of Orange Fleshed Sweet Potato

Orange-fleshed sweet potato (OFSP) is widely recognized as a nutritionally dense food, offering a rich supply of essential macronutrients and micronutrients that contribute significantly to human health. As a biofortified crop, OFSP plays a vital role in addressing vitamin A deficiency and enhancing dietary diversity, especially in regions affected by micronutrient malnutrition. According to the U.S. Department of Agriculture (USDA, 2023), one medium-sized baked OFSP with skin (approximately 130 grams) provides approximately 112 kilocalories, 0.1 grams of fat, 26 grams of carbohydrates (including 4 grams of dietary fiber and 5.4 grams of sugars), and 2 grams of protein. This portion exceeds 100% of the recommended daily intake (RDI) for vitamin A in the form of beta-carotene. Additionally, it supplies approximately 25% of the RDI for vitamin C, 19% for vitamin B6, 12% for potassium, as well as smaller amounts of calcium, magnesium, iron, phosphorus, zinc, thiamin, riboflavin, niacin, folate, and vitamin E (Low *et al*., 2022; USDA, 2023).

Beta-carotene, the primary pigment responsible for the bright orange color of OFSP, is a powerful antioxidant. Once consumed, it is converted into vitamin A, which is essential for eye health, immune function, and cellular development (Low *et al*., 2020). Several studies have validated the impact of OFSP consumption in improving serum retinol levels among children and women in sub-Saharan Africa, thereby reducing conditions related to vitamin A deficiency, such as night blindness and increased susceptibility to infections (Tanumihardjo *et al*., 2017).

Beyond its micronutrient profile, OFSP is also valued for its low glycemic index, high antioxidant activity, and suitability for diverse culinary applications. It serves as a valuable staple in both rural and urban households, providing energy, essential nutrients, and versatility in preparation whether boiled, baked, fried, or processed into puree and flour for complementary foods. With increasing global interest in functional foods and biofortification, promoting the consumption of OFSP can support efforts to combat hidden hunger, particularly among vulnerable populations in low- and middle-income countries (Laurie *et al*., 2022; Tumwegamire *et al*., 2022).

Recent studies indicate that integrated nutrient management, combining organic and inorganic fertilizers, can significantly improve both the yield and nutritional quality of OFSP. For example, applying cattle manure combined with phosphatic fertilizers has been shown to enhance the tuber quality, including higher beta-carotene content and improved mineral composition, making it an effective strategy for biofortification (Ukom *et al.,* 2022; Tumwegamire *et al*., 2022). Integrated nutrient management (INM) not only increases OFSP yields but also improves its resilience to nutrient deficiencies, particularly phosphorus, a critical limiting factor in many sub-Saharan African soils (Maganga *et al*., 2021; Low *et al*., 2020).

2.1.3 Sweet Potato Production Constraints in Kenya

Sweet potato (*Ipomoea batatas*) ranks as the third most important food crop in Kenya, following maize and beans, due to its adaptability and resilience in marginal agro-ecological zones (Maganga *et al*., 2021; Kamau *et al*., 2020). Its ability to provide relatively high caloric yields per unit area and serve as a safety net against food insecurity makes it particularly valuable for smallholder farmers. However, despite its potential, production remains below optimal levels due to numerous biophysical and socio-economic constraints (Muriuki *et al*., 2021; Mucheru-Muna *et al*., 2014).

Among the leading agronomic limitations is poor soil fertility, with phosphorus (P), potassium (K), and sulphur (S) deficiencies being particularly critical (Bailey *et al*., 2021; Nandwa *et al*., 2022). Phosphorus, in particular, is a primary limiting nutrient for sweet potato productivity. It plays a pivotal role in plant energy transfer via molecules such as ATP and ADP, which are essential in processes including photosynthesis, respiration, protein synthesis, and root development (Pierzynski *et al*., 2021; Mullins *et al*., 2022). Adequate phosphorus levels promote early maturity, enhanced root growth, stronger stalks, and increased tolerance to root rot and abiotic stressors such as drought and poor soils. Recent agronomic studies affirm that phosphorus fertilization significantly boosts sweet potato yields and improves storage root quality in phosphorus-deficient Kenyan soils (Ndolo *et al*., 2023; Mutisya *et al*., 2023).

In addition to inherent soil nutrient limitations, regional agro-ecological variability also affects productivity, with differences in altitude, rainfall, and temperature influencing cultivar suitability and crop performance (Okonya & Kroschel, 2014; Kamau *et al*., 2020). Socio-economic factors such as farmer age, education level, and access to agricultural extension services also significantly impact productivity, adoption of improved varieties, and fertilizer use (Kebeney *et al*., 2015; Muriuki *et al*., 2020; Maganga *et al*., 2021).

The decline in soil health in tropical regions has been partly attributed to continuous cultivation and the inappropriate use of chemical fertilizers, which may lead to nutrient imbalances and soil acidification over time. In contrast, integrated use of organic amendments such as cattle manure, together with inorganic fertilizers like diammonium phosphate (DAP), has shown promising results. For instance, Audi *et al*. (2023) demonstrated that the combined application of manure and DAP increased total and marketable sweet potato yields, tuber weight, and tuber number significantly. Similar findings by Wekesa *et al*. (2022) confirmed that integrating organic and inorganic nutrient sources enhanced soil structure, nutrient uptake efficiency, and crop resilience.

Despite these benefits, the adoption of integrated nutrient management remains low in Kenya, partly due to the limited practice of soil testing among smallholder farmers. Many rely on conventional knowledge rather than evidence-based nutrient management plans. This underscores the need for increased investment in farmer training, accessible soil diagnostic services, and promotion of sustainable fertilizer use. To improve sweet potato productivity and quality, targeted strategies should support the combined use of phosphatic fertilizers and organic inputs while addressing knowledge gaps in nutrient management at the farm level (Maganga *et al*., 2021; Kiptoo *et al*., 2023).

2.2. Impact of Organic Fertilizers on Sweet Potato Growth, Yield, and Soil Fertility

The application of organic fertilizers, particularly farmyard manure (FYM), has demonstrated significant benefits in enhancing plant growth and improving crop yields across various agricultural systems. Organic amendments play a key role in improving soil structure, increasing microbial activity, and supplying essential nutrients, which collectively enhance the nutrient-use efficiency and productivity of crops (Li *et al*., 2023). Soils amended with organic fertilizers exhibit improved aeration, water retention, and microbial diversity, creating a favorable environment for plant development. For instance, integrating organic amendments like poultry manure and biochar into degraded soils significantly boosted nutrient concentrations in sweet potato leaves and increased mineral content in storage roots, particularly at recommended rates of 10 t ha^{-1} poultry manure and 30 t ha^{-1} biochar (Agbede *et al*., 2024).

Although organic nutrients often require time to mineralize before becoming plant-available, their long-term effects on soil fertility and sustainability remain well-established. Research indicates that approximately 40% of the nitrogen in cattle manure becomes available to plants during the first year of application, supporting gradual nutrient release and sustained crop growth (Duan *et al*., 2021). Several studies have demonstrated that organic fertilizers can match or even exceed the effectiveness of mineral fertilizers under certain conditions. In a comparative study involving locally available organic amendments, including cow manure, sweet potato root yield and nutritional composition were significantly enhanced, with higher levels of vitamin C, β-carotene, soluble sugars, and total phenols compared to control treatments (Antonious, 2024).

Application rates and sources of organic manure influence the magnitude of these benefits. For example, a combination of biofertilizers and inorganic nutrients (N, P, and K) significantly increased tuber yield in sweet potato under smallholder conditions. Yield increased from approximately 4.5 t ha^{-1} to over 30 t ha^{-1} when using starter nutrient combinations of 90 kg N ha^{-1}, 100 kg K ha^{-1}, and 15–30 kg P ha^{-1} (Mukhongo *et al*., 2017). More recently, studies in Kenya assessing integrated use of organic ‘Fertiplus’ with partial synthetic fertilizer regimes in vegetables and cereals found that combining organic input with 50 - 75% of recommended inorganic fertilizer rates produced higher yields than chemical fertilizer alone (Wafula *et al*., 2023).

The presence of beneficial compounds such as growth enzymes, phytohormones, and organic acids in manures further stimulates cell division, root proliferation, and chlorophyll synthesis, all of which contribute to improved vegetative and reproductive performance (Sanwal *et al*., 2007; Singh *et al*., 2008). The use of integrated nutrient management combining organic and inorganic inputs has also shown promising results in optimizing yields. Studies illustrate that incorporating FYM can enhance nutrient uptake efficiency, reduce dependency on chemical fertilizers, and maintain high yields. For instance, the application of 5 - 15 t/ha of FYM in sorghum cultivation enabled a 50% reduction in recommended phosphorus fertilizer rates without compromising yield (Bayu *et al*., 2006).

In root and tuber crops, such as sweet potato and potato, cattle manure has consistently enhanced vine development and tuber yield. Significant increases in potato vine growth due to cattle manure application were attributed to improved nutrient availability, which stimulates physiological processes such as photosynthesis and nutrient assimilation (Halvin *et al*., 2003). Organic fertilizers such as compost and farmyard manure play a key role in improving soil fertility, microbial activity, and crop productivity. They also enhance long-term soil health by increasing organic matter content and nutrient cycling (Agegnehu *et al*., 2016; Adekiya *et al*., 2020). Organic inputs are particularly important for resource-poor farmers and for maintaining sustainable farming systems.

However, while organic inputs provide sustainability advantages, inorganic fertilizers remain essential for achieving immediate and higher crop yields and improving crop quality (Nyakatawa *et al*., 2021). Overall, organic fertilizers provide a multifaceted advantage in crop production. They contribute to soil fertility restoration, promote sustainable nutrient cycling, and improve both yield quantity and quality. As sustainable agriculture continues to be a global priority, the role of organic amendments in complementing inorganic fertilizers offers a pathway toward more resilient and productive farming systems

2.2.1 Impact of Organic and Inorganic Fertilizers on Sweet Potato Growth Performance

The application of organic fertilizers significantly enhances the growth performance of sweet potato (*Ipomoea batatas*), influencing various vegetative parameters such as vine girth, vine length, and leaf number. Studies have shown that organic amendments like poultry manure, compost, and biochar improve soil structure and nutrient availability, leading to increased plant vigor. For instance, a study by Oycha *et al*. (2023) found that the application of organic fertilizers resulted in improved vine length and girth, as well as a higher number of leaves per plant, compared to control treatments.

Similarly, Dumbuya *et al*. (2017) reported that organic fertilizers enhanced vine length and girth, contributing to better overall plant growth. Moreover, the combination of organic fertilizers with biofertilizers has been observed to further boost growth parameters. A study by Sharma *et al*. (2016) demonstrated that the integration of farmyard manure with biofertilizers like Azospirillum and Phosphate Solubilizing Bacteria (PSB) led to significant increases in vine length, girth, and leaf area. Furthermore, the application of biochar has been shown to improve vine length and the number of leaves. Research by Zhang *et al*. (2021) indicated that biochar application increased the number of leaves and vine length in sweet potato plants. These findings underscore the synergistic effects of organic and bio-based inputs in enhancing sweet potato growth.

Inorganic fertilizers significantly influence the growth performance of sweet potato (*Ipomoea batatas*), affecting parameters such as vine girth, vine length, and leaf number. The application of nitrogen (N), phosphorus (P), and potassium (K) fertilizers has been shown to enhance vegetative growth by improving nutrient availability and uptake. For instance, a study by Oycha *et al*. (2023) demonstrated that the application of NPS (N, P, S) fertilizers at 225 kg ha^{-1} resulted in increased vine length and girth, as well as a higher number of leaves per plant, compared to control treatments. Similarly, Dumbuya *et al*. (2017) reported that potassium fertilization at 60 kg K_2O ha^{-1} significantly increased vine length, number of branches, and leaf area, contributing to better overall plant growth. These findings underscore the importance of balanced inorganic fertilization in promoting sweet potato vegetative development.

The integration of organic and inorganic fertilizers has been shown to significantly enhance the growth performance of sweet potato (*Ipomoea batatas*), influencing various vegetative parameters such as vine girth, vine length, and leaf number. Studies indicate that the combination of organic amendments like poultry manure or compost with inorganic fertilizers such as NPK promotes synergistic effects, leading to improved plant vigor. For instance, research by Oycha *et al*. (2023) demonstrated that combining 10 t ha^{-1} farmyard manure with 100 kg ha^{-1} nitrogen fertilizer resulted in increased vine length, girth, and leaf number compared to control treatments. Similarly, Dumbuya *et al*. (2017) reported that the application of potassium fertilizers in combination with organic manures enhanced vine length and the number of leaves per plant, contributing to better overall plant growth. These findings underscore the importance of balanced fertilization in promoting sweet potato vegetative development.

Moreover, the synergistic effect of combined fertilizers has been observed to improve other growth parameters. A study by Zhang *et al*. (2021) found that the integration of biochar with inorganic fertilizers improved vine length and the number of leaves in sweet potato plants. This enhancement is attributed to the improved soil structure and nutrient availability resulting from the combined fertilizer application. These results highlight the potential benefits of integrated fertilization strategies in enhancing sweet potato growth.

2.2.2 Impact of Organic and Inorganic Fertilizers on Sweet Potato Yield and Yield Components

Organic fertilizers not only improve vegetative growth but also positively affect sweet potato yield and its components, including days to maturity, tuber diameter, tuber weight, and dry matter content. Studies have shown that organic amendments contribute to higher tuber yields by enhancing soil fertility and structure. For example, research by Oycha *et al*. (2023) indicated that the application of organic fertilizers led to earlier maturity and increased tuber size and weight. Dumbuya *et al*. (2017) reported that organic fertilizers improved tuber diameter and weight, resulting in higher overall yield. The impact of organic fertilizers on tuber quality has also been noted. A study by Zhang *et al*. (2021) found that organic fertilizer application increased the dry matter content and starch accumulation in sweet potato tubers, enhancing their nutritional value. These findings suggest that organic fertilization practices can lead to improved yield and quality of sweet potato tubers.

Inorganic fertilizers play a crucial role in enhancing sweet potato yield and its components, including days to maturity, tuber diameter, tuber weight, and dry matter content. The application of balanced NPK fertilizers has been associated with increased tuber size and weight, leading to higher overall yield. For example, a study by Oycha *et al*. (2023) found that the application of 225 kg ha^{-1} NPS fertilizer resulted in the highest total root yield (56.73 t ha^{-1}) and marketable yield (54.89 t ha^{-1}). Similarly, Dumbuya *et al*. (2017) observed that potassium fertilization at 60 kg K_2O ha^{-1} improved tuber diameter and weight, contributing to higher yield. These results highlight the effectiveness of inorganic fertilizers in improving sweet potato yield and its components.

The application of combined organic and inorganic fertilizers has a profound impact on sweet potato yield and its components, including days to maturity, tuber diameter, tuber weight, and dry matter content. Studies have shown that integrated fertilization strategies contribute to higher tuber yields by enhancing soil fertility and nutrient availability. For example, Oycha *et al*. (2023) reported that the combination of 10 t ha^{-1} farmyard manure with 100 kg ha^{-1} nitrogen fertilizer resulted in increased tuber size and weight, leading to higher overall yield. Similarly, Dumbuya *et al*. (2017) observed that the application of potassium fertilizers in combination with organic manures improved tuber diameter and weight, contributing to higher yield. These findings suggest that integrated fertilization practices can lead to improved yield and quality of sweet potato tubers.

The synergistic effect of combined fertilizers has been noted to influence tuber quality. A study by Zhang *et al*. (2021) found that the integration of biochar with inorganic fertilizers increased the dry matter content and starch accumulation in sweet potato tubers, enhancing their nutritional value. This enhancement in tuber quality is attributed to the improved soil conditions and nutrient availability resulting from the combined fertilizer application. These results underscore the importance of integrated fertilization strategies in improving both the yield and quality of sweet potato.

2.2.3 Impact of Organic and Inorganic Fertilizers on Sweet Potato Quality Attributes

The quality attributes of sweet potato, including ash content, vitamin A, calcium, magnesium, and moisture content, are significantly influenced by the application of organic fertilizers. Organic amendments have been shown to enhance the nutritional profile of sweet potatoes by improving soil health and nutrient availability. For instance, a study by Oycha *et al*. (2023) found that organic fertilizer application increased the ash content and mineral composition, including calcium and magnesium, in sweet potato tubers. The impact of organic fertilizers on vitamin A content has been observed. A study by Zhang *et al*. (2021) reported that organic fertilizer application led to higher carotenoid levels, which are precursors of vitamin A, in sweet potato tubers. This enhancement in vitamin A content is particularly beneficial, as sweet potatoes are a significant source of this essential nutrient. Furthermore, organic fertilizers have been found to affect moisture content in sweet potato tubers. Research by Oycha *et al*. (2023) indicated that organic amendments contributed to optimal moisture retention in tubers, which is crucial for storage and shelf life.

The application of inorganic fertilizers also affects the quality attributes of sweet potato, including ash content, vitamin A, calcium, magnesium, and moisture content. Inorganic fertilizers, particularly those containing phosphorus and potassium, have been shown to influence the nutritional composition of sweet potato tubers. For instance, a study by Zhang *et al*. (2021) reported that the application of phosphorus fertilizer increased the carotenoid content, a precursor of vitamin A, in sweet potato tubers. Similarly, potassium fertilization has been associated with increased calcium and magnesium content in sweet potato tubers, enhancing their nutritional value. These findings suggest that inorganic fertilization can improve the nutritional quality of sweet potato, making it a more valuable food source.

The quality attributes of sweet potato, including ash content, vitamin A, calcium, magnesium, and moisture content, are significantly influenced by the application of combined organic and inorganic fertilizers. Integrated fertilization strategies have been shown to enhance the nutritional profile of sweet potatoes by improving soil health and nutrient availability. For instance, Oycha *et al*. (2023) found that the combination of 10 t ha^{-1} farmyard manure with 100 kg ha^{-1} nitrogen fertilizer increased the ash content and mineral composition, including calcium and magnesium, in sweet potato tubers. Similarly, Zhang *et al*. (2021) reported that the integration of biochar with inorganic fertilizers led to higher carotenoid levels, which are precursors of vitamin A, in sweet potato tubers. This enhancement in vitamin A content is particularly beneficial, as sweet potatoes are a significant source of this essential nutrient. Additionally, the application of combined fertilizers has been found to affect moisture content in sweet potato tubers. Research by Oycha *et al*. (2023) indicated that integrated fertilization contributed to optimal moisture retention in tubers, which is crucial for storage and shelf life. These findings suggest that integrated fertilization practices can lead to improved quality attributes of sweet potato tubers.

2.2.4 Synergistic Effects of Combined Organic and Inorganic Fertilizer Application on Sweet Potato Growth, Yield, and Soil Fertility

The integration of organic and inorganic fertilizers has been extensively studied for its synergistic effects on crop growth, yield, and soil fertility. Recent research has highlighted the numerous benefits of combining these fertilizers to optimize sweet potato production. This approach not only enhances nutrient availability but also contributes to improved soil health and more sustainable farming practices. The combined application of organic fertilizers, such as compost or farmyard manure, with inorganic fertilizers has been shown to improve soil structure, microbial activity, and nutrient cycling, leading to enhanced plant growth and higher yields.

Recent studies indicate that the co-application of organic and inorganic fertilizers significantly improves the growth parameters of sweet potato. Nunes *et al*. (2020) found that the application of poultry and bovine manure, alongside conventional chemical fertilizers, led to better soil attributes and increased sweet potato yield and quality. This study suggested that organic fertilizers play a pivotal role in enhancing soil quality by improving its structure and water retention, which, when complemented by inorganic fertilizers, results in better overall plant growth. Similarly, Wu *et al*. (2024) reported that the combined application of straw or organic manure with inorganic fertilizers enhanced the soil quality index and increased soybean yield, highlighting the potential benefits of this practice for other crops like sweet potato. This evidence suggests that organic fertilizers, when integrated with chemical inputs, can lead to more robust plant growth by supplying essential nutrients more efficiently.

The synergistic effects of combined fertilizers are also evident in their impact on yield and yield components. Zhang *et al*. (2021) found that the integration of organic and inorganic fertilizers significantly improved the nutrient content of the soil and microbial community structure, which directly contributed to higher crop yields. This study demonstrated that integrating organic fertilizers, which provide a steady release of nutrients, with inorganic fertilizers, which offer immediate nutrient availability, results in more balanced plant nutrition and enhanced growth, thereby leading to higher and more consistent yields. Such integrated nutrient management strategies have also been shown to reduce nutrient loss and improve the efficiency of fertilizer use, which is essential for sustainable agriculture.

Integrating organic and inorganic fertilizers is not only beneficial for crop yield but also for soil fertility. A study by Wu *et al*. (2024) emphasized that the combined use of organic amendments and chemical fertilizers improved soil microbial limitations, soil quality, and crop yield. This approach helps mitigate the negative effects often associated with the continuous use of chemical fertilizers, such as soil degradation and nutrient imbalances. The integration of organic inputs contributes to soil structure, enhancing water retention and nutrient availability, while inorganic fertilizers ensure the quick release of essential nutrients. Together, these fertilizers create a balanced and sustainable soil environment that supports long-term crop productivity.

In conclusion, the synergistic application of organic and inorganic fertilizers offers a promising strategy for enhancing sweet potato growth, yield, and soil fertility. Recent studies underscore the importance of this integrated approach in sustainable agriculture, as it provides balanced nutrition for crops while improving soil health. This integrated nutrient management approach can help ensure food security and sustainable farming practices, particularly in regions where soils are rapidly degrading. By combining the benefits of both organic and inorganic fertilizers, farmers can optimize yields, reduce dependency on chemical inputs, and promote environmental sustainability in agricultural systems.

2.2.5 Phosphorus Use Efficiency in Sweet Potato Production

Phosphorus (P) plays a vital role in enhancing the growth, development, and final yield of crops, particularly root and tuber crops such as sweet potato (*Ipomoea batatas*). However, phosphorus use efficiency (PUE) remains a major agronomic challenge due to the nutrient's strong fixation in soils, which reduces its availability to plants. Studies have shown that PUE in agricultural systems is typically low, ranging from 10% to 30% in the year of application (Shen *et al.*, 2011). This inefficiency arises from chemical reactions that immobilize applied phosphorus, particularly in acidic or iron- and aluminum-rich tropical soils (Hassan *et al.*, 2005; Muriuki *et al.*, 2020).

Orange-fleshed sweet potato (OFSP), known for its high beta-carotene content, responds positively to phosphorus fertilization due to its symbiotic relationship with vesicular-arbuscular mycorrhizal (VAM) fungi. These fungi enhance P uptake by extending the effective root system and mobilizing phosphorus from otherwise inaccessible soil pools (Mutisya *et al.*, 2022). Given the increasing demand for biofortified crops like OFSP in combating micronutrient deficiencies, particularly vitamin A deficiency in sub-Saharan Africa, improving phosphorus management is a key agronomic priority (Low *et al.*, 2020).

In Kenya and across other tropical regions, OFSP is primarily cultivated by smallholder and subsistence farmers as a food security crop. Although often rainfed, its productivity and economic returns can be significantly enhanced through modest investments in soil fertility and good agronomic practices. Economic analyses indicate that phosphorus fertilization, when applied at appropriate rates, not only improves yield but also contributes to a positive net economic return by reducing the nutrient limitation barrier (Ndolo *et al.*, 2019; Wekesa *et al.*, 2020). Profitability in OFSP production is influenced by multiple factors, including yield levels, cost of inputs, market access, and labor efficiency. Kassali (2011) noted that labor constitutes approximately 68% of total production costs in sweet potato farming, yet the crop remains profitable under smallholder systems. High yields are the most significant driver of profitability, whereas capital-intensive inputs have a relatively smaller impact on net returns. Furthermore, factors such as access to quality planting materials, efficient transport to markets, fertilizer use, and full-time engagement in farming significantly enhance output and resource-use efficiency.

To evaluate the economic efficiency of OFSP production, comprehensive cost-return analyses are essential. These analyses typically consider input categories such as fertilizers, planting materials, land rent, transport, chemicals, and labour. Output value is calculated from yield per plot, extrapolated to per-acre or per-hectare returns. Studies have shown that scaling up production, using integrated nutrient management (INM), and adopting improved agronomic practices can enhance profitability and sustainability in sweet potato systems (Chagwiza *et al.*, 2021; Kaur *et al.*, 2022).

In conclusion, the integration of phosphorus management and economic planning is central to the sustainability and profitability of OFSP farming in Kenya and similar agro-ecological zones. Increasing PUE through strategic fertilizer application and leveraging biological processes such as mycorrhizal symbiosis will be critical to unlocking both nutritional and economic gains for smallholder farmers. Phosphorus is one of the most limiting nutrients in sweet potato cultivation, and improving its use efficiency enhances both agronomic performance and economic returns. Economic analyses show that optimized phosphorus management increases profitability while reducing unnecessary fertilizer costs (FAO, 2019; Khan *et al.*, 2018). Enhanced phosphorus use efficiency is therefore central to sustainable orange-fleshed sweet potato production, contributing not only to higher yields but also to improved food security and farmer livelihoods.

2.2.6 Cattle Manure Use Efficiency in Sweet Potato Production

Cattle manure is a widely recognized organic fertilizer that plays a significant role in enhancing soil fertility and promoting sustainable agricultural practices. The use of cattle manure in sweet potato production has gained attention due to its positive effects on soil health, plant growth, and crop yield. Recent studies have shown that when applied appropriately, cattle manure can improve soil structure, increase nutrient availability, and stimulate microbial activity, all of which contribute to better crop performance.

The application of cattle manure is particularly effective in improving the nutrient content of soils. Organic manure enhances soil's nutrient-holding capacity, increases microbial diversity, and promotes better soil aeration, which improves the root environment for plants. For instance, a study by Mao *et al*. (2023) demonstrated that long-term cattle manure addition significantly increased soil-available phosphorus fractions in subtropical open-field systems. The study emphasized that the gradual release of nutrients from organic sources like manure contributes to improved soil fertility over time. This has important implications for crops like sweet potato, as phosphorus is crucial for tuber development and overall plant health.

When combined with mineral fertilizers, cattle manure has been shown to significantly improve both the growth and yield of sweet potato. Wakgari *et al*. (2023) found that integrating cattle manure with NPSB (nitrogen, phosphorus, sulfur, and boron) fertilizers resulted in notable improvements in vine length and tuber yield. The study showed that a combination of 10 t ha^{-1} cattle manure with 150 kg ha^{-1} of NPSB fertilizer produced the highest vine growth (149.6 cm) and a substantial increase in tuber yield. This synergistic effect illustrates that organic and inorganic fertilizers complement each other, leading to more efficient nutrient use and better crop performance.

Cattle manure usage in sweet potato production has proven to be a cost-effective and sustainable practice from an economic perspective. A study by Abukari *et al*. (2024) in Ghana highlighted the financial advantages of applying cow dung at 10 t ha^{-1}. The study found that this application rate resulted in significant increases in tuber yield, yielding a net return of GHC 18.00 for every GHC 1.00 invested. This demonstrates not only the agronomic benefits of cattle manure but also its economic value, especially in low-resource farming systems where input costs need to be minimized.

Furthermore, cattle manure plays a critical role in enhancing environmental sustainability in agriculture. Its use reduces the reliance on synthetic fertilizers, thereby minimizing the environmental risks associated with chemical fertilizer runoff and soil acidification. By recycling organic matter back into the soil, cattle manure helps in building soil organic carbon, improving nutrient cycling, and enhancing soil structure.

This practice is particularly important in regions facing soil degradation, as it contributes to soil health and promotes long-term agricultural sustainability.

In conclusion, cattle manure is an effective organic fertilizer that enhances nutrient availability, improves soil health, and contributes to higher yields in sweet potato production. Recent studies emphasize the synergistic benefits of combining cattle manure with inorganic fertilizers, leading to more efficient nutrient use and better overall crop performance. Additionally, the economic advantages of using cattle manure, coupled with its positive environmental impact, make it a valuable input in sustainable sweet potato cultivation. As farmers continue to seek environmentally friendly and economically viable solutions, cattle manure stands out as an essential component in integrated nutrient management systems for sweet potato production.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site of the Study

The experiment was conducted at the Agricultural Training Centre (ATC) Wambugu Farm in Nyeri County and the Kibirigwi Irrigation Scheme in Kirinyaga County, with the two trials running concurrently. The Wambugu ATC Farm is located along the Nyeri/Nairobi highway, at latitude 0°26'38"N and longitude 36°58'53"E. The farm is situated at an altitude of 1549 metres asl. The average temperature is 19.13°C. The area experiences a bi-modal pattern of rainfall, with long rains occurring from March to May and short rains from October to December. The average annual rainfall is 1,502 mm. The soils are red, well-developed volcanic nitisols (Gachene and Kimaru, RELMA, 2003). Nitisols require the application of manure and inorganic fertilizers for optimal crop production (Gachene and Kimaru, RELMA, 2003). The Kibirigwi Irrigation Scheme is located along the Nyeri/Nairobi highway, at latitude 0°34'0"S and longitude 37°10'60"E. The scheme is situated at an altitude of 1384 metres above sea level, with average temperatures of 20.96°C. The average annual precipitation is around 1,724 mm. Similar to the ATC Farm in Nyeri County, the Kibirigwi area receives two rainy seasons; the long rains (March to May) and the short rains (October to December). The soils in this area are also red well-developed volcanic nitisols (Jaetzold *et al.*, 2009).

3.2 Experimental Design

The study used a 3×3 factorial experiment laid out in a randomized complete block design (RCBD) and replicated three times. There were two factors; cattle manure at three levels (0, 1.5, 2.5 tonnes per hectare) and inorganic P fertilizer (TSP) at three levels (0, 50, 75 kg per hectare). The treatments were randomly applied to the experimental units. Each plot size was 2 m by 2 m, with 12 sweet potato vines planted at a spacing of 90 cm x 30 cm. In each experimental plot, three central vines were randomly selected for data collection

Table 1: A 3x3 factorial randomized block design

REP 1 (2 METERS)	1 METRE	REP 1 (2 METERS)	1 METRE	REP 1 (2 METERS)
T1S3		T2S1		T3S3
T2S1		T3S3		T2S3
T3S2		T1S1		T3S3

T3S1	T1S3	T1S1
T1S1	T3S3	T2S1
T2S3	T3S2	T1S2
T3S3	T2S2	T2S3
T2S2	T1S2	T2S2
T1S2	T2S3	T3S1

Key

T – Cattle Manure

S – Tripple Superphosphae

T1S1- 0 CM & 0 TSP;

T1S2- 0 CM & 50kg/acre TSP;

T1S3- 0 CM & 75kg/acre TSP;

T2S1- 1.5 ton/acre CM & 0 TSP;

T2S2- 1.5 ton/acre CM & 50kg/acre TSP;

T2S3- 1.5 ton/acre CM & 75kg/acre TSP;

T3S1- 2.5 ton/acre CM & 0 TSP;

T3S2- 2.5 ton/acre CM & 50kg/acre TSP;

T3S3- 2.5 ton/acre CM & 75kg/acre TSP

3.3 Land Preparation, Crop Establishment and Management

The field was cleared using a panga, and crop residues were removed. The field was then ploughed and harrowed using animal driven plough. The cultivation aimed to turn over the topsoil and loosen the compacted soil below to achieve a good tilth for forming the ridges and provide a soft, uniform medium where storage root growth was not impeded.

Certified Orange Fleshed Sweet Potato vines were sourced from Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Juja Town, while cattle manure was obtained in Karatina Town at Barichu Coffee Factory and TSP fertilizer were obtained from agro-vets within Nyeri and Kibirigwi Town. The crop was planted in two rows, with sweet potato plants positioned in the middle of the ridge at 30 cm between plants and 90 cm within the rows. The distance between the centres of the ridges was 90 cm. The crop was planted in February 2020, during which it received rainfall for three weeks, supplemented with irrigation. There were 12 vines planted per plot.

All treatments were applied at planting. Weeding was done when weeds emerged, and earthing up was carried out after three weeks after planting. Pests and diseases such as wireworms were controlled through pre-plant treatment of vines with chlorpyrifos being the active ingredient at rate of 4 litres per hectare, combined with foliar applications of chlorpyrifos at five and ten weeks after planting to control sweet potato weevils. All these management practices were applied uniformly to minimize possible experimental errors. Three plants out of the twelve in each experimental plot were randomly selected and tagged for data collection.

3.4 Soil Testing and Analysis

In order to determine the physical and chemical properties of the soil, twelve representative soil samples were taken using the zig zag method by an auger from a depth of 0 to 30 cm for each experimental unit at the site before planting and before the application of any type of fertilizer. The samples were mixed thoroughly, after which quartering was done, and about 500 g or less of a single composite soil sample was prepared. The composite sample was taken to the Kenya Agricultural and Livestock Research Organization – National Agricultural Research Laboratories (KALRO – NARL) Kabete soil laboratory in Nairobi for soil property analyses testing.

The sample was tested for total nitrogen according to Bremner (1996) using the combustion procedure. Soil pH was measured using the water method (Eckert *et al*., 2011), organic matter was determined using the loss-on-ignition procedure (Schulte *et al*., 2011), and available phosphorus and potassium were tested using the Mehlich 3 (ICP) method (Wolf and Beegle, 2011). The cation exchange capacity (CEC) was measured using the summation method as described by Ross and Ketterings (2011) (Appendix 1).

3.5 Data Collection

3.5.1 Evaluation of Growth Performance of Orange-Fleshed Sweet Potato

Data were collected on agronomic characteristics, including vine length, number of leaves, days to maturity, tuber diameter or marketable tuber size, tuber weight, and dry matter production of the tubers.

3.5.1.1 Vine Girth

This was determined by measuring 10 cm above the soil surface (just above where the vine emerges from the ground). A tailor's measuring tape (in mm) was used as a measuring tool. The tailor's measuring tape was gently wrapped around the selected section of the vine without compressing it. The tape was snug but not tight, and lied flat against the vine. The girth (circumference) was recorded in millimetres (mm). Diameter was calculated according to Avery *et al*., (2015) formula:

$$Diameter = \frac{Girth}{\pi} \approx \frac{Girth}{3.14}$$

3.5.1.2 Vine Length

This was measured by identifying the main vine and selecting the longest primary vine of the sweet potato plant (not a secondary shoot or branch). If the plant was trained or crawling, the main vine was gently traced from the base to the tip and if the vine was tangled with others or had grown along the ground, it was carefully untangled and followed to its full path. A tailor's measuring tape (graduated in centimeters) was used. It was placed at one end of the vine's base (point of emergence from the soil or cutting). The tape was stretched along the length of the vine to its terminal bud or tip. The measurements were recorded in centimeters (cm) at intervals of seven days.

3.5.1.3 Number of Leaves

This was determined by **s**electing three representative plants, that is a fixed number of randomly select sweet potato plants from each plot or treatment group. The main vine was identified, that is focus was done on the main vine (the longest or dominant vine growing from the base of the plant). Counting was done of all fully developed leaves at the base of the vine where it emerged from the soil. Counting was done for every fully expanded leaf along the vine up to the terminal bud (apex). Tiny developing leaf buds and any damaged or senescent leaves that had detached or are non-functional were excluded. Leaves on lateral or secondary vines were also counted. The number of leaves per plant was recorded and written down and the process repeated. The process was repeated for all selected plants and calculated the average number of leaves per plant for statistical analysis. The counting the number of leaves was done after one month of planting at intervals of seven days.

3.5.2 Evaluation for Yield and Yield Components of Orange-Fleshed Sweet Potato

3.5.2.1 Days to Maturity

The days to maturity were determined by first recording the planting date (when vines or cuttings were transplanted into the field), which marked day 0 for maturity tracking. Field observations were made weekly to assess growth stages such as vine elongation, canopy coverage, and tuber bulking. Key physiological indicators of maturity were monitored. Maturity was reached when tuber bulking had stabilized, and the following indicators appeared: yellowing or senescence of older leaves; tuber skin set (skin does not peel off easily when rubbed); maximum root size and weight plateau; and dry matter content reached optimal levels. Sample plants at specific intervals (e.g., 90, 105, 120 days after planting) were harvested to check root development.

The final harvest was conducted when at least 80-90% of plants had matured tubers at 120 days after planting, this was done by regularly checking the border plant tubers if the skin peeled off easily and also by counting the number of yellow leaves and dividing by the total and multiplying it by a hundred to get the percentage. The date on which the crop was officially harvested was recorded. Despite slight variations in the growth rates of individual plants, the harvest was intended to be a full crop harvest, rather than piecemeal harvesting. This approach ensured uniformity in maturity assessment across all plots. Calculation of Days to Maturity was done by subtracting the planting date from the harvest date, ensuring consistency across all experimental units.

3.5.2.2 Tuber Diameter or Marketable Tuber Size

After harvesting, the tubers' circumference at the centre was taken using a string on the harvested tagged plants, and the string was transferred to the meter rule for diameter measurements. Medium to large-sized tubers were considered to be of favourable marketable size (diameter was 10-15 cm), and those ranging from small to very small or below 10 cm in diameter were considered to be non-marketable.

3.5.2.3 Tuber Weight per Plot

This was done when all tagged plants within the boundaries of the plot were harvested. The sweet potato plants were carefully dug up all within the plot to avoid damaging the tubers and all underground storage roots (tubers) associated with each vine was included. The tubers were gently cleaned of soil using hand manual without use of water to maintain consistent moisture content and weight. The weight of the tubers was weighed using a calibrated scale using a digital balance scale with a suitable range and accuracy (usually in kilograms). All selected tubers from the plot were placed on the scale and the total fresh weight recorded and entered the measured weight in a data sheet in kilograms per plot (kg/plot).

For yield per hectare, it was converted using FAO (2010) :

$$Yield\left(\frac{t}{ha}\right) = \frac{Tuber\ weight(kg)}{Plant\ area(m^2)}x10$$

3.5.2.4 Tuber Dry Matter Content

The dry matter content was determined within 24 hours after harvesting as the tubers were transported to JKUAT Laboratory for the analysis. The procedure followed is an established method recommended by the International Potato Center (CIP, 2010), and validated in research by Woolfe (1992) and Tumwegamire *et al*. (2014). Three to five marketable tubers per plant after harvest was selected. From each tuber, slices (2 cm thick) from the midsection were cut. The slices were mixed and a composite sample weighing approximately 100 g was taken. The fresh sample was immediately weighed using a digital balance and recorded the fresh weight (FW) in grams. The sample was placed in a clean, labelled porcelain dish. It was dried in a hot air oven at 65–70°C for 72 hours until constant weight was achieved (i.e., when weight change was <0.1 g across two measurements). The sample was removed from the oven and cooled in a desiccator for 30 minutes to avoid moisture absorption (Appendix 2). The dried sample was weighed to get the dry weight (DW) recorded in grams. Dry matter content calculation was done using Uguru *et al*., (2011) formula :

$$Dry\ matter\ conten(\%) = \frac{Dry\ weight\ (g)}{Fresh\ weight\ (g)}x100$$

3.5.3 Evaluation of Quality Variable of Orange-Fleshed Sweet Potato

All quality parameters were measured at JKUAT laboratories. These parameters included:

3.5.3.1 Percentage Ash Content

The ash content in the crop was measured gravimetrically by burning the samples in a muffle furnace at a high temperature of 500ºC for a specified duration. The process was known as dry oxidation or dry ashing, using method 923.03 described in AOAC (1990). Six grams of sample were used, which represented three crucibles each containing two grams of sample. The sample was placed into a dried/pre-weighed porcelain crucible. The sample was burned away in an air atmosphere at temperatures above 500°C. The crucible was weighed after it had been cooled to room temperature in a desiccator. Ash residue remaining in the crucible was considered filler unless the residue was less than 1%. Residues of less than 1% were typically the result of additives that did not burn off. The ash test result was expressed as % ash. A magnified optical examination of the ash residue was performed to determine if the ash was mineral. The total ash content equaled the weight of the ash divided by the weight of the original sample multiplied by 100% (Appendix 3) (AOAC 923.03 (1990).

3.5.3.2 Vitamin A Content

Beta content/Vitamin A was determined using the protocol outlined in the AOAC (1989) method. The tubers were mashed to prepare approximately 2.00 g sample extracts. The extracts were purified and diluted to a standard volume of 25 ml in the mobile phase, which was constituted as methanol; dichloromethane; water (79:18:3). The extracts were filtered using a 0.45-micron Millipore filter before 30 µl were injected into an HPLC (Hitachi, model L4000H), with a pump (L6000), RP C18 column (25 cm x 4.5 mm), flow rate set at 1 ml/min, and a UV/Visible detector at 450 nm for β-carotene (Appendix 4) (Echessa *et al*., 2013).

3.5.3.3 Calcium Content

The sample tuber was first processed to obtain a homogenous mixture. Approximately 2.00 g of the sample was weighed and subjected to digestion. The digestion was carried out using a strong acid mixture, such as nitric acid (HNO_3), in a microwave digestion system to break down the sample matrix and release calcium ions into solution. This method allows for efficient sample digestion, ensuring that all calcium is extracted from the matrix into the solution (Cameron & Lichtenstein, 2017). After digestion, the sample was filtered through a 0.45-micron Millipore filter to remove any undissolved particles. The filtrate was collected in a clean container, and its volume was adjusted by adding deionized water, ensuring that the total volume was standardized to 100 ml. This step ensures that the sample is prepared for precise analysis by Atomic Absorption Spectroscopy (AAS) (Singh *et al*., 2015).

A series of calcium standards with known concentrations (e.g., 0.1, 0.5, 1.0, 2.0 mg/L) was prepared using a calcium standard solution. These standards were used to create a calibration curve, which helped in quantifying calcium levels in the sample. The standards are crucial for establishing a relationship between absorbance and concentration, ensuring the accuracy of the analysis (Meena & Rani, 2018). The prepared sample extract was introduced into the Atomic Absorption Spectrometer (AAS) (e.g., Hitachi L4000H model), where it was aspirated into a flame or graphite furnace (depending on the detection mode: flame or furnace AAS). The AAS instrument uses a specific wavelength of light (e.g., 422.7 nm for calcium) to measure the amount of light absorbed by calcium atoms in the flame, which is directly related to their concentration in the sample (Patel *et al*., 2019). The flow rate of the flame was adjusted (typically around 1.0-2.0 L/min) to ensure optimal atomization of the sample. The calcium hollow cathode lamp was used as the light source, and the detector recorded the absorption, which was then correlated to the concentration of calcium in the sample.

The AAS system was calibrated using the prepared standards to obtain a calibration curve. The calcium concentration in the sample was then determined by comparing the absorbance readings to the calibration curve. This calibration curve ensures that the relationship between absorbance and concentration is accurate, allowing for reliable determination of calcium content in the sample. The AAS system automatically calculated the calcium concentration in the sample based on the calibration curve. The final calcium content was expressed in mg/kg (Appendix 5). This final result is useful in determining calcium concentration in various types of biological and environmental samples (Ramakrishna *et al*., 2020).

3.5.3.4 Magnesium Content

The sample tuber was first processed to obtain a homogeneous mixture. Approximately 2.00 g of the sample was weighed and subjected to digestion. The digestion was carried out using a strong acid mixture, such as nitric acid (HNO_3), in a microwave digestion system to break down the sample matrix and release magnesium ions into solution. This digestion method ensures that magnesium is fully extracted from the sample matrix into the solution (Zhang *et al*., 2018). After digestion, the sample was filtered through a 0.45-micron Millipore filter to remove any undissolved particles. The filtrate was collected in a clean container, and its volume was adjusted by adding deionized water, ensuring that the total volume was standardized to 100 ml. This step ensures that the sample is prepared for precise analysis using Atomic Absorption Spectroscopy (AAS) (Singh *et al*., 2017).

A series of magnesium standards with known concentrations (e.g., 0.1, 0.5, 1.0, 2.0 mg/L) was prepared using a magnesium standard solution. These standards were used to create a calibration curve, which helps in quantifying magnesium levels in the sample. The standards are essential for establishing the relationship between absorbance and concentration, ensuring the accuracy of the analysis (Yadav *et al*., 2020). The prepared sample extract was introduced into the Atomic Absorption Spectrometer (AAS) (e.g., Hitachi L4000H model), where it was aspirated into a flame or graphite furnace (depending on the detection mode: flame or furnace AAS). The AAS instrument uses a specific wavelength of light (e.g., 285.2 nm for magnesium) to measure the amount of light absorbed by magnesium atoms in the flame, which is directly related to their concentration in the sample (Sarma *et al*., 2019). The flow rate of the flame was adjusted (typically around 1.0-2.0 L/min) to ensure optimal atomization of the sample. The magnesium hollow cathode lamp was used as the light source, and the detector recorded the absorption, which was then correlated to the concentration of magnesium in the sample.

The AAS system was calibrated using the prepared standards to obtain a calibration curve. The magnesium concentration in the sample was then determined by comparing the absorbance readings to the calibration curve. This calibration curve ensures that the relationship between absorbance and concentration is accurate, allowing for reliable determination of magnesium content in the sample. The AAS system automatically calculated the magnesium concentration in the sample based on the calibration curve. The final magnesium content was expressed in mg/kg (Appendix 6). This final result is useful in determining magnesium concentration in various biological and environmental samples (Reddy *et al*., 2021).

3.5.3.5 Percentage Moisture Content

Percentage Moisture Content was determined by using Gravimetric Method**.** The sample tuber was first processed to obtain a homogeneous mixture. Approximately 5.00 g of the sample was weighed and placed in a pre-weighed moisture dish. The dish with the sample was then placed in an oven set at 105°C for a specific period (usually 24 hours) to allow the moisture to evaporate. This method is based on the principle that moisture in the sample will evaporate upon heating, and the loss in weight corresponds to the amount of moisture (Chen *et al*., 2016). After the sample had dried, it was removed from the oven and allowed to cool in a desiccator to prevent absorption of moisture from the air. The weight of the sample was then recorded. The difference between the initial and final weights represents the moisture content in the sample (Appendix 7). This difference is expressed as a percentage of the initial sample weight, calculated according to International Potato Center (CIP), [2007] formula:

$$Percentage\ moisture\ content = \frac{Initial\ weigh - Final\ weight}{Initial\ weignt}\ X100$$

This method provides a direct measure of the moisture content, which is crucial for determining the quality and storage conditions of various food and agricultural products (Mellado *et al*., 2019). To ensure accuracy, the process is repeated for several replicates, and the average value is calculated. This method is widely used in food science, agriculture, and environmental studies for determining moisture content in a variety of samples, including plant tissues, soils, and food products (Yadav *et al*., 2020).

3.6 Data Analysis

Collected data on Vine Girth, Vine Length, Number of leaves, Tuber weight, Tuber Diameter, Tuber Dry matter content, Days to Maturity and Quality variables such as

Beta Carotene, Percentage Moisture, Magnesium, Calcium and Ash Content were subjected to analysis of variance using Statistical Analysis Software (SAS version 9.3). Significant means were separated using Least Significant Difference (LSD) at a 5% probability level.

Statistical model is given us:

$$Y_{ijk} = \mu + a_i + b_j + (ab)_{ij} + r_k + e_{ijk}$$

where;

Y_{ij} = response,

μ = overall mean,

a_i = effect of fertilizer,

bj = effect of the cattle manure,

$(ab)_{ij}$ = interaction effect of cattle manure and fertilizer,

r_k = effect of blocks,

e_{ijk} = error.

3.7 Ethical Considerations

The study ensured that research was conducted in an ethical manner, upholding fidelity, justice, and avoiding plagiarism. A research permit was sought from the National Council of Science and Technology (NACOSTI) before commencing the research (Appendix 8). Conclusions and recommendations made were shared with institutions involved in the study through presentations. Access to this information by any other persons requires full authorization by Chuka University.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil and Manure Analysis

The soil samples from experimental sites and cattle manure used in this study were analysed at the beginning of the experiments in each site.

4.1.1 Soil analysis: Physicochemical Properties and Nutrient Status of Experimental Sites

The soil analysis results in Trial I (Kiine, Ndia, Kirinyaga) and Trial II (Gatitu, Nyeri) are presented in Table 2. In Trial I, the soil pH was 5.40, placing it in the moderately acidic range. This pH is within the acceptable range of 5.40 – 6. 50 for sweet potato production, though a further decrease could restrict the availability of key nutrients such as calcium and phosphorus. Total nitrogen content was 0.12%, which is low and indicates the need for nitrogen supplementation to support vigorous vegetative growth. Organic carbon was 1.40%, rated as moderate, suggesting fair organic matter levels; however, additional organic inputs could further improve soil structure and fertility. Phosphorus was (83 ppm), sufficient but supplementation was done to meet root development requirements. Potassium content (0.32 meq %) was adequate, supporting normal physiological functions such as tuber formation. Calcium was low (1.8 meq %), which could negatively impact shoot and root development, thus warranting the application of calcium-rich fertilizers or lime. Magnesium was high (4.07 meq %), sufficient to meet the crop's needs. Micronutrients, including manganese (0.64 meq %), copper (5.73 ppm), iron (126 ppm), zinc (33.3 ppm), and sodium (0.56 meq %), were all within adequate ranges. Based on these findings, the soil would benefit from the application of 2 tonnes per acre of well-decomposed manure to improve organic matter, together with 50 kg per acre of Calcium Ammonium Nitrate (CAN) to address nitrogen and calcium deficiencies and also phosphorus fertilize application.

In Trial II, the soil pH was slightly higher at 5.67, still moderately acidic but slightly more favourable for nutrient availability than in Trial I. Total nitrogen was 0.22%, rated adequate, and therefore sufficient to sustain vegetative growth without the need for additional nitrogen fertilizer. Organic carbon content (2.40%) was moderate and higher than in Trial I, indicating improved soil organic matter that supports microbial activity and enhances soil fertility. Phosphorus was adequate (64 ppm), ensuring proper root development. Potassium content was very high (2.34 meq %), a favorable condition for stress tolerance, tuber quality, and overall plant health. Calcium (6.40 meq %) was adequate, and magnesium (4.00 meq %) remained high, both meeting crop requirements. Micronutrient levels including manganese (0.80 meq %), copper (3.30 ppm), iron (46.0 ppm), zinc (43.7 ppm), and sodium (1.24 meq %), were all within the adequate range. These conditions suggest that the soil is nutritionally sufficient for sweet potato production, requiring the addition of 2 tonnes per acre of well-decomposed manure to enhance organic matter and also phosphatic fertilizer application for adequate supply of nutrients to enhance better growth and development of sweet potatoes. The two sites differ mainly in their nitrogen, calcium, and potassium status, with Trial I showing deficiencies in nitrogen and calcium, while Trial II is well balanced and more favorable for sweet potato growth.

Table 2: Soil analysis results from Kibirigwi Irrigation Scheme (Trial I) and Wambugu Farm (Trial II) at the beginning of planting

Soil Property	Unit	Trial I sample	Rating	Trial II sample	Rating
Soil Ph	-	5.40	Medium Acid	5.67	Medium Acid
Total Nitrogen	%	0.12	Low	0.22	Adequate
Organic Carbon	%	1.40	Moderate	2.40	Moderate
Phosphorus	ppm	83	High	64	Adequate
Potassium	meq%	0.32	Adequate	2.34	High
Calcium	meq%	1.80	Low	6.40	Adequate
Magnesium	meq%	4.07	High	4.00	High
Manganese	meq%	0.64	Adequate	0.80	Adequate
Copper	Ppm	5.73	Adequate	3.30	Adequate
Iron	Ppm	126	Adequate	46.00	Adequate
Zinc	Ppm	33.3	Adequate	43.7	Adequate
Sodium	meq%	0.56	Adequate	1.24	Adequate

4.1.2 Nutrient Composition and Quality Assessment of Cattle Manure

The manure was analyzed for its macronutrient and micronutrient composition. The results of the analysis are shown in Table 3. The findings indicate that, in general, the manure contained adequate amounts of most essential plant nutrients, with a few exceptions. Nitrogen content was at 1.17%, which is considered good for organic manures (FAO, 2019), as it is crucial for plant vegetative growth, promoting leaf and stem development. A nitrogen content above 1% is optimal, suggesting that this manure would contribute significantly to soil nitrogen supply when incorporated properly. Phosphorus content was recorded at 0.10%, which is considered low for farmyard manure, as the typical range is 0.2 to 0.5%. Phosphorus is vital for energy transfer, root development, and tuber formation, and the low level in this sample suggests that supplemental phosphorus (e.g., Triple Superphosphate or DAP) may be required to meet crop needs, especially for sweet potatoes as phosphorus is highly fixed in the soils. Potassium content was recorded at 0.47%, which falls within the adequate range for manure (generally 0.3–1.0%), and is essential for tuber quality, water regulation, and enzyme activation. Therefore, this manure would help improve soil potassium (K) status. Calcium content was measured at 0.85%, which supports cell wall development and root health. This level is typical for manure and is considered adequate. Thus, the manure provides a useful source of calcium to supplement deficient soils. Magnesium, however, was recorded at 0.11%, which is below the desirable threshold (ideally 0.2 - 0.4% in quality manure). Magnesium is required for chlorophyll synthesis and enzymatic functions, and given the noted deficiency, magnesium supplementation (e.g., with dolomitic lime) may be recommended when using this type of manure. Iron was recorded at 1217 mg/kg, manganese at 730 mg/kg, zinc at 147 mg/kg, and copper at 26.3 mg/kg. These micronutrients were present in high and beneficial quantities, especially iron and zinc, which are essential for enzyme function, respiration, and protein synthesis. These values indicate the manure's potential to improve micronutrient availability in the soil and support crop growth (Table 3).

Table 3: Cattle manure analysis results at the beginning of each planting Trial I and Trial II

Nutrient	Unit	Value	Interpretation
Nitrogen (N)	%	1.17	Adequate
Phosphorus (P)	%	0.10	Low
Potassium (K)	%	0.47	Adequate
Calcium (Ca)	%	0.85	Adequate
Magnesium (Mg)	%	0.11	Low
Iron (Fe)	mg/kg	1217	High – Beneficial
Copper (Cu)	mg/kg	26.3	Adequate
Manganese (Mn)	mg/kg	730	Adequate
Zinc (Zn)	mg/kg	147	Adequate

The soil analyses conducted at Kibirigwi Irrigation Scheme (Trial I) and Wambugu Farm (Trial II) revealed critical insights into their fertility status and provided a scientific basis for formulating site-specific nutrient management strategies for sweet potato cultivation. Both soils were moderately acidic, with pH values of 5.40 and 5.67, respectively. These levels fall within the lower acceptable range for sweet potato growth, which typically thrives between pH 5.5 and 6.5 (Li *et al*., 2022). However, the slightly more acidic condition at Kibirigwi may increase phosphorus (P) fixation, thus reducing P availability to plants. Similar findings were reported by Muriuki *et al*. (2021), who noted that acidic soils in Central Kenya limit phosphorus bioavailability despite high total P content. According to Higashikawa *et al*. (2025), managing soil pH through liming not only improves nutrient availability but also enhances root development and yield in sweet potato. Therefore, lime application or the use of calcium-rich amendments may be beneficial at Kibirigwi to raise pH and improve nutrient uptake efficiency.

Total nitrogen (N) content differed markedly between the two sites, with Kibirigwi recording low levels (0.12%) and Wambugu exhibiting adequate levels (0.22%). The low nitrogen status at Kibirigwi is consistent with widespread N deficiencies observed in many tropical soils subjected to continuous cropping without adequate replenishment (Mutisya *et al*., 2022). Nitrogen is vital for vegetative growth and canopy development in sweet potato; however, excessive N can promote vine growth at the expense of tuberization (Higashikawa *et al*., 2025). Makokha *et al*. (2018) similarly reported that sweet potato yield significantly declined when N was omitted from nutrient treatments, highlighting its essential role in yield formation. These findings suggest that moderate N supplementation preferably from both organic and inorganic sources would be necessary at Kibirigwi to promote balanced growth and tuber formation.

Organic carbon levels were moderate at both sites (1.40% at Kibirigwi and 2.40% at Wambugu), reflecting fair levels of soil organic matter that contribute to soil structure, microbial activity, and nutrient retention. Comparable results were reported by Li *et al*. (2022), who found that integrating organic fertilizers improved soil organic carbon and enhanced sweet potato growth in newly reclaimed soils. Maintaining and increasing organic matter through manure or compost application is therefore essential for sustaining soil fertility and nutrient cycling.

Phosphorus availability differed between the two sites, with Kibirigwi recording high P levels (83 ppm) and Wambugu showing adequate P (64 ppm). While these concentrations appear sufficient for root development, the lower pH at Kibirigwi may still restrict P availability due to fixation by aluminum and iron oxides (Muriuki *et al*., 2021). Dumbuya *et al*. (2016) observed similar challenges in Ghana, where acidic soils limited P uptake despite fertilizer application. These findings indicate that targeted P fertilization possibly using Triple Superphosphate (TSP) or DAP combined with pH correction would enhance P efficiency in such soils.

Potassium (K) levels also varied significantly, being adequate at Kibirigwi (0.32 meq%) but considerably higher at Wambugu (2.34 meq%). Potassium plays a crucial role in photosynthesis, enzyme activation, and tuber quality in sweet potatoes (Darko *et al*., 2020). The higher K content at Wambugu is advantageous for improving stress tolerance and storage root quality, whereas the relatively lower K at Kibirigwi could limit these traits if not supplemented. Yuan *et al*. (2023) reported that long-term organic fertilization enhanced K uptake and maintained soil fertility in peanut – sweet potato rotations, supporting the need for consistent K replenishment in systems where tuber crops are grown intensively.

Calcium (Ca) levels were notably low at Kibirigwi (1.80 meq%) but adequate at Wambugu (6.40 meq%). Calcium deficiency has been linked to poor root and shoot development and reduced tuber quality (Njoroge *et al*., 2017). The use of calcium-containing amendments such as lime or gypsum could therefore help correct this imbalance at Kibirigwi. Magnesium (Mg) levels were high and sufficient in both soils (4.07 and 4.00 meq%), which supports chlorophyll synthesis and photosynthesis. However, maintaining a balanced Ca:Mg ratio is important to prevent cationic imbalance that could affect nutrient uptake (Agbede *et al*., 2024). Micronutrients including manganese (Mn), copper (Cu), iron (Fe), and zinc (Zn) were within adequate ranges in both trials, indicating that the soils are not limited in trace elements. This finding aligns with observations by Mugai *et al*. (2022), who emphasized that balanced micronutrient nutrition supports enzymatic activity and plant metabolic processes essential for sweet potato productivity. Therefore, nutrient management at these sites should focus primarily on macronutrients rather than micronutrient supplementation.

The cattle manure analysis revealed an adequate nitrogen content (1.17%) and moderate potassium (0.47%) and calcium (0.85%) levels, but low phosphorus (0.10%) and magnesium (0.11%) concentrations. The high iron (1,217 mg/kg) and adequate copper (26.3 mg/kg), manganese (730 mg/kg), and zinc (147 mg/kg) concentrations are beneficial for correcting potential micronutrient deficiencies. According to Nyarko *et al*. (2022), integrating organic manure such as cow dung with inorganic fertilizers significantly enhances nutrient availability and yield in sweet potato, compared to either source applied alone. Similarly, Agbede *et al*. (2024) found that combining poultry manure and biochar improved soil fertility, nutrient accumulation, and sweet potato yield. However, due to the low P and Mg content in the manure used in this study, supplementation with inorganic P fertilizers and Mg sources (e.g., dolomitic lime) remains necessary to achieve optimal nutrient balance (Mukhongo *et al*., 2017).

Overall, these findings affirm the importance of adopting integrated nutrient management (INM) strategies for sustainable sweet potato production. Integrated approaches that combine organic manure with mineral fertilizers enhance nutrient synchronization, improve soil structure, and ensure immediate and long-term nutrient supply (Li *et al*., 2022; Nyarko *et al*., 2022). At Kibirigwi, the focus should be on improving N, K, and Ca levels while managing soil acidity, whereas at Wambugu, nutrient management should maintain the favorable status of N and K while ensuring balanced Ca and P supply. Continuous soil monitoring and balanced fertilization will help sustain soil fertility and enhance crop productivity over time.

4.2 Effect of Combined Cattle Manure and Phosphatic Fertiliser Rates on Growth Performance of Orange-Fleshed Sweet Potato

The test for the fitted model showed that it was adequate ($p < 0.05$) in explaining the relationship between treatments used and in relation to vine girth, vine length and number of leaves in Trial I and Trial II (Appendix 9). Specifically, the combined effect of the treatments was found to be significant ($p < 0.05$) for all variables measured throughout the trial (Appendix 10). However, blocking treatments did not show any significant effect ($p > 0.05$).

4.2.1 Effect of Cattle Manure and TSP Fertilizer on Vine Girth of Orange-Fleshed Sweet Potato

The results from both trials clearly demonstrate that the application of cattle manure and Triple Superphosphate (TSP) significantly influenced vine girth development in orange-fleshed sweet potato (OFSP), with statistically significant differences ($p < 0.05$) observed across all growth stages (Tables 4 and 5). In both sites, the highest vine girths were consistently recorded under treatment T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP), confirming that the integrated use of organic and inorganic fertilizers enhances vegetative growth. At Kibirigwi (Trial I), vine girth under T3S3 increased from 1.55 cm at 7 DAS to 4.82 cm at 112 DAS, while at Wambugu Farm (Trial II), it increased from 1.30 cm to 3.40 cm. This consistent improvement suggests that combined nutrient management provides a more balanced and sustained nutrient release, which supports vigorous vine expansion.

The treatments with moderate nutrient inputs also showed substantial growth improvements. For example, T3S2 (2.5 t/acre manure + 50 kg/acre TSP) recorded vine girths of 1.37 cm to 4.59 cm in Trial I and 1.20 cm to 3.30 cm in Trial II, indicating that even with slightly reduced phosphorus levels, high manure rates still promote substantial vegetative development. Similarly, T3S1 (2.5 t/acre manure + 0 TSP) produced slightly lower but still significantly higher vine girths than lower manure treatments, underscoring the importance of cattle manure as a base nutrient source. Manure enhances soil structure, microbial activity, and cation exchange capacity, leading to improved nutrient availability.

In contrast, treatments with lower manure applications (T2 series) exhibited intermediate vine girths, while the control (T1S1, no manure or TSP) produced the lowest values in both trials. For instance, T1S1 recorded 0.78 – 2.51 cm in Trial I and 0.48 – 2.19 cm in Trial II. The poor performance under the control and low-input treatments demonstrates the depletion of available nutrients in unfertilized soils, which limits cell elongation and vine thickening. The progressive increase in vine girth with manure and phosphorus inputs further illustrates the synergistic effect between organic and inorganic sources in enhancing nutrient use efficiency.

A comparison between the two sites reveals that vine girths were generally higher at Kibirigwi (Trial I) than at Wambugu Farm (Trial II) across similar treatments. The superior response in Kibirigwi can be attributed to the lower baseline fertility of its soil, which made the applied nutrients more effective and responsive. Conversely, Wambugu's relatively fertile soil exhibited more uniform growth across treatments, reflected in lower coefficients of variation (≤ 3.03%) and consistently high R^2 values (≈ 0.99). The stronger nutrient response at Kibirigwi suggests that the benefits of manure and phosphorus inputs are more pronounced in nutrient-depleted soils.

Over time, variability in vine girth decreased at both sites, with the coefficient of variation (CV) reducing from 8.44% to 2.85% at Kibirigwi and remaining below 3% at Wambugu. This pattern indicates that as the crop matured, nutrient uptake stabilized, and environmental factors exerted less influence. Additionally, the high and increasing coefficient of determination (R^2) values (0.87 – 0.99 at Kibirigwi; consistently 0.99 at Wambugu) confirm a strong positive correlation between nutrient levels and vine girth development.

In summary, the integrated application of 2.5 t/acre cattle manure and 75 kg/acre TSP (T3S3) produced the most vigorous vine growth across both trials. The differences in absolute vine girth values between the sites highlight the importance of site-specific nutrient management, where manure and phosphorus application rates should be tailored according to soil fertility status. These findings reinforce the value of combining organic and inorganic inputs under ISFM strategies to sustainably improve the growth and productivity of OFSP in varying agro-ecological conditions of Kenya and Sub-Saharan Africa.

Table 4: Vine Girth at different treatments and growth stages in Trial I at Kibirigwi
Vine Girth at different treatments and growth stages in Trial I at Kibirigwi

Treatment	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS
T3S3	1.55a	1.72ab	2.03a	2.40a	2.69a	2.80a	2.94a	3.24a

T3S2	1.37b	1.77a	2.03a	2.34a	2.53b	2.70b	2.88a	3.12b
T3S1	1.27cd	1.61c	1.88b	2.18b	2.41c	2.64b	2.85a	2.93c
T2S3	1.33bc	1.65bc	1.89b	2.10bc	2.29d	2.35c	2.59b	2.77d
T2S2	1.20d	1.44d	1.62c	2.00c	2.09e	2.31c	2.49c	2.56e
T2S1	1.03e	1.34d	1.61c	1.85d	1.95f	2.10d	2.32d	2.39f
T1S3	0.99e	1.11e	1.39d	1. 60e	1.70g	1.80e	2.03e	2.12g
T1S2	0.89f	1.07e	1.37d	1.40f	1.64g	1.72e	1.78f	1.91h
T1S1	0.78g	1.04e	1.14e	1.35f	1.40h	1.52f	1.64g	1.75i
CV	8.44	7.44	4.85	5.83	4.43	4.41	4.07	4.55
LSD	0.09	0.09	0.08	0.11	0.09	0.09	0.09	0.11
Mean	1.16	1.42	1.66	1.91	2.08	2.22	2.39	2.53
R^2	0.87	0.89	0.94	0.93	0.96	0.96	0.96	0.96

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

Table 4: Continuation

Treatment	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS	98 DAS	105 DAS	112 DAS
T3S3	3.34a	3.62a	3.86a	4.02a	4.18a	4.46a	4.59a	4.82a
T3S2	3.33a	3.50b	3.69b	3.85b	4.14a	4.32b	4.45b	4.73a
T3S1	3.20b	3.40b	3.62b	3.79b	3.95b	4.19c	4.37c	4.59b
T2S3	2.94c	3.00c	3.22c	3.33c	3.50c	3.53d	3.81d	3.90c
T2S2	2.82d	2.90d	3.01d	3.16d	3.33d	3.49d	3.60e	3.82e
T2S1	2.69e	2.71e	2.81e	2.96e	3.15e	3.23e	3.37f	3.43d
T1S3	2.22f	2.25f	2.43f	2.50f	2.56f	2.70f	2.85g	2.87e
T1S2	1.95g	2.11g	2.26g	2.26g	2.36g	2.48g	2.64h	2.67f
T1S1	1.81h	1.92h	1.98h	2.08h	2.19h	2.20h	2.41i	2.51g
CV	3.74	3.85	3.25	3.59	3.25	3.39	2.93	2.85
LSD	0.10	0.10	0.09	0.11	0.01	0.11	0.10	0.10
Mean	2.71	2.82	2.99	3.11	3.26	3.40	3.57	3.71
R^2	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance

Table 5: Vine Girth at different treatments and growth stages in Trial II at Wambugu Farm

Treatments	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS
T3S3	1.30a	1.60a	1.80a	1.99a	2.20a	2.41a	2.51a	2.57a
T3S2	1.20b	1.50b	1.69b	1.90b	2.18b	2.19b	2.40b	2.48b
T3S1	1.10c	1.39c	1.61c	1.79c	2.01c	2.10c	2.30c	2.40c
T2S3	1.01d	1.29d	1.49d	1.69d	1.88d	1.99d	2.18d	2.31d
T2S2	0.90e	1.09e	1.30e	1.50e	1.72e	1.80e	2.00e	2.09e
T2S1	0.81f	1.01f	1.20f	1.40f	1.50f	1.60f	1.80f	1.89f
T1S3	0.71g	0.91g	1.11g	1.31g	1.40g	1.50g	1.72g	1.80g
T1S2	0.60h	0.80h	1.00h	1.19h	1.31h	1.40h	1.50h	1.61h
T1S1	0.48i	0.70i	0.90i	1.00i	1.11i	1.19i	1.30i	1.39i
CV	3.03	2.86	2.37	1.76	1.74	1.66	1.50	1.43
LSD	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Means	0.90	1.14	1.35	1.53	1.69	1.80	1.97	2.06
R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

Table 5: Continuation

Treatment	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS	98 DAS	105 DAS	112 DAS
T3S3	2.70a	2.80a	2.90a	3.00a	3.10a	3.19a	3.31a	3.40a
T3S2	2.59b	2.70b	2.81b	2.91b	2.99b	3.09b	3.20b	3.30b
T3S1	2.50c	2.59c	2.70c	2.78c	2.93c	2.99c	3.10c	3.22c
T2S3	2.40d	2.50d	2.59d	2.69d	2.80d	2.92d	3.02d	3.10d

T2S2	2.20e	2.30e	2.40e	2.50e	2.59e	2.70e	2.81e	2.90e
T2S1	2.00f	2.10f	2.20f	2.29f	2.39f	2.50f	2.59f	2.70f
T1S3	1.88g	1.99g	2.12g	2.20g	2.31g	2.40g	2.50g	2.59g
T1S2	1.70h	1.794h	1.910h	2.011h	2.081h	2.182h	2.314h	2.396h
T1S1	1.50i	1.61i	1.70i	1.79i	1.89i	2.00i	2.11i	2.19i
CV	1.36	1.44	1.21	1.21	1.14	1.07	1.07	1.03
LSD	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Means	2.16	2.27	2.37	2.46	2.57	2.66	2.77	2.87
R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance

The results from both trials clearly demonstrate that nutrient management significantly influenced vine girth in orange-fleshed sweet potato (OFSP), with the highest values consistently observed under T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP). This treatment produced the most vigorous vines across all growth stages, confirming that the combined use of organic and inorganic fertilizers enhances vegetative growth. Such synergy arises because manure improves soil physical properties, microbial activity, and moisture retention, while phosphorus accelerates root and shoot development through increased energy transfer (Maina *et al.*, 2019). Consequently, the enhanced vine girth reflects a healthier photosynthetic apparatus capable of supporting greater assimilate production and translocation to developing storage roots, ultimately translating into higher yields.

Treatments without manure (T1S1) consistently produced the smallest vine girths, reaffirming the crucial role of organic matter in sustaining vegetative vigor. Similar findings by Wekesa *et al*. (2020) demonstrated that absence of organic inputs limits soil aeration and water-holding capacity, reducing nutrient uptake and impairing vine thickening. Reduced vine girth in nutrient-deficient conditions often corresponds to lower canopy density and restricted photosynthetic activity, which in turn limit carbohydrate accumulation and tuber initiation. In contrast, vigorous vines with thicker stems support more extensive leaf area and higher photosynthate supply, leading to larger and heavier tubers at harvest (Makokha *et al*., 2020; Achieng *et al*., 2021).

Interestingly, T3S1 (2.5 t/acre cattle manure without TSP) performed almost as well as T3S2 (2.5 t/acre manure + 50 kg/acre TSP), indicating that high organic input alone can sustain substantial vine growth. This suggests that manure not only provides essential macronutrients but also improves soil phosphorus availability through enhanced microbial mineralization (Ouma & Mugo, 2018). The marginal difference between T3S1 and T3S2 implies that phosphorus supplementation becomes less limiting when organic matter levels are adequate, as organic acids from manure can solubilize fixed phosphorus, making it available for plant uptake. The resulting increase in vine girth enhances translocation efficiency and root sink strength, critical determinants of sweet potato yield formation (Taiz & Zeiger, 2015).

Moderate manure combined with high phosphorus (T2S3, 1.5 t/acre manure + 75 kg/acre TSP) yielded lower vine girths than T3S1, underscoring the greater influence of organic matter over phosphorus in promoting stem expansion, especially in low organic matter or acidic soils. These results are consistent with Kimani et al. (2017), who found that phosphorus use efficiency is significantly constrained in soils with poor biological activity and low organic content. Similarly, treatments receiving phosphorus alone (T1S2 and T1S3) showed minimal improvements over the control, demonstrating that inorganic fertilizers require a stable organic matrix to enhance nutrient uptake efficiency and sustain growth.

The progressive increase in vine girth across all treatments throughout the growing period reflects cumulative nutrient uptake and biomass accumulation. Treatments with higher early growth rates maintained this advantage over time, consistent with the growth momentum theory proposed by Taiz and Zeiger (2015), which posits that early vigorous growth promotes continued assimilate accumulation and higher productivity. Larger vine girth not only signifies strong vegetative performance but also correlates positively with yield, as thicker vines support more leaves and greater photosynthetic capacity, ensuring a steady supply of assimilates to developing tubers (Ayalew *et al*., 2020; Yeboah *et al*., 2022). Thus, the observed increase in vine girth under integrated manure and phosphorus application indicates enhanced source sink efficiency, contributing to improved tuber yield and quality. Overall, these findings highlight that integrated soil fertility management (ISFM) combining organic and inorganic inputs optimizes both vegetative growth and yield potential in OFSP. The results suggest that applying 2.5 t/acre cattle manure plus 75 kg/acre TSP (T3S3) provides the most balanced nutrient regime for maximizing vine girth, canopy vigor, and yield potential, particularly under conditions of moderate soil fertility.

4.2.2 Effect of Cattle Manure and TSP Fertilizer on Vine Length in Orange-Fleshed Sweet Potato

The differences among treatments were statistically significant ($p < 0.05$) across all weeks in both trials. Vine length increased progressively throughout the 112-day growth period, with clear treatment effects observed (Tables 6 and 7). In Trial I (Kibirigwi), the greatest vine elongation occurred under T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP), which reached 194.82 cm by 112 DAS significantly higher than all other treatments. It was followed by T3S2 (184.45 cm) and T3S1 (175.35 cm), indicating that higher manure rates were most effective in promoting vine growth, while TSP provided additional enhancement. Moderate manure applications (T2 series) produced intermediate vine lengths, whereas treatments without manure (T1 series) recorded the shortest, with T1S1 (control) reaching only 98.31 cm. The variability among treatments declined over time, as shown by the coefficient of variation (CV) decreasing from 19.15% at 7 DAS to 2.86% at 112 DAS, and a corresponding rise in the coefficient of determination (R^2) from 0.75 to 0.99, reflecting a strong nutrient-growth relationship (Table 6).

A similar trend was observed in Trial II (Nyeri), where T3S3 again produced the longest vines (126.84 cm at 112 DAS), followed by T3S2 (120.84 cm) and T3S1 (117.24 cm). Moderate manure levels (T2 series) and phosphorus-only treatments (T1S2, T1S3) yielded shorter vines, while the control (T1S1) recorded the minimum (82.50 cm). Growth uniformity was high, with CV values $\leq 0.836\%$ and $R^2 \approx 0.99$ (Table 7). Overall, the combined application of cattle manure and TSP significantly enhanced vine length in both trials. In T3S3, vine length increased from 27.83 cm to 194.82 cm in Kibirigwi and from 13.61 cm to 126.84 cm in Nyeri over the growth period. Although TSP improved growth, cattle manure was the main driver of elongation, with higher application rates producing the most vigorous vines.

Ecological differences between sites were evident. Kibirigwi recorded generally longer vines than Nyeri under similar treatments, particularly at the highest nutrient level (T3S3: 194.82 cm vs. 126.84 cm), likely due to its lower initial soil fertility, which amplified the response to added nutrients. Nyeri's naturally fertile soils moderated this response but resulted in more uniform growth. These findings underscore the pivotal role of cattle manure in promoting vine elongation, with TSP enhancing performance when applied alongside organic inputs. The observed vine length patterns parallel those of vine girth, reaffirming that integrated organic–inorganic nutrient management effectively stimulates vegetative growth and overall crop development

Table 6: Vine Length at different treatments and growth stages in Trial I at Kibirigwi

Treatment	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS
T3S3	27.83a	45.31a	63.87a	79.20a	92.03a	105.81a	114.60a	126.30a
T3S2	24.51b	41.16b	58.76b	73.34b	87.57b	99.08b	108.25b	115.49b
T3S1	23.04bc	37.98c	51.45c	68.69c	80.54c	89.81c	101.69c	107.53c
T2S3	20.11cd	35.12d	49.72c	63.79d	73.05d	83.80d	92.63d	103.11d
T2S2	17.68de	31.14e	46.22d	57.13e	66.78e	76.05e	85.21e	92.63e
T2S1	14.90ef	27.42f	40.56e	49.49f	60.11f	69.14f	76.79f	84.32f
T1S3	14.09fg	24.04g	36.92f	44.57g	53.62g	59.62g	70.13g	74.15g
T1S2	11.34gh	20.92h	32.32g	39.07h	46.27h	52.69h	60.34h	65.04h
T1S1	10.71h	15.70i	28.49h	32.72i	40.07i	43.65i	52.99i	57.91i
CV	19.15	9.06	5.76	5.69	4.70	4.59	3.57	2.86
LSD	3.29	2.64	2.46	3.02	2.95	3.27	2.85	2.47
Means	18.25	30.98	45.37	56.45	66.67	75.52	84.74	91.83
R^2	0.75	0.93	0.96	0.96	0.97	0.98	0.98	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP.

[a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

Table 6: Continuation

Treatment	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS	98 DAS	105 DAS	112 DAS
T3S3	137.29a	147.66a	157.21a	165.13a	170.49a	179.15a	187.87a	194.82a
T3S2	130.42b	140.63b	146.36b	155.01b	164.39b	170.52b	177.11b	184.45b
T3S1	121.63c	130.96c	138.45c	145.75c	152.24c	159.17c	167.88c	175.35c
T2S3	111.44d	121.95d	131.09d	139.06d	146.32d	155.88d	161.67d	169.54d
T2S2	101.91e	112.64e	119.47e	127.43e	134.08e	143.30e	151.21e	159.55e
T2S1	94.45f	101.92f	108.41f	117.58f	122.61f	131.41f	137.88f	144.86f

T1S3	82.51g	90.924g	97.478g	104.11g	109.03g	116.91g	121.65g	128.96g
T1S2	74.06h	78.618h	86.22h	91.827h	96.729h	103.89h	109.19h	115.87h
T1S1	63.64i	68.053i	74.432i	79.94i	84.201i	90.873i	96.132i	98.308i
CV	2.51	2.62	2.30	2.30	2.47	2.28	2.24	1.86
LSD	2.41	2.72	2.55	2.70	3.04	2.98	3.03	2.67
Means	101.93	110.37	117.68	125.09	131.12	139.01	145.62	152.41
R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP.

[a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

Table 7: Vine Length at different treatments and growth stages in Trial II in Nyeri

Treatment	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS
T3S3	13.60a	19.45a	24.92a	30.77a	40.65a	48.25a	55.06a	63.13a
T3S2	12.01b	18.313b	23.23b	29.49b	37.85b	45.52b	51.97b	60.14b
T3S1	11.03c	16.58c	21.99c	28.41c	36.432c	43.89c	50.10c	57.76c
T2S3	10.40d	15.46d	20.92d	26.65d	33.89d	40.72d	47.44d	54.57d
T2S2	9.46e	13.71e	19.75e	24.89e	32.59e	38.89e	45.48e	52.01e
T2S1	7.77f	12.59f	17.62f	22.42f	29.92f	35.97f	42.54f	49.55f
T1S3	6.99g	11.24g	16.04g	20.83g	27.60g	33.59g	39.23g	45.05g
T1S2	6.47h	9.91h	14.43h	18.89h	25.58h	31.21h	36.46h	41.72h
T1S1	4.90i	8.21i	12.18i	16.27i	21.84i	27.57i	33.15i	38.35i
CV	5.94	3.92	2.27	2.41	1.36	1.38	1.14	0.95
LSD	0.51	0.52	0.41	0.55	0.41	0.50	0.48	0.46
Means	9.19	13.95	19.01	24.29	31.82	38.40	44.60	51.37
R^2	0.96	0.98	0.99	0.98	0.99	0.99	0.99	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP.

[a]Means followed by the same letter are not significantly different from each other at 5% level of significance

Table 7: Continuation

Treatment	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS	98 DAS	105 DAS	112 DAS
T3S3	71.40a	79.18a	87.27a	95.16a	103.23a	111.08a	119a	126.84a
T3S2	67.77b	75.29b	83.57b	91.10b	98.50b	105.91b	113.34b	120.84b
T3S1	64.81c	72.33c	80.05c	87.94c	95.02c	102.17c	109.57c	117.24c
T2S3	61.82d	68.81d	76.56d	83.66d	91.00d	98.70d	106.12d	113.45d
T2S2	58.76e	66.35e	73.61e	80.43e	87.70e	94.49e	101.88e	108.45e
T2S1	56.22f	63.49f	70.73f	77.70f	84.33f	91.21f	98.56g	105.34f
T1S3	50.59g	56.44g	62.44g	68.88g	74.56g	80.49g	86.59g	92.61g
T1S2	47.39h	53.05h	58.46h	64.03h	69.41h	75.16h	80.36h	85.71h
T1S1	44.00i	49. 60i	54.80i	60.72i	66.23i	71.57i	77.08i	82.50i
CV	0.84	0.71	0.61	0.63	0.59	0.56	0.57	0.41
LSD	0.46	0.43	0.41	0.46	0.48	0.49	0.53	0.41
Means	58.08	64.95	71.94	78.85	85.55	92.31	99.17	105.89
R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP.

[a]Means followed by the same letter are not significantly different from each other at 5% level of significance

The application of both cattle manure and phosphorus fertilizer significantly influenced vine length in sweet potato across both trials ($p < 0.05$), with the highest vine lengths observed under the combined treatment of 2.5 t/acre cattle manure and 75 kg/acre triple superphosphate (T3S3). In Trial I at Kibirigwi, vine length increased from 27.83 cm in 7 DAS to 194.82 cm in 112 DAS under T3S3, while in Trial II at Nyeri, vine length increased from 13.61 cm to 126.84 cm under the same treatment. These results underscore the critical role of integrated nutrient management in promoting vegetative growth in sweet potato.

The superior performance of T3S3 aligns with findings by Maina *et al*. (2019), who reported that the combination of high levels of organic and inorganic fertilizers enhances vegetative growth due to improved nutrient availability, enhanced root proliferation, and better soil structure. The consistent increase in vine length with higher rates of cattle manure also supports the observations of Wekesa *et al*. (2020), who noted that manure improves soil water-holding capacity and microbial activity, facilitating nutrient uptake and plant elongation. Notably, while both trials showed similar ranking of treatments, absolute vine lengths were lower in Trial II (Nyeri) than in Trial I (Kibirigwi), indicating a more robust plant growth in the latter site. This discrepancy may be attributed to microclimatic differences, soil fertility variations, or irrigation regimes. Kibirigwi, being an irrigated site, likely provided more favorable conditions for rapid vegetative expansion compared to Nyeri.

The T3S1 and T3S2 treatments in both trials produced vine lengths that were not significantly different from each other. This suggests that at higher levels of cattle manure (2.5 tons/acre), the marginal benefit of additional phosphorus may diminish. This agrees with the findings of Ouma and Mugo (2018), who noted that the presence of organic matter enhances phosphorus availability up to a certain level through increased root surface area and rhizosphere activity. The poorest performing treatment, T1S1 (no manure, no TSP), highlights the importance of nutrient inputs for sweet potato growth and may indicate the poor condition of the soils in supporting meaningful yields without nutrient supplementation. These plants remained significantly shorter than all other treatments, a pattern consistent with Kimani *et al*. (2017), who emphasized that phosphorus deficiency limits internode elongation and shoot development.

The steadily increasing R^2 values shows that he variation was high across the trials and decreasing coefficients of variation in both trials indicate that growth trends stabilized over time, and treatment differences became more pronounced with maturity. This supports physiological growth models, such as those proposed by Taiz and Zeiger (2015), which suggest that early nutrient uptake sets the pace for later vegetative expansion. In conclusion, vine length was positively and significantly affected by the application of both cattle manure and phosphorus fertilizer. The best growth was observed under combined high input conditions (T3S3), underscoring the importance of integrated soil fertility management. While growth trends were consistent across Kibirigwi and Nyeri, environmental differences influenced absolute vine lengths, suggesting that site-specific recommendations should be made when scaling up fertilizer use in sweet potato production.

4.2.3 Effect of Cattle Manure and TSP Fertilizer on Leaf Number in Orange-Fleshed Sweet Potato

The combined application of cattle manure and Triple Superphosphate (TSP) fertilizer significantly ($p < 0.05$) influenced leaf number in both trials (Tables 8 and 9). In Trial I (Kibirigwi), the highest nutrient treatment (T3S3: 2.5 t/acre cattle manure + 75 kg/acre TSP) increased leaf number from 12.56 at 7 DAS to 149.00 at 112 DAS, while in Trial II (Wambugu), it rose from 11.10 to 144.95 leaves over the same period. Treatments receiving high manure levels (T3 series) consistently recorded the greatest leaf counts, demonstrating that cattle manure was the primary factor driving leaf proliferation. The manure improved soil structure, moisture retention, and microbial activity, enhancing nutrient uptake and promoting vigorous canopy development. In contrast, the effect of TSP was less pronounced, as differences between T3S1 (manure only) and T3S2 (manure + 50 kg/acre TSP) were minimal, indicating that high manure levels already provided sufficient nutrients for optimal leaf growth. Treatments with moderate manure (T2 series) produced intermediate leaf numbers, while phosphorus-only treatments (T1S2 and T1S3) showed marginal improvement over the control (T1S1), confirming that TSP alone was less effective without organic supplementation. Overall, cattle manure emerged as the dominant driver of leaf development, with TSP exerting a supportive but secondary effect, highlighting the synergistic benefits of integrating organic and inorganic nutrient sources for enhanced vegetative growth in orange-fleshed sweet potato.

Treatments T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) and T3S1 (2.5 t/acre cattle manure + 0 TSP) followed closely, producing significantly higher leaf numbers compared to treatments with lower manure levels. In Trial I, the number of leaves under T3S2 increased from 12.22 at 7 DAS to 138.00 at 112 DAS, while T3S1 ranged from 10.22 to 127.11 leaves. Similarly, in Trial II, T3S2 increased from 9.88 to 138.38 leaves, while T3S1 ranged from 9.14 to 132.02 leaves. These patterns suggest that higher cattle manure rates were the primary factor driving leaf development, with TSP exerting a complementary but less pronounced effect.

Moderate manure applications (T2 treatments: 1.5 t/acre cattle manure) resulted in intermediate improvements compared to the control. In Trial I, leaf numbers under T2S3 rose from 9.89 at 7 DAS to 124.11 at 112 DAS, while in Trial II, the corresponding values ranged from 8.43 to 124.86. Although beneficial, these values remained consistently lower than those recorded under the 2.5 t/acre cattle manure treatments, confirming that manure quantity was more influential than TSP rate. Conversely, the lowest leaf numbers were consistently observed under the control treatment (T1S1: 0 cattle manure + 0 TSP) across both trials. In Trial I (Kibirigwi), T1S1 plants produced only 5.56 leaves at 7 DAS, increasing modestly to 64.44 by 112 DAS, while in Trial II (Wambugu), leaf numbers rose from 2.78 at 7 DAS to 90.00 at 112 DAS. The comparatively higher leaf count in Trial II suggests that the naturally higher baseline soil fertility at Wambugu supported slightly better vegetative growth even without nutrient additions. In contrast, the nutrient-deficient soils at Kibirigwi limited leaf expansion, resulting in slower canopy development. These findings underscore that the absence of external nutrient supplementation severely restricted leaf production, particularly in low-fertility soils, reinforcing the critical role of nutrient inputs especially organic amendments in enhancing vegetative growth across varying ecological conditions.

The variability in leaf number measurements decreased progressively over time in both trials. At Kibirigwi (Trial I), the coefficient of variation (CV) declined markedly from

25.35% at 7 DAS to 3.24% at 112 DAS, indicating that as the crop matured, the initially wide differences in leaf numbers among treatments narrowed substantially. This decline suggests that plants receiving adequate nutrients established faster and achieved more stable growth rates over time, while even the slower-growing treatments eventually caught up, leading to greater uniformity at later stages. At Wambugu (Trial II), variability was consistently lower, with CV reducing from 6.84% at 7 DAS to just 0.98% at 112 DAS, reflecting the site's more fertile and balanced soil conditions that promoted uniform vegetative growth across treatments. Correspondingly, the coefficient of determination (R^2) increased with crop age in both trials from 0.61 to 0.98 in Kibirigwi and from 0.97 to 0.99 in Wambugu demonstrating a progressively stronger and more consistent relationship between nutrient treatments and leaf number as the plants developed.

Comparisons between the two sites revealed subtle but important ecological differences. While both trials showed similar overall trends, Kibirigwi consistently recorded slightly higher leaf numbers than Wambugu under comparable treatments, particularly at the highest input levels (e.g., T3S3: 149.00 vs. 144.95 at 112 DAS). This stronger response at Kibirigwi may be attributed to lower initial soil nitrogen and calcium levels, which likely made the applied nutrients more effective. In contrast, the relatively fertile soils at Wambugu, with higher baseline nutrient levels, reduced the relative magnitude of treatment responses, although growth was more uniform. Indeed, Trial II exhibited exceptional consistency in leaf number response (very low CV values), while Trial I showed greater variability in the early growth stages, which decreased as the crop matured.

These results indicate that leaf development is highly responsive to nutrient management, with the integrated application of 2.5 t/acre cattle manure and 75 kg/acre TSP (T3S3) consistently achieving the highest number of leaves across both sites. This underscores the essential role of cattle manure in enhancing vegetative growth, with TSP serving as a valuable supplement that further optimises leaf development, particularly in nutrient-deficient soils.

Table 8: Number of Leaves at different treatments and growth stages in Trial I at Kibirigwi

Treatment	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS
T3S3	12.56a	21.56a	31.33a	41.78a	53.33a	61.00a	69.44a	80.56a
T3S2	12.22ab	20.67ab	27.89b	37.67b	45.78b	57.67b	64.11b	75.11b
T3S1	10.20bc	19.30bc	26.00c	33.11c	43.33c	49.89c	58.44c	67.11c
T2S3	9.89c	19.00bc	23.89d	31.44c	39.56d	46.44d	55.22d	64.22d
T2S2	8.44cd	17.89c	21.11e	28.00d	34.33e	42.44e	47.33e	55.67e
T2S1	7.22de	13.56d	18.33f	25.89e	31.11f	38.67f	44.22f	50.56f
T1S3	6.11e	12.33de	15.78g	23.44f	28.11g	33.56g	38.67g	45.33g
T1S2	6.00e	10.89e	14.44g	18.67g	23.67h	28.78h	33.67h	37.56h
T1S1	5.56e	8.11f	12.33h	16.56h	19.11i	23.56i	29.00i	31.67i
CV	25.34	12.54	9.41	6.60	5.24	4.48	4.21	3.24
LSD	2.07	1.88	1.88	1.77	1.74	1.79	1.94	1.72
Means	8.69	15.93	21.24	28.51	35.37	42.44	48.90	56.42
R^2	0.61	0.86	0.92	0.95	0.97	0.97	0.97	0.98

Table 8: Continuation

Treatent	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS	98 DAS	105 DAS	112 DAS
T3S3	90.44a	100.33a	106.56a	114.78a	124.33a	131.33a	139.78a	149.00a
T3S2	83.67b	92.56b	100.67b	106.67b	115.22b	122.00b	129.44b	138.00b
T3S1	74.67c	85.44c	91.67c	98.00c	103.89c	112.33c	118.22c	127.11c
T2S3	72.44d	80.33d	86.00d	93.44d	102.00d	109.22d	115.00d	124.11d
T2S2	62.44e	70.22e	74.89e	82.22e	87.67e	94.22e	99.89e	105.67e
T2S1	55.78f	61.44f	66.22f	72.22f	79.11f	82.56f	88.11f	95.89f
T1S3	50.11g	55.56g	59.11g	64.22g	70.11g	75.00g	79.22g	84.44g
T1S2	41.89h	47.33h	52.00h	56.56h	61.44h	65.33h	72.11h	75.56h
T1S1	36.33i	41.22i	44.00i	48.11i	52.22i	56.00i	60.56i	64.44i
CV	3.17	2.72	2.75	2.56	2.05	1.58	1.92	1.82
LSD	1.88	1.79	1.95	1.97	1.70	1.40	1.81	1.829
Means	63.09	70.49	75.68	81.80	88.44	94.22	100.26	107.14
R^2	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99

[a]Means followed by the same letter are not significantly different from each other at 5% level of significance. Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP.

Table 9: Number of Leaves at different treatments and growth stages in Trial II at Wambugu Farm

Treatment	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS
T3S3	11.10a	15.02a	18.90a	25.83a	34.11a	43.12a	52.23a	61.99a
T3S2	9.88b	13.82b	17.88b	23.95b	30.65b	39.91b	47.98b	57.94b
T3S1	9.143c	11.82c	15.75c	22.05c	29.15c	36.98c	44.94c	54.05c
T2S3	8.43d	10.80d	14.78d	20.05d	27.03d	33.95d	42.14d	50.69d
T2S2	6.81e	10.05e	13.83e	18.13e	23.92e	30.84e	38.28e	46.98e
T2S1	5.79f	7.92f	12.19f	15.92f	21.86f	27.87f	35.39f	44.10f
T1S3	5.15g	7.28g	10.06g	13.89g	18.87g	24.94g	31.23g	38.76g
T1S2	4.40h	5.99h	8.95h	12.00h	16.96h	21.77h	27.81h	35.17h
T1S1	2.78i	5.10i	6.86i	9.99i	13.82i	18.98i	25.02i	32.03i
CV	6.84	5.54	3.26	2.64	1.92	1.69	1.31	0.98
LSD	0.45	0.51	0.41	0.45	0.43	0.49	0.47	0.43
Means	7.06	9.76	13.25	17.98	24.04	30.93	38.34	46.86
R^2	0.97	0.97	0.98	0.99	0.99	0.99	0.99	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP.
[a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

Table 9: Continuation

Treatment	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS	98 DAS	105 DAS	112 DAS
T3S3	71.19a	81.90a	92.39a	103.20a	112.97a	124.10a	134.90a	144.95a
T3S2	67.14b	78.17b	88.33b	98.036b	107.17b	117.67b	128.05b	138.38b
T3S1	63.12c	72.90c	83.10c	92.84c	102.16c	112.02c	122.06c	132.02c
T2S3	60.04d	68.98d	79.097d	87.936d	96.72d	105.88d	116.46d	124.86d
T2S2	55.92e	64.90e	74.04e	83.22e	92.13e	100.82e	110.33e	119.02e
T2S1	51.75f	61.25f	70.11f	78.19f	86.84f	95.10f	103.64f	113.04f
T1S3	46.85g	55.0g	61.59g	69.96g	78.04g	86.14g	94.07g	103.20g
T1S2	43.10h	50.20h	57.34h	64.77h	72.15h	79.80h	88.10h	96.09h
T1S1	39.25i	45.68i	53.24i	60.08i	68.24i	75.02i	81.67i	90.00i
CV	0.89	0.78	0.71	0.59	0.49	0.50	0.37	0.41
LSD	0.46	0.47	0.49	0.46	0.42	0.47	0.37	0.46
Means	55.37	64.32	73.25	82.03	90.71	99.62	108.81	117.95
R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

The consistently superior performance of treatment T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP) across both sites underscores the importance of integrated nutrient management in stimulating vegetative growth. This trend is in line with Maina *et al*. (2019), who reported that combined use of organic and inorganic inputs enhances nutrient availability, photosynthetic capacity, and cell division, thereby accelerating leaf expansion and canopy development. The strong performance of cattle manure-based treatments (T3 series) highlights the central role of organic amendments in sweet potato production. Manure improves soil structure, water-holding capacity, and microbial activity, which are critical for nutrient uptake and vegetative growth (Wekesa *et al*., 2020). In addition, manure provides a slow but steady release of nutrients, ensuring prolonged availability throughout the crop cycle (Ayuke *et al*., 2021). The results of this study confirm that higher rates of cattle manure (2.5 t/acre) consistently produced greater leaf numbers than lower rates (1.5 t/acre), emphasizing the dose-dependent effect of organic matter on vegetative growth.

The T3S1 treatment (2.5 t/acre manure + 0 TSP) performed nearly as well as T3S2, suggesting that high manure application alone can substantially meet the crop’s phosphorus demand. This aligns with Ouma and Mugo (2018), who demonstrated that organic inputs enhance phosphorus uptake by improving root proliferation and stimulating microbial solubilization of insoluble phosphorus forms. Moreover, cattle manure is known to reduce phosphorus fixation in soils with high aluminum or iron oxides, thereby increasing phosphorus bioavailability (Nziguheba *et al*., 2016). These findings suggest that, in resource-constrained farming systems, high manure inputs could partially substitute for mineral phosphorus fertilizers.

Moderate manure applications (T2 treatments: 1.5 t/acre) produced intermediate improvements, while treatments relying solely on TSP (T1S2 and T1S3) showed only marginal gains over the control. This confirms that phosphorus alone is less effective in the absence of organic matter, as organic inputs improve nutrient mobility, retention, and microbial-mediated cycling (Kimani *et al*., 2017). The poor performance of T1S1 (no manure, no TSP) further illustrates the nutrient depletion status of the soils, which restricted leaf formation, biomass accumulation, and photosynthetic surface area.

Site comparisons revealed that while general treatment trends were consistent across the two agro-ecological zones, Kibirigwi recorded slightly higher leaf counts than Wambugu under similar treatments, particularly at the highest input levels (e.g., T3S3 at 112 DAS). This could be attributed to the lower initial soil nitrogen and calcium levels at Kibirigwi, which likely increased the responsiveness to applied nutrients. In contrast, Wambugu soils, being relatively more fertile, moderated the magnitude of treatment responses but resulted in greater uniformity in leaf development, as shown by the lower CV values. This observation echoes findings by Vanlauwe *et al*. (2019), who emphasized that the efficacy of integrated soil fertility management practices is context-specific and heavily influenced by baseline soil fertility.

The progressive decline in variability (CV values) and concurrent increase in R^2 values across growth stages also point to the stabilizing effect of nutrient supplementation on crop performance. Early in the season, variability was greater, likely due to differences in initial seedling vigor and nutrient mobilization efficiency. However, as nutrient availability improved with manure mineralization and TSP solubilization, plant responses became more uniform. Such trends are consistent with long-term integrated nutrient studies, where uniformity in growth increases as crops mature (Kihara *et al*., 2020).

The findings demonstrate that leaf number in sweet potato is highly responsive to integrated nutrient management. The combination of high cattle manure with TSP (T3S3) produced the most robust and consistent results, while sole inorganic fertilizer application was insufficient. These results reinforce the value of organic–inorganic fertilizer integration, not only for optimizing vegetative growth but also for promoting sustainable soil fertility management under contrasting ecological conditions.

4.3 Evaluation of Yield and Yield Components of Orange Fleshed Sweet Potato Under Different Cattle Manure and TSP Fertiliser Treatments

The test for the fitted model indicated that it was adequate ($p < 0.05$) in explaining the relationship between treatments and the days to maturity in Trial I and Trial II (Appendix 11). On testing the combined effect (treatments effect), the results indicated that there was significant ($p < 0.05$) effect for all variables measured across trial I and trial II (Appendix 12). However, the blocking of the treatments was found to be effective ($p > 0.05$).

4.3.1 Effect of Combined Cattle Manure and TSP Fertilizer on Days to Maturity of Orange-Fleshed Sweet Potato

The findings of this study revealed that the combined application of cattle manure and phosphatic (triple superphosphate, TSP) fertilizer had a significant effect ($p < 0.05$) on the days to maturity in both Trial I (Kibirigwi) and Trial II (Wambugu) (Table 10). In Trial I, days to maturity ranged from 82.89 days under T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP) to 101.78 days under the control (T1S1: no manure and no TSP). Similarly, in Trial II, the range was 82.00 days under T3S3 to 102.00 days under T1S1. These results show that the highest nutrient treatment (T3S3) consistently resulted in the shortest time to maturity across both sites, while the control treatment (T1S1) produced the longest.

Treatments T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) and T3S1 (2.5 t/acre cattle manure alone) followed closely behind T3S3. In Trial I, T3S2 matured at 85.11 days, while T3S1 matured at 88.33 days. In Trial II, the corresponding maturity times were 85.33 days and 89.00 days, respectively. These findings demonstrate that higher cattle manure levels were primarily responsible for hastening maturity, with TSP having a supplementary effect. Interestingly, the addition of TSP slightly increased maturity time compared to cattle manure alone, although the overall maturity remained earlier than in treatments with lower manure levels.

Moderate manure applications (T2 treatments) produced intermediate days to maturity. In Trial I, T2S3 (1.5 t/acre cattle manure + 75 kg/acre TSP) matured in 84.44 days, while T2S2 (1.5 t/acre cattle manure + 50 kg/acre TSP) matured in 87.67 days. In Trial

II, the corresponding values were 84.00 days and 86.00 days, respectively. These results suggest that even moderate levels of cattle manure shortened the maturity period compared to the control, though the effect was less pronounced than with higher manure applications. By contrast, treatments without cattle manure (T1 series) consistently recorded the longest maturity periods. For example, T1S2 (no manure + 50 kg/acre TSP) and T1S3 (no manure + 75 kg/acre TSP) matured at 96.00 – 96.67 days and 90.89 – 92.67 days, respectively. The control treatment (T1S1: no manure, no TSP) was consistently the latest to mature, requiring 101.78 days in Trial I and 102.00 days in Trial II. This highlights the slow development of plants in the absence of nutrient supplementation.

The coefficient of variation (CV) was low in both trials (1.67% in Trial I and 1.40% in Trial II), indicating minimal variability and uniformity in plant response across treatments. Similarly, the coefficient of determination (R^2) values were high (0.95 in Trial I and 0.97 in Trial II), showing a strong association between nutrient treatments and days to maturity. These results confirm that nutrient management significantly influences the time to maturity in sweet potato. The combined application of 2.5 t/acre cattle manure and 75 kg/acre TSP (T3S3) led to the fastest maturity at both sites, while the absence of manure and TSP delayed maturity the most. A comparison between the two sites shows consistent trends, with Trial I (Kibirigwi) and Trial II (Wambugu) producing nearly similar values. For instance, T3S3 matured in 82.89 days at Kibirigwi compared to 82.00 days at Wambugu. The slight differences may be attributed to inherent variations in soil fertility between the sites, but in both cases, nutrient supplementation accelerated maturity relative to the control.

Table 10: Days to maturity of orange-fleshed sweet potato under different cattle manure and TSP fertilizer treatments in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

Treatment	Trial I	Trial II
T3S3	82.89g	82.00g
T3S2	85.11f	85.33f
T3S1	88.33e	89.00e
T2S3	84.44f	84.00fg
T2S2	87.67e	86.00f
T2S1	94.44c	94.33c
T1S3	90.89d	92.67c
T1S2	96.00b	96.67b

T1S1	101.78a	102.00a
CV	1.67	1.40
LSD	1.41	2.17
Means	90.17	90.22
R^2	0.95	0.97

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

The significant reduction in days to maturity observed under higher nutrient regimes, particularly the integrated application of 2.5 t/acre cattle manure + 75 kg/acre TSP (T3S3), aligns with findings from previous studies. Mwangi (2025) reported that nutrient availability, especially phosphorus, plays a pivotal role in regulating the phenological development of sweet potato. The accelerated maturity under T3S3 was likely due to the synergistic effects of adequate phosphorus and organic matter, both of which are essential for vigorous vegetative growth, rapid root initiation, and expansion. These results corroborate the observations of Mutisya *et al*. (2022), who found that phosphorus application hastens root initiation and bulking, particularly in phosphorus-deficient soils. The significantly longer maturity period recorded under the control (T1S1) in both trials underscores the adverse effects of nutrient deficiency on crop development. Phosphorus deficiency, in particular, delays physiological transitions from vegetative to tuberous growth by impairing energy transfer and cell division. This observation is consistent with Ndolo *et al*. (2019), who similarly reported delayed maturity in sweet potato grown under nutrient-limited conditions without phosphorus or organic inputs.

The results also indicate that high rates of cattle manure alone (e.g., T3S1) did not produce the earliest maturity. This suggests that although cattle manure supplies organic matter and improves soil structure, it may not meet crop phosphorus demand in phosphorus-fixing soils such as nitisols. Such imbalances can stimulate excessive vegetative growth at the expense of timely tuber initiation, a trend also noted in other studies using farmyard manure as the sole amendment (Abebe *et al*., 2017; Terefe *et al*., 2022). The observed maturity range of 85–89 days under the T3 treatments falls well within the reported 80–105-day window for sweet potato across varied soil fertility conditions and agroecologies (Ndolo *et al*., 2019). From an agronomic perspective, the accelerated maturity under integrated nutrient management has important practical implications. It enables farmers to harvest earlier, create opportunities for double cropping, and minimize risks associated with terminal droughts. These outcomes are particularly valuable in smallholder systems, where shorter crop cycles can directly improve food security and household incomes. The combined application of cattle manure and phosphorus fertilizer, particularly the T3S3 treatment, significantly reduced the days to maturity of orange-fleshed sweet potato. This finding underscores the importance of balanced nutrient management in promoting earlier harvests, enhancing cropping efficiency, and improving time-to-market returns for smallholder farmers operating under resource-limited and drought-prone conditions.

4.3.2 Effect of Combined Cattle Manure and TSP Fertilizer on Tuber Diameter of Orange-Fleshed Sweet Potato

The findings of the study revealed that the combined application of cattle manure and phosphatic (triple superphosphate) fertilizer had a significant effect ($p < 0.05$) on tuber diameter in both Trial I (Kibirigwi) and Trial II (Wambugu) (Table 11). In Trial I, tuber diameter ranged from 8.21 cm under T1S1 (0 cattle manure & 0 TSP) to 9.40 cm under T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP), while in Trial II, it ranged from 8.19 cm under T1S1 to 9.29 cm under T3S3. These results demonstrate that the highest nutrient inputs consistently promoted the largest tuber diameters across both sites. Treatments T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) and T3S1 (2.5 t/acre cattle manure + 0 TSP) followed closely behind T3S3. In Trial I, tuber diameters were 9.16 cm (T3S2) and 9.02 cm (T3S1), while in Trial II they were 9.09 cm and 8.91 cm, respectively. This indicates that although TSP supplementation enhanced tuber diameter, the higher level of cattle manure was the dominant factor driving tuber size.

Moderate applications of cattle manure (1.5 t/acre; T2S treatments) also improved tuber diameter relative to the control. In Trial I, T2S2 (8.99 cm) and T2S3 (8.93 cm) were significantly larger than the control (8.21 cm), while in Trial II, T2S2 (8.94 cm) and T2S3 (8.97 cm) showed similar improvements. However, these increments were less pronounced than those achieved under the higher manure application rates. The control treatment (T1S1), with no cattle manure or TSP, consistently produced the smallest tuber diameters in both trials, highlighting the limited growth of sweet potato tubers in the absence of nutrient supplementation. The coefficient of variation (CV) for tuber diameter was higher in Trial I (3.53%) compared to Trial II (1.06%), indicating greater variability in tuber size in the first site. The coefficient of determination (R^2) values were 0.61 for Trial I and 0.94 for Trial II, suggesting a stronger and more consistent relationship between nutrient treatments and tuber diameter at Wambugu Farm than at Kibirigwi. These results confirm that tuber diameter is highly responsive to integrated nutrient management. The combined application of 2.5 t/acre cattle manure with 75 kg/acre TSP (T3S3) resulted in the largest tuber diameters across both sites, whereas the control consistently yielded the smallest. A comparison between locations showed slightly larger tuber diameters in Trial I than Trial II, suggesting that site-specific soil fertility differences may have influenced treatment effectiveness.

Table 11: Mean tuber diameter (cm) of orange-fleshed sweet potato under different cattle manure and TSP fertilizer treatments in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

Treatment	Trial I	Trial II
T3S3	9.40a	9.29a
T3S2	9.16ab	9.09b
T3S1	9.02bc	8.91c
T2S3	8.93bc	8.97c
T2S2	8.99bc	8.94c
T2S1	8.75cd	8.70d
T1S3	8.60de	8.58e
T1S2	8.37ef	8.36f
T1S1	8.21f	8.19g
CV	3.53	1.06
LSD	6.29	0.08
Means	8.83	8.78
R^2	0.61	0.94

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

The data from this study indicate that the integrated application of cattle manure and phosphorus fertilizer significantly enhances tuber diameter in orange-fleshed sweet potatoes. Across both Trial I (Kibirigwi) and Trial II (Wambugu), the T3S3 treatment (2.5 t/acre cattle manure + 75 kg/acre TSP) consistently recorded the largest tubers.

This finding is consistent with previous research, where combined organic and inorganic nutrient inputs were shown to improve root development and final tuber size in sweet potatoes (Wekesa *et al*., 2020; Boru *et al*., 2017).

The average tuber diameters observed in this study (8.2–9.4 cm) align closely with the range reported under integrated nutrient management in comparable agro-ecological zones, such as 8.0–9.5 cm documented by Mutisya *et al*. (2022). Importantly, these values surpass the commercial threshold of ≥8 cm diameter required for marketability (Gonzalez *et al*., 2018). Thus, the largest tubers produced under T3S3 are of marketable quality, providing both agronomic and economic benefits to farmers.

Moderate treatments, such as T2S3 (1.5 t/acre cattle manure + 75 kg/acre TSP), also produced sizeable tubers but consistently lagged behind T3S3. This reinforces the importance of a sufficient organic baseline for optimal tuber growth. Cattle manure plays a critical role in enhancing soil moisture retention, microbial activity, and cation exchange capacity, which are essential for tuber bulking and enlargement (Wekesa *et al*., 2020). In contrast, treatments with phosphorus alone (e.g., T1S3) did not achieve comparable tuber diameters, highlighting that phosphorus cannot fully compensate for poor soil structure or low organic matter.

The smallest tubers consistently occurred in the control (T1S1), underscoring the necessity of nutrient supplementation for root expansion and assimilate accumulation (Njoroge *et al*., 2017). From a physiological perspective, higher cattle manure rates promote slow and sustained nutrient release, while phosphorus facilitates carbohydrate translocation and root growth key processes in tuber enlargement (Singh *et al*., 2015; Abukari et al., 2024). The synergy of these mechanisms explains the superior performance of T3S3 across both sites.

Site-specific differences were also observed. Trial I (Kibirigwi) exhibited greater variability in tuber diameter (CV = 3.53%) and lower explanatory power of treatment effects ($R^2 = 0.61$) compared to Trial II (Wambugu), where variability was minimal (CV = 1.06%) and treatment effects were stronger ($R^2 = 0.94$). This suggests that Wambugu had more uniform soil conditions and treatment responses, while Kibirigwi's heterogeneity in fertility or microenvironment introduced variability. The results demonstrate that integrated nutrient management, particularly the combination of higher cattle manure rates with phosphorus (T3S3), enhances tuber diameter in orange-fleshed sweet potatoes. This strategy ensures that tubers not only meet but exceed market size standards, providing a practical and economically viable pathway for improving sweet potato production and farmer livelihoods (Ngugi *et al*., 2018; Mutisya *et al*., 2022).

4.3.3 Effect of Combined Cattle Manure and TSP Fertilizer on Tuber Dry Matter Content of Orange-Fleshed Sweet Potato

The findings of the study revealed that the combined application of cattle manure and phosphatic (TSP) fertiliser had a significant effect ($p < 0.05$) on tuber dry matter content in both Trial I (Kibirigwi) and Trial II (Wambugu) (Table 12). In Trial I, the tuber dry matter content ranged from 24.95% under T1S1 (0 cattle manure & 0 TSP) to 28.44% under T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP), while in Trial II, it ranged from 24.72% under T1S1 to 28.89% under T3S3. These results demonstrate that the highest nutrient treatments consistently resulted in the highest tuber dry matter content across both locations, underscoring the importance of nutrient supplementation.

Treatments T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) and T3S1 (2.5 t/acre cattle manure + 0 TSP) followed closely in terms of performance. In Trial I, T3S2 produced 28.17%, while T3S1 recorded 28.23%. In Trial II, T3S2 resulted in 28.03%, while T3S1 yielded 27.84%. These results indicate that both organic manure and phosphatic fertiliser had a significant influence on tuber dry matter content, with the highest values achieved when both were combined.

Moderate manure applications (T2S treatments) also enhanced tuber dry matter content, though to a lesser extent than the higher manure levels. In Trial I, T2S3 (1.5 t/acre cattle manure + 75 kg/acre TSP) produced 27.73%, while T2S2 (1.5 t/acre cattle manure + 50 kg/acre TSP) recorded 26.33%. Similarly, in Trial II, T2S3 yielded 27.70%, and T2S2 produced 27.19%. These results confirm that moderate levels of cattle manure combined with TSP increased dry matter content, though the effect was less pronounced compared to higher manure applications.

The control treatment (T1S1), with no cattle manure or TSP, consistently recorded the lowest tuber dry matter content in both trials, with 24.95% in Trial I and 24.72% in Trial II. This highlights the limitation of tuber quality in the absence of nutrient supplementation. The coefficient of variation (CV) for tuber dry matter content was 3.34% in Trial I and 3.04% in Trial II, indicating moderate variability across treatments, with Trial II showing slightly more consistent results. The coefficient of determination (R^2) values were 0.70 in Trial I and 0.73 in Trial II, suggesting a moderate to strong relationship between nutrient treatments and tuber dry matter content.

Overall, the results show that tuber dry matter content is highly responsive to integrated nutrient management. The combined application of 2.5 t/acre cattle manure and 75 kg/acre TSP (T3S3) resulted in the highest dry matter content across both sites, while the control treatments (T1S1) consistently recorded the lowest values. A comparison between the two trial sites revealed that although the overall trends were similar, dry matter content was slightly higher in Trial II (Wambugu) than in Trial I (Kibirigwi), particularly under the highest nutrient treatment (T3S3: 28.89% vs. 28.44%). This difference may be attributed to variations in baseline soil fertility between the sites, with Trial II soils likely more fertile and less variable, as reflected by the lower CV (3.04%) compared to Trial I (3.34%).

Table 12: Mean dry matter content (%) of orange-fleshed sweet potato tubers under different cattle manure and TSP fertilizer treatments in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

Treatment	Trial I	Trial II
T3S3	28.44a	28.89a
T3S2	28.17a	28.03b
T3S1	28.23a	27.84bc
T2S3	27.73a	27.70bc
T2S2	26.33b	27.19cd
T2S1	26.47b	26.92d
T1S3	25.75bc	26.12e
T1S2	25.33c	25.57e
T1S1	24.95c	24.72f
CV	3.34	3.04
LSD	0.84	0.77
Means	26.82	27.00
R^2	0.70	0.73

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre

TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

The present study shows that integrating cattle manure with phosphorus (TSP) substantially increases sweet potato tuber diameter across contrasting sites, with the highest rate combination (T3S3: 2.5 t/acre cattle manure + 75 kg/acre TSP) consistently outperforming all other treatments. These findings align with previous reports that balanced organic–inorganic inputs enhance root development and final tuber girth by improving nutrient supply, soil physical quality, and rhizosphere activity (Boru *et al*., 2017; Wekesa *et al*., 2020). The observed diameter range (≈8.2–9.4 cm) is consistent with values reported under integrated nutrient management (INM) in comparable agro-ecologies (Mutisya *et al*., 2022) and meets the widely recognized market threshold (≥8 cm) for commercial-quality tubers (Gonzalez *et al*., 2018).

The superiority of T3S3 reflects the complementarity of organic and mineral inputs. Cattle manure improves soil structure, water-holding capacity, and cation exchange, supporting sustained nutrient uptake during bulking, while phosphorus drives ATP-dependent carbohydrate synthesis and translocation to the storage root, reinforcing sink strength and tuber girth (Singh *et al*., 2015).

Recent research underscores this synergy across root crops. A 2024 integrative review of INM in horticultural systems found that manure-fertilizer combinations consistently increased root biomass and marketable yield compared with sole mineral or organic inputs, owing to concurrent improvements in nutrient supply and soil function (Sarkar *et al*., 2024). Field studies in potato also show that pairing farmyard manure with mineral blends (e.g., NPSB fertilizers) enhances tuber size distribution and marketable quality relative to mineral-only fertilization (Abebe *et al*., 2024). Similarly, cassava trials under the Joint FAO/IAEA programme (2023) demonstrated that organic-inorganic nutrient packages improve nutrient use efficiency, root uniformity, and long-term soil fertility, principles transferable to sweet potato and yam production in tropical soils. Cassava and yam studies from 2023-2024 further confirm that manure combined with mineral P delivers larger, more uniform storage organs than either input alone, particularly in P-fixing soils typical of sub-Saharan agro-ecosystems (FAO/IAEA, 2023; Van Den Broek *et al*., 2024).

Treatment rankings (T3S3 > T3S2 ≈ T3S1 > T2S* > T1S*) indicate that manure rate was the dominant driver of tuber diameter gains, with mineral P acting as a synergistic amplifier. Moderate improvements under T2S treatments highlight a dose-responsive effect, whereas treatments with high P but no manure (e.g., T1S3) failed to achieve comparable girth. This underscores the consensus that mineral P alone cannot overcome soil structural and organic matter limitations (Sanwal *et al*., 2007; Mutisya *et al*., 2022).

Site-level contrasts (higher CV and lower R^2 at Kibirigwi vs. Wambugu) suggest greater heterogeneity in the former. This aligns with FAO/IAEA (2023) guidance on tailoring INM packages to site-specific soil fertility and micro-environmental conditions for optimal response. The robust and repeatable performance of T3S3 across sites demonstrates the agronomic and economic value of organic-inorganic integration. By enhancing tuber diameter into the commercially preferred class, such regimes echo the most recent cross-crop evidence base for root and tuber systems, reinforcing their relevance for promoting orange-fleshed sweet potato quality, marketability, and profitability.

4.3.4 Effect of Combined Cattle Manure and TSP Fertilizer Combinations on Orange-Fleshed Sweet Potato tuber weight

The findings of this study highlight the significant effect ($p < 0.05$) of combined cattle manure and phosphatic fertilizer (triple superphosphate, TSP) applications on tuber weight in both Trial I (Kibirigwi) and Trial II (Wambugu) (Table 13). In Trial I, tuber weight ranged from 2.13 kg/plant in the control treatment (T1S1: 0 cattle manure + 0 TSP) to 2.82 kg/plant under the highest nutrient treatment (T3S3: 2.5 t/acre cattle manure + 75 kg/acre TSP). In Trial II, tuber weight ranged from 2.18 kg/plant (T1S1) to 2.94 kg/plant (T3S3). These results clearly indicate that the highest nutrient supplementation consistently produced the largest tubers, underlining the positive effect of integrated nutrient management.

Treatments with high manure inputs but varying TSP rates followed closely behind T3S3. In Trial I, T3S2 (2.79 kg/plant) and T3S1 (2.65 kg/plant) recorded statistically comparable yields, while in Trial II, T3S2 (2.86 kg/plant) and T3S1 (2.83 kg/plant) also produced large tubers. This pattern demonstrates that the combined use of cattle manure and TSP resulted in slightly higher tuber weights than manure alone, confirming the synergistic effect of mineral phosphorus in boosting tuber growth.

Moderate manure applications (T2S treatments) also improved tuber weight relative to the control, though the effect was less pronounced compared to T3S treatments. In Trial I, T2S3 (1.5 t/acre manure + 75 kg/acre TSP) yielded 2.784 kg/plant, while T2S2 (1.5 t/acre manure + 50 kg/acre TSP) produced 2.64 kg/plant. Similarly, in Trial II, T2S3 gave 2.80 kg/plant, and T2S2 produced 2.70 kg/plant. These findings suggest that moderate manure levels provide yield benefits but are less effective than higher manure rates when integrated with mineral phosphorus.

The control treatment (T1S1) consistently produced the smallest tubers, with 2.13 kg/plant in Trial I and 2.180 kg/plant in Trial II, confirming that the absence of nutrient supplementation severely limits tuber development. Experimental variability was greater at Kibirigwi (CV = 4.99%) than at Wambugu (CV = 1.64%), suggesting more uniform crop response under the latter site's conditions. Similarly, the coefficient of determination (R^2) was 0.76 for Trial I and 0.98 for Trial II, indicating a strong association between nutrient application and tuber weight, with Trial II showing near-perfect predictability. The slightly lower R^2 at Kibirigwi may reflect greater heterogeneity in soil fertility or environmental conditions at the site. These results demonstrate that tuber weight is highly responsive to integrated nutrient management, with the combined application of 2.5 t/acre cattle manure and 75 kg/acre TSP (T3S3) consistently producing the heaviest tubers. Conversely, the control (T1S1) produced the lightest tubers. A comparison between sites reveals that while both trials showed similar trends, Wambugu exhibited slightly higher tuber weights under all treatments and more uniform responses, likely due to relatively fertile and stable soil conditions.

Table 13: Effect of combined cattle manure and TSP fertilizer on sweet potato tuber weight (kg per plant) in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

Treatment	Trial I	Trial II
T3S3	2.82a	2.94a
T3S2	2.79a	2.86b
T3S1	2.65b	2.83bc
T2S3	2.78a	2.80c
T2S2	2.64b	2.70d
T2S1	2.57bc	2.61e
T1S3	2.47cd	2.40f
T1S2	2.36d	2.30g
T1S1	2.13e	2.18h
CV	4.99	1.64
LSD	0.12	0.04
Means	2.58	2.62
R^2	0.76	0.98

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

The results from this study clearly demonstrate a strong and consistent relationship between integrated nutrient input and tuber weight in orange-fleshed sweet potatoes. The superior performance of the T3S3 treatment (2.5 t/acre cattle manure + 75 kg/acre TSP), which produced tuber weights of 2.82 kg/plant at Kibirigwi and 2.94 kg/plant at Wambugu, highlights the effectiveness of combining organic and inorganic nutrient sources. These findings confirm earlier reports by Ndolo *et al*. (2019) and Wekesa *et al*. (2020), who observed that optimal root and tuber yields are best achieved through integrated soil fertility management (ISFM) that leverages both organic matter and mineral fertilizers.

The tuber weights achieved under T3S3 in this study are comparable, and in some cases superior, to those reported in similar agro-ecological zones. For example, Mutisya *et al*. (2022) recorded mean tuber weights ranging between 2.1 and 2.7 kg under combined nutrient regimes, while Gonzalez *et al*. (2018) noted that marketable sweet potatoes typically fall within the 2.0-2.9 kg range. The slightly higher yields observed at Wambugu may reflect more favorable soil fertility and stability, as suggested by the low variability (CV = 1.64%) and near-perfect predictability (R^2 = 0.98). These outcomes align with FAO (2023) reports emphasizing that nutrient synergy is often site-specific, with soil fertility and climatic conditions influencing the degree of response to integrated fertilizer use.

Physiologically, the improved tuber weight under T3S3 can be attributed to the complementary roles of cattle manure and phosphorus. Cattle manure contributes to soil organic matter, enhancing soil structure, water retention, microbial activity, and nutrient availability, while phosphorus plays a central role in root bulking, energy transfer, and carbohydrate translocation. This synergy improves both vegetative growth and assimilate partitioning to the storage roots, as previously demonstrated in sweet potato by Singh *et al*. (2015) and more recently in cassava and yam systems by FAO (2024). FAO's recent synthesis (2024) underscores that the co-application of organic and inorganic fertilizers enhances nutrient-use efficiency and improves carbon sequestration, while minimizing yield variability in root crops.

The performance of treatments such as T3S1 (2.65-2.83 kg/plant) and T2S3 (2.78-2.80 kg/plant) indicates that cattle manure alone or moderate levels of manure combined with phosphorus can sustain relatively high tuber weights. However, these treatments did not consistently match the yields of T3S3, reinforcing the concept that higher balanced nutrient inputs are most effective. This agrees with the ISFM framework advanced by Wekesa *et al*. (2020), which emphasizes that while organic inputs alone improve soil health, their integration with inorganic fertilizers ensures immediate nutrient supply, maximizing both short-term productivity and long-term sustainability.

The control treatment (T1S1: 0 cattle manure + 0 TSP) consistently produced the smallest tubers (2.13-2.18 kg/plant), underscoring the severe yield penalties associated with nutrient omission. This is consistent with broader evidence from African root crop systems, where nutrient deficiencies, especially phosphorus, are among the leading causes of low yields (Mutisya *et al*., 2022; FAO, 2023). These findings strongly support the adoption of integrated nutrient management for sweet potato production. The consistent superiority of T3S3 across both sites suggests that a combination of 2.5 t/acre cattle manure and 75 kg/acre TSP provides the optimal balance for maximizing tuber weight while aligning with market size expectations. These results also mirror recent FAO (2024) recommendations on root and tuber crops, which stress that integrating organic and inorganic fertilizer inputs not only increases yields but also enhances soil health and long-term resilience of production systems.

4.4 Evaluation of Quality Attributes of Orange-Fleshed Sweet Potato Tubers

The test for the fitted model indicated that it was adequate ($p < 0.05$) in explaining the relationship between treatments and the ash content, Beta-carotene content, calcium content, magnesium content and moisture content of Orange-Fleshed sweet potato tubers in Trial I and Trial II (Appendix 13). On testing the combined effect (treatments effect), the results indicated that there was significant ($p < 0.05$) effect for all variables measured across Trial I (Appendix 14). However, the blocking of the treatments was found to be effective ($p > 0.05$).

4.4.1 Effect of Combined Cattle Manure and TSP Fertilizer on Ash Content of Orange- Fleshed Sweet Potato Tubers

The findings of the study revealed that the combined application of cattle manure and phosphatic (TSP) fertilizer had a significant effect ($p < 0.05$) on ash content in both Trial I (Kibirigwi) and Trial II (Wambugu) (Table 14). In Trial I (Kibirigwi), ash content ranged from 1.50% under T2S1 (1.5 t/acre cattle manure + 0 TSP) to 4.45% under T3S1 (2.5 t/acre cattle manure + 0 TSP). The control treatment (T1S1: 0 cattle manure + 0 TSP) recorded 2.12%, which was statistically similar to T2S2 (2.12%), T1S3 (1.98%), and T2S3 (1.88%). The highest ash content was observed in T3S1, highlighting that increased manure application without TSP enhanced ash accumulation in sweet potato tubers. The relatively high coefficient of variation (CV = 11.85%) indicates moderate variability among replicates, while the coefficient of determination ($R^2 = 0.91$) shows a strong association between nutrient inputs and ash content.

In Trial II (Wambugu), ash content ranged from 0.10% under T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) to 4.80% under the control (T1S1: 0 cattle manure + 0 TSP). Treatments combining cattle manure and TSP generally resulted in lower ash contents, with T3S3 (0.80%) and T2S2 (0.83%) being statistically similar and among the lowest. By contrast, phosphorus-only treatments such as T1S2 (0.20%) and T1S3 (0.15%) recorded low values, significantly different from the control. Trial II exhibited very high model precision ($R^2 = 0.98$) and minimal variability (CV = 3.18%), suggesting highly uniform treatment effects. A notable contrast emerged in the performance of treatments across sites. For example, T3S1 (2.5 t/acre cattle manure + 0 TSP) produced the highest ash content in Trial I (4.45%) but a relatively low value in Trial II (0.38%). Similarly, T3S2 yielded 2.15% in Trial I but only 0.10% in Trial II. These differences indicate that while manure inputs strongly influenced ash accumulation in Kibirigwi, their effect was markedly less pronounced in Wambugu, where baseline soil fertility may have suppressed treatment responses.

On average, mean ash content was 2.38% in Trial I and 0.10% in Trial II, underscoring strong site-specific variation in mineral accumulation. The consistently higher control value in Trial II suggests that inherent soil nutrient reserves may have elevated ash content without fertilizer inputs, whereas Kibirigwi soils appeared more responsive to added manure. These findings demonstrate that ash content in sweet potato tubers is strongly influenced by nutrient management but also shaped by ecological and soil conditions. While higher rates of cattle manure (particularly without TSP) enhanced ash content in Kibirigwi, the control treatment dominated in Wambugu, pointing to fundamental differences in soil fertility status. The contrast between the two sites highlights the importance of tailoring integrated nutrient management strategies to local soil characteristics for optimized tuber quality.

The ash content, an indicator of the total mineral concentration in sweet potato tubers, was significantly influenced by the application of cattle manure and phosphorus (TSP) fertilizers, with outcomes varying considerably between the two trial sites. In Trial I (Kibirigwi), the application of cattle manure at 2.5 t/acre without phosphorus (T3S1) resulted in the highest ash content. This outcome can be attributed to improved soil organic matter and enhanced microbial activity that promoted mineralization and nutrient release, thereby increasing the availability of minerals to the developing tubers. These results corroborate the findings of Wekesa *et al*. (2020), who demonstrated that cattle manure enriches soil with both macro- and micronutrients, contributing to elevated ash accumulation in root crops. Similar outcomes have also been reported in cassava and yam, where organic manure application improved tuber mineral density by enhancing soil organic carbon and cation exchange capacity (Adetunji *et al*., 2022; FAO, 2023).

Table 14: Effect of cattle manure and TSP fertilizer combinations on ash content of sweet potato tubers in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

Treatment	Trial I Estimates	Trial II Estimates
T3S3	2.29c	0.80c
T3S2	2.15cd	0.10h
T3S1	4.45a	0.38e
T2S3	1.88e	1.18b
T2S2	2.12cde	0.83c
T2S1	1.50f	0.55d
T1S3	1.98de	0.15g
T1S2	2.95b	0.20f
T1S1	2.12cde	4.80a
CV	11.85	3.18
LSD	0.27	0.03
Means	2.38	1.00
R^2	0.91	0.98

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

Intermediate combinations such as T2S1 and T2S3 in Trial I yielded lower ash contents, suggesting that suboptimal rates of manure were insufficient to drive significant mineral accumulation. The moderate ash level in the control treatment (T1S1) implies that the baseline fertility of Kibirigwi soils provided some capacity for mineral uptake even without added fertilizer inputs. Trial II (Wambugu) revealed an opposite trend, where the control treatment produced the highest ash content, while combined cattle manure and TSP applications consistently reduced ash levels. This unexpected reversal may be explained by the inherent fertility status of the Wambugu soils, which might have higher native mineral concentrations or lower leaching losses compared to Kibirigwi. Moreover, manure-TSP combinations may have induced nutrient imbalances or altered rhizosphere microbial dynamics, reducing mineral uptake efficiency, as suggested by Maina *et al*. (2019). Specifically, antagonistic interactions between high phosphorus inputs and the uptake of micronutrients such as zinc, iron, and magnesium have been reported in sweet potato and other root crops (Kimani *et al*., 2017; FAO & IITA, 2024). The extremely low ash content observed in T3S2 (0.097%) supports the hypothesis that excess phosphorus combined with manure may have restricted mineral bioavailability under Wambugu's soil conditions.

Recent studies strengthen this interpretation. A 2023 FAO technical report on integrated nutrient management in root and tuber crops emphasized that excessive phosphorus fertilization, especially when combined with organic inputs, can depress micronutrient availability due to nutrient antagonism and soil pH shifts, leading to reduced mineral concentrations in tubers (FAO, 2023). Similarly, Oyedele *et al*. (2024) in Nigeria found that cassava grown under high phosphorus and manure synergy showed suppressed zinc uptake, mirroring the patterns observed in Wambugu.

These results demonstrate that while organic manure generally improves mineral content through ash accumulation, its benefits are context-dependent and can be offset by interactions with inorganic phosphorus under certain soil conditions. The contrasting outcomes between Kibirigwi and Wambugu reinforce the need for site-specific nutrient management, as also emphasized in recent regional guidelines for sustainable root crop fertilization (FAO, 2024). This implies that blanket fertilizer recommendations may not optimize tuber nutritional quality across diverse agro-ecological zones. The study shows that cattle manure at higher application rates enhances ash content in sweet potato tubers under soils responsive to organic inputs, but when combined with high phosphorus inputs in mineral-rich soils, negative interactions may suppress mineral accumulation. These findings highlight the importance of soil testing, balanced nutrient management, and adaptive fertilizer recommendations to achieve both yield and nutritional quality goals in sweet potato production.

4.4.2 Effect of Combined Cattle Manure and TSP Fertilizer on Beta-Carotene Content of Orange-Fleshed Sweet Potato Tubers in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

The findings of the study revealed that the combined application of cattle manure and phosphatic fertilizer (triple superphosphate, TSP) had a significant effect ($p < 0.05$) on the beta-carotene content of sweet potato tubers in both Trial I (Kibirigwi) and Trial II (Wambugu) (Table 15). In Trial I (Kibirigwi), beta-carotene content ranged from 60.52 µg/g under the control treatment (T1S1: 0 cattle manure + 0 TSP) to 82.53 µg/g under T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP). Treatments with higher nutrient input consistently enhanced beta-carotene levels. For instance, T3S2 (78.26 µg/g) and T3S1 (75.81 µg/g) were significantly higher than lower-input treatments such as T1S3 (67.69

µg/g) and T1S2 (66.32 µg/g). Moderate applications also contributed positively, with T2S3 (73.68 µg/g) and T2S2 (72.33 µg/g) recording relatively high values compared to the control. The coefficient of variation (CV = 4.60%) indicated relatively low variability, while the coefficient of determination ($R^2 = 0.80$) confirmed a strong treatment effect.

In Trial II (Wambugu), beta-carotene content ranged from 24.76 µg/g under the control (T1S1) to 86.94 µg/g under T3S3. The highest nutrient treatment (T3S3) again produced the greatest values, slightly surpassing Trial I. Other high-nutrient combinations such as T1S2 (64.12 µg/g), T2S1 (60.82 µg/g), and T2S3 (59.74 µg/g) also showed improved beta-carotene content compared to the control. However, certain combinations such as T3S2 (36.92 µg/g) and T1S3 (40.80 µg/g) were less effective, suggesting possible imbalances between cattle manure and TSP under the site's conditions. Trial II exhibited very high precision (CV = 0.11%) and strong explanatory power ($R^2 = 0.93$), indicating highly consistent treatment effects across replicates.

Overall, the mean beta-carotene concentration was 72.08 µg/g in Trial I and 53.80 µg/g in Trial II. The highest nutrient treatment (T3S3: 2.5 t/acre cattle manure + 75 kg/acre TSP) consistently produced the greatest beta-carotene values at both sites. By contrast, the control (T1S1) gave the lowest values in both trials, emphasizing the importance of nutrient supplementation for enhancing beta-carotene content.

Comparison between sites further highlighted ecological differences. Trial I (moderately nutrient-deficient soils) showed a gradual decrease in beta-carotene with reduced nutrient inputs, whereas Trial II (likely more fertile soils) exhibited a sharper decline, especially under the control treatment, where beta-carotene was much lower (24.76 µg/g) compared to Trial I (60.52 µg/g). The minimal variability in Trial II suggests that soil fertility and stability contributed to a more uniform treatment response. These results demonstrate that beta-carotene content in sweet potato is highly responsive to integrated nutrient management, with combined applications of cattle manure and TSP enhancing accumulation across different environments. The magnitude of response, however, was site-dependent, being more pronounced in Trial I than in Trial II.

Table 15: Effect of combined cattle manure and TSP fertilizer on Beta-carotene content (µg/100 g FW) in sweet potato tubers in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

Treatment	Trial I Estimates	Trial II Estimates
T3S3	82.53a	86.94a
T3S2	78.26b	36.92h
T3S1	75.81bc	58.77e
T2S3	73.68cd	59.74d
T2S2	72.33d	51.33f
T2S1	71.57d	60.82c
T1S3	67.69e	40.80g
T1S2	66.32e	64.12b
T1S1	60.52f	24.76i
CV	4.60	0.11
LSD	3.12	0.05
Means	72.08	53.80
R^2	0.80	0.93

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

Beta-carotene, a key provitamin A carotenoid, is strongly influenced by both genetic factors and environmental conditions, particularly nutrient availability in the soil. The present study demonstrated that the combined application of cattle manure and phosphorus fertilizer significantly enhanced beta-carotene content in sweet potato tubers across both trial sites. This observation corroborates earlier findings by Owori *et al*. (2017), who reported increased carotenoid accumulation in orange-fleshed sweet potatoes under integrated organic and inorganic fertilization. The synergistic role of manure in improving soil organic matter and microbial activity, together with phosphorus in stimulating root development and enzymatic processes, likely facilitated efficient nutrient uptake and enhanced carotenoid biosynthesis pathways (Tumwegamire *et al*., 2022; Maganga *et al*., 2021).

The consistently low beta-carotene levels under the control treatments (T1S1) in both trials underscore the detrimental effects of nutrient deficiency on carotenoid metabolism. Nutrient-poor soils restrict the supply of precursors and cofactors necessary for carotenoid synthesis, thereby limiting tuber nutritional quality. This aligns with the observations of Wekesa *et al*. (2020), who highlighted that organic amendments improve microbial activity, soil aeration, and water retention, thereby supporting metabolic processes responsible for secondary metabolite accumulation, including carotenoids. Similar conclusions have been drawn by Nakitto *et al*. (2021), who emphasized that improved soil fertility enhances carotenoid expression in biofortified crops.

Notably, site-specific responses were evident. In Trial I (Kibirigwi), beta-carotene content increased steadily with higher nutrient inputs, reflecting the benefits of supplementation in moderately nutrient-deficient soils. By contrast, in Trial II (Wambugu), the control treatment recorded much lower beta-carotene values (24.76 µg/g) compared to Trial I (60.52 µg/g), suggesting stronger environmental or edaphic limitations. Yet, the highest nutrient treatment (T3S3) in Trial II achieved the greatest beta-carotene concentration (86.94 µg/g), slightly surpassing Trial I. These differences may be attributed to site-specific variations in soil fertility, temperature, light intensity, and moisture regimes, which are known to influence carotenoid accumulation (Low *et al*., 2017; Neela & Fanta, 2019; Motsa *et al*., 2020; Laurie *et al*., 2022).

The sharp drop in beta-carotene observed in T3S2 at Wambugu (36.92 µg/g), compared to a much higher level in the same treatment at Kibirigwi (78.26 µg/g), may indicate nutrient antagonisms or imbalances in the soil. High phosphorus levels can interfere with the availability of micronutrients such as zinc and iron, both of which play roles in enzymatic regulation of carotenoid biosynthesis (Maina *et al*., 2019). Recent evidence by Nyakuni *et al*. (2023) and Kiptoo *et al*. (2021) also confirms that phosphorus–micronutrient interactions can lead to suppressed carotenoid accumulation in root crops under certain conditions. This highlights the need for balanced fertilization strategies to avoid negative nutrient interactions that may offset the benefits of fertilization.

Trial II, the T1S2 treatment (0 manure + 50 kg/acre TSP) outperformed some manure-amended treatments in beta-carotene accumulation. This suggests that phosphorus alone, under certain site conditions, may directly stimulate energy metabolism and precursor pathways for carotenoid synthesis. However, the general trend across both sites demonstrates that integrated use of cattle manure and phosphorus results in the most consistent improvements, further supporting integrated nutrient management as a sustainable approach to enhancing sweet potato nutritional quality (Musundire *et al*., 2021; Ukom *et al*., 2022).

The very low coefficient of variation (CV = 0.11%) and strong coefficient of determination (R^2 = 0.93) observed in Trial II reflect highly uniform treatment responses and strong predictability of beta-carotene accumulation under the given management practices. Such stability is advantageous for biofortification efforts and scaling nutrient management recommendations to farmers. Beta-carotene content in sweet potato tubers responded positively to increasing levels of cattle manure and phosphorus, with the highest values consistently achieved under the T3S3 treatment at both sites. Nevertheless, site-specific variations underscore the importance of tailoring fertilization strategies to local soil and climatic conditions. These findings not only reinforce the role of integrated nutrient management in improving tuber nutritional quality but also provide practical insights for biofortification and food-based approaches to combating vitamin A deficiency in vulnerable populations (HarvestPlus, 2021; Low *et al*., 2022; FAO, 2023).

4.4.3 Effect of Cattle Manure and TSP Fertilizer Combinations on Calcium Content of Orange-Fleshed Sweet Potato Tubers in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

The findings of this study revealed that the combined application of cattle manure and phosphatic fertilizer (triple superphosphate, TSP) had a significant effect ($p < 0.05$) on calcium content in both Trial I (Kibirigwi) and Trial II (Wambugu) (Table 16). In Trial I, calcium content ranged from 6.96 mg/100 g under T2S1 (1.5 t/acre cattle manure + 0 TSP) to 45.55 mg/100 g under T3S1 (2.5 t/acre cattle manure + 0 TSP). Treatments T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) and T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP) also recorded relatively high calcium levels of 30.89 mg/100 g and 35.17 mg/100 g, respectively. These findings demonstrate that higher manure levels without TSP, as well as with moderate TSP supplementation, were highly effective in boosting calcium accumulation in Kibirigwi soils.

In Trial II, calcium content varied from 3.32 mg/100 g under T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) to 42.23 mg/100 g under the control treatment T1S1 (0 cattle manure + 0 TSP). The next highest values were obtained in T1S3 (0 cattle manure + 75 kg/acre TSP) at 30.47 mg/100 g and T2S1 (1.5 t/acre cattle manure + 0 TSP) at 28.23 mg/100 g. Unlike Trial I, nutrient supplementation in Wambugu was less effective, with the control treatment showing the highest calcium levels, suggesting that inherent soil fertility strongly influenced calcium content.

Moderate manure applications (T2S treatments) produced inconsistent results across the sites. At Kibirigwi, T2S2 (1.5 t/acre cattle manure + 50 kg/acre TSP) yielded 35.35 mg/100 g, while T2S3 (1.5 t/acre cattle manure + 75 kg/acre TSP) recorded only 8.46 mg/100 g. Conversely, at Wambugu, T2S2 showed a low of 2.52 mg/100 g, while T2S3 produced 15.50 mg/100 g, further illustrating site-specific responses. The control treatment (T1S1) revealed a striking difference between sites, with Wambugu showing 42.23 mg/100 g, compared to 33.23 mg/100 g at Kibirigwi. This disparity underscores the influence of soil fertility, where Wambugu soils inherently supported higher calcium accumulation without external inputs, while Kibirigwi soils required organic and inorganic amendments for similar outcomes.

The coefficient of variation (CV) for calcium content was 10.08% at Kibirigwi and 11.74% at Wambugu, indicating moderate variability across treatments in both trials. The coefficients of determination (R^2) were 0.96 and 0.98 for Trial I and Trial II, respectively, showing a strong association between treatments and calcium accumulation. The results demonstrate that calcium content in sweet potato roots is highly responsive to nutrient management, though with strong site-specific differences. At Kibirigwi, maximum calcium content was achieved with 2.5 t/acre cattle manure alone (T3S1), while at Wambugu, the highest values were obtained in the unfertilized control (T1S1). This contrast highlights the importance of soil conditions in modulating the effects of cattle manure and TSP on calcium accumulation, with nutrient-deficient soils benefiting more from supplementation than relatively fertile soils.

Table 16: Effect of combined cattle manure and TSP fertilizer on calcium content (mg/kg) in sweet potato tubers in Trial I (Kibirigwi) and Trial II (Wambugu Farm

Treatment	Trial I	Trial II
T3S3	35.17c	16.14d
T3S2	30.89d	3.32f
T3S1	45.55a	7.14e
T2S3	8.46f	15.50d
T2S2	35.35b	2.52f
T2S1	6.96f	28.23c
T1S3	13.39e	30.47b
T1S2	33.28cd	4.10f
T1S1	33.23cd	42.23a
CV	10.08	11.74
LSD	2.55	1.84
Means	26.92	16.63
R^2	0.96	0.98

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

The variability in calcium content across treatments and sites highlights the complex interaction between soil fertility, organic and inorganic inputs, and nutrient uptake by sweet potato roots. In Trial I (Kibirigwi), the significantly higher calcium concentrations observed under treatments such as T3S1 (2.5 t/acre cattle manure + 0 TSP) and T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP) can be attributed to the positive influence of organic matter on soil nutrient dynamics. Cattle manure improves soil aggregation, water-holding capacity, and cation exchange capacity (CEC), thereby enhancing the mobility and uptake of divalent cations like calcium (Ca^{2+}). Similar observations have been reported by Mucheru-Muna *et al*. (2014), who noted that organic inputs promote nutrient bioavailability and uptake efficiency in low-input cropping systems. Recent work by Motsa *et al*. (2020) also supports this, emphasizing that manure inputs enhance nutrient buffering capacity in root crops, leading to improved mineral accumulation.

Trial II (Wambugu), the unfertilized control (T1S1) exhibited the highest calcium levels (42.23 mg/100 g), surpassing even the manure and TSP amended treatments. This contrasts with the response at Kibirigwi, underscoring the strong role of site-specific soil fertility. The elevated calcium in the control treatment at Wambugu may reflect the inherently higher baseline soil calcium content or the presence of residual fertility, which could sustain mineral accumulation without external inputs. Furthermore, the relatively lower calcium concentrations in fertilized treatments may partly be explained by a dilution effect, where enhanced biomass production reduces nutrient concentration per unit dry matter. Ndolo *et al*. (2019) reported a similar phenomenon in sweet potato, where yield-enhancing fertilization led to reduced tuber mineral concentrations despite higher absolute nutrient uptake. This suggests a trade-off between yield quantity and nutrient density that must be carefully balanced in biofortification-oriented production systems.

The reduced calcium content observed in treatments with intermediate phosphorus levels, particularly those receiving 50 kg/acre TSP (e.g., T1S2, T2S2, T3S2), may be due to antagonistic interactions between phosphorus and calcium. Excess phosphorus can reduce calcium bioavailability by precipitating as insoluble calcium phosphate, especially in acidic soils, a condition noted at both experimental sites. Wekesa *et al*. (2020) highlighted similar phosphorus-induced antagonisms, which constrained calcium and magnesium uptake in root and tuber crops. This suggests that while phosphorus is essential for root development and tuber yield, its indiscriminate application may compromise micronutrient density, thereby diminishing the nutritional benefits of orange-fleshed sweet potatoes (OFSP).

The calcium content range recorded in this study (2.5-45.5 mg/100 g) aligns with values previously reported by Woolfe (1992) and Tumwegamire *et al*. (2014), who documented tuber calcium concentrations of 20-50 mg/100 g in sweet potato landraces and improved varieties. However, the inconsistency between Kibirigwi and Wambugu under comparable nutrient regimes points to the overriding influence of site-specific conditions such as soil pH, texture, organic matter content, and baseline nutrient pools. These findings reinforce calls for site-specific nutrient management strategies, as opposed to blanket fertilizer recommendations, to optimize both agronomic performance and nutritional outcomes.

From a nutritional standpoint, maximizing calcium density in OFSP is critical, given the role of the crop in addressing micronutrient deficiencies in sub-Saharan Africa (Low *et al.*, 2022). The contrasting site responses observed here highlight that soil fertility status dictates whether nutrient supplementation enhances or diminishes mineral accumulation. Thus, integrating manure with judicious phosphorus application tailored to soil conditions is essential to enhance the dual goals of yield improvement and nutrient biofortification. The study demonstrates that calcium accumulation in OFSP is highly responsive to cattle manure and TSP application, but outcomes are strongly modulated by environmental and soil-specific factors. While manure inputs alone enhanced calcium content at Kibirigwi, the Wambugu site benefited less from external inputs, with the control treatment outperforming fertilized plots. These results emphasize the need for integrated nutrient management approaches that consider both crop physiology and site fertility, ensuring that interventions improve not only yield but also the nutritional value of sweet potato tubers.

4.4.4 Effect of Combined Cattle Manure and TSP Fertilizer on Magnesium Content in Sweet Potato Tubers

The findings of the study revealed that the combined application of cattle manure and phosphatic (triple superphosphate, TSP) fertilizer had a significant effect ($p < 0.05$) on magnesium content in sweet potato roots at both Kibirigwi (Trial I) and Wambugu (Trial II) (Table 17). In Trial I (Kibirigwi), magnesium content ranged from 22.47 mg/100 g under T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) to 72.02 mg/100 g under T2S3 (1.5 t/acre cattle manure + 75 kg/acre TSP). Similarly, in Trial II (Wambugu), magnesium levels varied between 18.78 mg/100 g under T2S2 (1.5 t/acre cattle manure + 50 kg/acre TSP) and 55.98 mg/100 g under T2S3. These results indicate that nutrient supplementation substantially enhanced magnesium accumulation, with Trial I consistently showing higher levels than Trial II, particularly under high nutrient input treatments.

Treatments involving higher manure levels also produced notable magnesium concentrations. In Trial I, T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP) and T3S1 (2.5 t/acre cattle manure + 0 TSP) recorded 28.74 mg/100 g and 25.17 mg/100 g, respectively. At Wambugu, T3S3 yielded 25.19 mg/100 g, while T3S1 resulted in 21.14

mg/100 g. This suggests that although TSP enhanced magnesium accumulation at Kibirigwi, its effect was less pronounced at Wambugu, possibly due to differences in inherent soil fertility.

Moderate manure application (1.5 t/acre) combined with high TSP (75 kg/acre) emerged as the most effective treatment across both sites. T2S3 consistently resulted in the highest magnesium content (72.02 mg/100 g in Trial I and 55.98 mg/100 g in Trial II), highlighting the synergistic benefit of integrating organic and inorganic nutrient sources. Conversely, T2S2 (1.5 t/acre cattle manure + 50 kg/acre TSP) produced relatively low values (26.56 mg/100 g in Trial I and 18.78 mg/100 g in Trial II), suggesting that intermediate fertilizer combinations may not optimize magnesium uptake. The control treatment (T1S1: 0 manure + 0 TSP) yielded intermediate magnesium concentrations of 34.76 mg/100 g at Kibirigwi and 29.20 mg/100 g at Wambugu, implying that baseline soil nutrient reserves contributed to magnesium accumulation even without external inputs. The coefficient of variation (CV) was 7.67% in Trial I and 3.03% in Trial II, reflecting relatively low variability among replicates, with Trial II exhibiting greater consistency. The coefficient of determination (R^2) values were 0.97 and 0.99 for Trials I and II, respectively, confirming a strong association between nutrient treatments and magnesium content.

Overall, the results demonstrate that magnesium content in sweet potato roots is highly responsive to cattle manure and phosphorus interactions. The most favorable outcomes were observed under moderate manure application supplemented with high TSP (T2S3), while higher manure rates combined with moderate TSP (T3S2) resulted in the lowest magnesium levels. Differences between sites further suggest that soil fertility influenced treatment responses: Kibirigwi soils appeared to benefit more from nutrient supplementation, while Wambugu exhibited lower overall values but greater stability in response to treatments.

Table 17: Effect of combined cattle manure and TSP fertilizer on magnesium content (mg/kg) in sweet potato tubers in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

Treatment	Trial I	Trial II
T3S3	28.74e	25.192e

T3S2	22.47g	20.324f
T3S1	25.17fg	21.142f
T2S3	72.02a	55.982a
T2S2	26.56ef	18.784g
T2S1	25.65f	35.572c
T1S3	51.40c	39.960b
T1S2	56.65b	19.086g
T1S1	34.76d	29.203d
CV	7.67	3.03
LSD	2.75	0.84
Means	38.16	29.47
R^2	0.97	0.99

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

The magnesium content in sweet potato roots responded significantly to the combined application of cattle manure and phosphatic fertilizer (TSP), with site-specific trends observed across Kibirigwi (Trial I) and Wambugu (Trial II). The highest magnesium accumulation occurred under moderate cattle manure application (1.5 t/acre) combined with high phosphorus (75 kg/acre TSP; T2S3) reaching 72.02 mg/100 g in Trial I and 55.98 mg/100 g in Trial II. This matches patterns reported by Wekesa *et al*. (2020) and Mutisya *et al*. (2022), where integrated organic-inorganic fertilization enhanced micronutrient uptake without exceeding previous thresholds. Despite high organic input, treatments such as T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) yielded lower magnesium levels indicating that excessive manure, without balanced phosphorus, may inhibit uptake, potentially due to nutrient lock-up or shifts in soil dynamics (Wawire *et al*., 2021). This underscores the principle that “more is not always better,” emphasizing the need for balanced nutrient inputs.

T1S2 and T1S3 treatments (0 cattle manure + moderate to high phosphorus) achieved relatively high magnesium levels suggesting phosphorus alone can modulate magnesium uptake via improved root systems. This aligns with our understanding that phosphorus enhances root surface area and mycorrhizal interactions, which facilitate uptake of secondary minerals like magnesium. Baseline soil fertility also played a key role. The control (T1S1) yielded intermediate magnesium content (34.76 mg/100 g in

Trial I; 29.20 mg/100 g in Trial II), suggesting inherent soil reserves contributed significantly to magnesium uptake. This highlights the need for context-specific fertilization strategies that account for soil background fertility.

Magnesium is vital for chlorophyll synthesis and enzyme activation in crops, and for human health supports cardiovascular function, energy metabolism, and bone health (Rosanoff *et al*., 2012). Enhancing magnesium content in orange-fleshed sweet potato (OFSP) through optimized nutrient synergy is therefore a promising strategy for improving both yield quality and nutritional impact, advancing nutrition-sensitive agricultural objectives.

4.4.5 Effect of Combined Cattle Manure and TSP Fertilizer on Sweet Potato Tubers Moisture Content

The findings of the study revealed that the combined application of cattle manure and phosphatic (triple superphosphate, TSP) fertilizer had a significant effect ($p < 0.05$) on the percentage moisture content of sweet potato roots in both Trial I (Kibirigwi) and Trial II (Wambugu Farm) (Table 18). In Trial I, moisture content ranged from 53.60% under T1S3 (0 cattle manure + 75 kg/acre TSP) to 75.03% under T3S3 (2.5 t/acre cattle manure + 75 kg/acre TSP). In Trial II, values ranged from 53.02% under T1S3 to 66.85% under T3S1 (2.5 t/acre cattle manure + 0 TSP). These results demonstrate that higher nutrient inputs consistently resulted in greater root moisture content in both trials, with Trial I showing higher overall values than Trial II.

Treatments T3S2 (2.5 t/acre cattle manure + 50 kg/acre TSP) and T3S1 (2.5 t/acre cattle manure + 0 TSP) also produced high moisture levels in both trials. In Trial I, T3S2 recorded 65.10%, while T3S1 reached 66.01%. In Trial II, T3S2 produced 63.42%, while T3S1 achieved the highest value (66.85%). This indicates that while both cattle manure and TSP contributed to higher root moisture, the combined application at maximum rates (T3S3) had the strongest effect in Trial I, whereas in Trial II the effect of TSP was less pronounced. Moderate manure applications (T2S treatments) also improved moisture relative to the control. In Trial I, T2S2 (1.5 t/acre cattle manure + 50 kg/acre TSP) produced 70.24%, while T2S3 (1.5 t/acre cattle manure + 75 kg/acre TSP) had 59.88%. In Trial II, T2S2 and T2S3 resulted in 53.74% and 56.55%, respectively. These findings suggest that moderate manure application, particularly when supplemented with TSP, enhanced moisture retention, although the effect was more pronounced in Trial I. The control (T1S1), which received no manure or TSP, had among the lowest moisture contents, recording 54.38% in Trial I and 60.79% in Trial II. This highlights that the absence of nutrient supplementation limited soil water retention and led to drier roots.

The coefficient of variation (CV) was 4.70% in Trial I and 1.61% in Trial II, indicating moderate variability at Kibirigwi but higher consistency at Wambugu. The coefficients of determination (R^2) were 0.85 (Trial I) and 0.97 (Trial II), confirming a strong relationship between nutrient treatments and moisture content, with a stronger fit in Trial II. The combined application of 2.5 t/acre cattle manure and 75 kg/acre TSP (T3S3) resulted in the highest root moisture content, while the control consistently produced the lowest values across both sites. Comparisons between the sites suggest that Trial I, with relatively nutrient-deficient soils, exhibited greater responsiveness to nutrient management, while Trial II, with more fertile soils, showed more stable and uniform responses across treatments.

Table 18: Effect of combined cattle manure and TSP fertilizer on sweet potato tubers moisture content (%) in Trial I (Kibirigwi) and Trial II (Wambugu Farm)

Treatment	Trial I Estimates	Trial II Estimates
T3S3	75.03a	65.96a
T3S2	65.10c	63.42b
T3S1	66.01c	66.85a
T2S3	59.88d	56.55e
T2S2	70.24b	53.74f
T2S1	67.41c	61.00c
T1S3	53.60e	53.02f
T1S2	60.76d	58.24d
T1S1	54.38e	60.79c
CV	4.70	1.61
LSD	2.81	0.91
Means	63.60	59.95
R^2	0.85	0.97

Where T1S1 is 0 CM & 0 TSP, T1S2 is 0 CM & 50kg/acre TSP, T1S3 is 0 CM & 75kg/acre TSP, T2S1 is 1.5 ton/acre CM & 0 TSP, T2S2 is 1.5 ton/acre CM & 50kg/acre TSP, T2S3 is 1.5 ton/acre CM & 75kg/acre TSP, T3S1- 2.5 ton/acre CM & 0 TSP, T3S2 is 2.5 ton/acre CM & 50kg/acre TSP, T3S3 is 2.5 ton/acre CM & 75kg/acre TSP. [a]Means followed by the same letter are not significantly different from each other at 5% level of significance.

The moisture content observed in this study confirms the significant role of integrated organic and inorganic nutrient management in influencing tuber water composition and quality. The highest values under T3S3, particularly in Trial I (75.03%), demonstrate that the combined application of cattle manure and phosphorus fertilizer enhances not only vegetative growth but also the capacity of sweet potato roots to retain water. This aligns with the findings of Sanwal *et al*. (2007), who reported that organic inputs improve soil physical properties, including porosity and water-holding capacity, while stimulating physiological processes that favor moisture retention in tuberous crops. Similarly, Sharma *et al*. (2020) and Ouda & Mahadeen (2008) documented that integrated nutrient management enhances water availability and tuber hydration, further supporting the present results.

Site-specific differences between the two trials suggest that environmental and soil conditions modulated treatment effects. Trial I consistently showed higher moisture values compared to Trial II, despite both being under similar nutrient regimes. For instance, T3S3 achieved 75.03% in Trial I compared with 65.96% in Trial II. These differences may be attributed to variations in soil texture, rainfall distribution, and organic matter mineralization rates. Soils at Kibirigwi (Trial I) are relatively less fertile, which may have made them more responsive to nutrient inputs, whereas soils at Wambugu (Trial II) appear to have higher inherent fertility, resulting in more stable but slightly lower moisture responses. This pattern aligns with studies by Tittonell *et al*. (2008) and Bindraban et al. (2020), who observed that nutrient-deficient soils often display greater responsiveness to external amendments, particularly organic ones that enhance soil water retention and nutrient cycling.

The performance of T3S1 (2.5 t/acre manure + 0 TSP) in Trial II (66.85%) surpassed that of T3S3, suggesting that the role of phosphorus was less pronounced under the conditions at Wambugu Farm. This indicates that in fertile soils with adequate available phosphorus, organic amendments alone may be sufficient to sustain high moisture levels. Similar observations were made by Okalebo *et al*. (2007), who emphasized the site-specific nature of phosphorus responses in root and tuber crops. Conversely, in less fertile soils (Trial I), maximum phosphorus supplementation (T3S3) clearly enhanced moisture retention, underscoring the complementary role of mineral fertilizers when baseline soil fertility is low.

Moderate manure applications (T2S series) also improved moisture retention relative to the control, though to a lesser extent than the T3 treatments. For example, T2S2 produced 70.24% in Trial I but only 53.74% in Trial II. These results confirm that both the rate and balance of nutrient inputs are critical for optimizing tuber hydration. The consistently lower values in the control (54.38% and 60.79% for Trial I and II, respectively) further emphasize that the absence of nutrient supplementation limits soil water-holding capacity and reduces root moisture content.

The coefficients of variation (CV) and determination (R^2) also highlight important differences between sites. The higher CV at Kibirigwi (4.70%) compared to Wambugu (1.61%) suggests greater variability in response, consistent with more heterogeneous soils at nutrient-deficient sites. Conversely, the stronger R^2 value in Trial II (0.97 vs. 0.85) indicates a more uniform and predictable relationship between treatments and root moisture content in the relatively fertile soils at Wambugu. This observation supports the conclusions of Vanlauwe *et al*. (2015), who noted that integrated soil fertility management tends to produce more consistent outcomes in soils with relatively higher baseline fertility.

The implications of tuber moisture content extend beyond agronomic performance from a practical standpoint. Higher moisture levels enhance consumer acceptability by improving textural quality but may also compromise post-harvest shelf life and limit suitability for processing into flour or chips. Studies such as Laurie *et al*. (2018) have shown that high-moisture sweet potato varieties are more prone to spoilage and less ideal for storage, while lower-moisture roots may be preferred for processing. Thus, while T3S3 demonstrated superior agronomic performance in terms of moisture retention, the choice of nutrient management strategy should also be guided by the intended market use and post-harvest requirements.

The results demonstrate that integrated nutrient management, particularly at higher organic and phosphorus input levels, significantly enhances sweet potato root moisture content. The superior performance of T3S3 across both trials underscores its potential as an optimal treatment for improving soil water relations and tuber hydration. However, the site-specific differences observed highlight the need for context-based nutrient recommendations, with organic inputs playing a central role in enhancing moisture retention under both low and high-fertility conditions.

CHAPTER FIVE
SUMMARY, CONCLUSION AND RECOMMENDATIONS
5.1 Summary

Sweet potato (*Ipomoea batatas* L.), particularly Orange-Fleshed Sweet Potato (OFSP), is a nutrient-rich, drought-tolerant crop with potential to address food insecurity and vitamin A deficiency in Kenya. Despite its benefits, smallholder farmers achieve low yields (~7 t/ha) due to phosphorus-deficient soils, limited fertilizer access, and inadequate integrated nutrient management. Continuous cropping without appropriate soil fertility strategies restricts both productivity and tuber quality. This study investigated the effects of combined cattle manure and phosphatic fertilizer on OFSP growth, yield, tuber quality, and profitability. By evaluating different application rates, the research aimed to provide evidence-based, cost-effective recommendations for sustainable OFSP production, enhancing household nutrition, income, and food security, while addressing site-specific soil fertility constraints and supporting adoption of integrated soil fertility management practices.

The study was conducted concurrently at Wambugu Farm (Nyeri County) and Kibirigwi Irrigation Scheme (Kirinyaga County) on nitisol soils under bi-modal rainfall. A 3×3 factorial experiment in a randomized complete block design with three replicates evaluated three levels of cattle manure (0, 1.5, 2.5 t/ha) and TSP fertilizer (0, 50, 75 kg/ha) on Orange-Fleshed Sweet Potato (OFSP). Standard agronomic practices, including weeding, earthing-up, and pest control, were applied uniformly. Data were collected on growth parameters, yield, and quality traits, including tuber weight, diameter, dry matter, beta-carotene, mineral content, ash, and moisture. Soil samples were analysed for physical and chemical properties pre-planting. Yield per hectare and economic returns were calculated, and all data were subjected to ANOVA, with significant differences determined at $p < 0.05$ using LSD.

The results of the study indicated that integrated nutrient management (INM) significantly improved both the growth and nutritional quality of orange-fleshed sweet potatoes (OFSP) compared to the control. Treatment T3S3, with 2.5 t/ha of cattle manure and 75 kg/ha of TSP, resulted in superior vine growth, with increased vine girth and length, highlighting its effectiveness in enhancing vegetative development. In terms of nutritional quality, treatment T3S3 with 2.5 t/ha of cattle manure and 75 kg/ha of TSP also yielded the highest beta-carotene content, reinforcing its potential for biofortification. Treatments T2S1 (1.5 t/ha cattle manure + 0 kg/ha TSP) and T3S1 (2.5 t/ha cattle manure + 0 kg/ha TSP), notably had improved calcium and ash content, while treatment T2S3 (1.5 t/ha cattle manure + 75 kg/ha TSP) enhanced magnesium content. These results demonstrate the synergies between nutrients, as well as the antagonistic effects observed when certain nutrients are applied in isolation.

Combining cattle manure and phosphate fertilizer improves vegetative growth and nutritional quality of OFSP, with the highest input levels being most effective overall. However, other combinations optimized specific minerals, showing that nutrient management can be tailored to desired outcomes. The study rejected the null hypotheses, affirming that integrated nutrient application significantly influences yield and quality. Recommendations include promoting balanced integrated nutrient management, farmer training on nutrient interactions, and policy support for ISFM adoption.

5.2 Conclusion

The combined application of cattle manure and phosphatic fertilizer significantly enhances both the vegetative growth and nutritional quality of orange-fleshed sweet potatoes (OFSP). Among the various treatment combinations tested, Treatment T3S3, which incorporated the highest levels of both cattle manure (2.5 t/ha) and phosphorus (75 kg/ha TSP), emerged as the most effective. It consistently promoted superior vine development and increased beta-carotene content, with the highest recorded values for vine girth, vine length, and the number of leaves. Moreover, T3S3 demonstrated enhanced nutritional quality, as evidenced by its elevated beta-carotene levels, which are crucial for biofortification. These results support the hypothesis that integrated nutrient management (INM), combining both organic and inorganic inputs, is superior to applying either input in isolation.

However, the varying responses of the mineral composition (such as calcium, magnesium, and ash content) across different treatments highlight the complexity of nutrient interactions. While the highest application of both manure and phosphorus

(T3S3) maximized overall plant growth and nutritional quality, other treatments like T3S1 (high manure, no phosphorus) and T2S3 (moderate manure, high phosphate) demonstrated specific strengths in enhancing particular mineral content, such as calcium and magnesium. These differences underscore the importance of achieving a balanced nutrient application strategy, which could further optimize sweet potato yield and nutritional value.

Given these findings, the null hypothesis (H01 and H02) which posited that there would be no statistically significant effect of the combined application of cattle manure and phosphatic fertilizer on the tuber yield and quality of OFSP can be rejected. The data clearly indicates that integrated nutrient application has a significant positive effect on both growth parameters and the nutritional quality of the sweet potatoes.

These results reinforce the relevance and efficacy of Integrated Soil Fertility Management (ISFM) for sustainable crop production in smallholder farming systems. The combination of organic and inorganic inputs not only increases yield but also improves the nutritional profile of crops, aligning with broader goals of food and nutrition security. For smallholder farmers in Kenya and similar agro-ecological regions, the adoption of INM practices could significantly enhance productivity, contributing to improved food security and nutrition, particularly by increasing the availability of vitamin A-rich OFSP varieties.

Thus, this study highlights the importance of optimizing nutrient management strategies for sweet potato cultivation. Future recommendations include the promotion of balanced nutrient application, considering soil fertility conditions and crop needs, to achieve maximum agronomic and nutritional benefits. It is also crucial for policy interventions and extension services to encourage the adoption of ISFM, providing farmers with the knowledge and tools necessary to integrate both organic and inorganic fertilization methods effectively.

5.3 Recommendation of the Study

The current study recommends the following:

i. Farmers should adopt the combination of 2.5 t/ha cattle manure and 75 kg/ha TSP to enhance growth, yield, and quality of orange-fleshed sweet potato (OFSP) especially the beta carotene content.
ii. Farmers should tailor their nutrient management strategies and practices according to the local soil conditions of an area.
iii. Farmers should incorporate Organic manure in their sweet potato cultivation as it improves soil structure and biological activity and enhances long term soil fertility.
iv. Where specific nutritional outcomes are desired, farmers could adjust their nutrient combinations, for instance, treatments with high manure but no TSP (T3S1) can be prioritized to enhance calcium and ash content, while high manure and phosphorus levels (T3S3) should be used when improving beta-carotene and vitamin A enrichment.
v. Agricultural extension service providers and policymakers should promote farmer training on Integrated Soil Fertility Management (ISFM), emphasizing the complementary roles of organic and inorganic inputs, such as manure management training, soil testing services, and input.

5.4 Recommendations for Further Studies

Further study is needed to:

i. Future research should evaluate the long-term impacts of repeated manure and phosphate fertilizer use on soil fertility, nutrient balance, and sustainability to determine the residual benefits or depletion effects over multiple cropping seasons.
ii. Further work should assess the cost–benefit ratio of different nutrient combinations to guide farmers in selecting economically viable nutrient management practices.
iii. Future research should evaluate multiple orange-fleshed sweet potato varieties to determine whether similar growth, yield, and quality responses occur across different genotypes under integrated nutrient management.

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APPENDICES

Appendix 1: Laboratory Analysis Methods for Soil Samples

The sample was tested for total nitrogen according to Bremner (1996) using the combustion procedure. Soil pH was measured using the water method (Eckert, D. and Sims, J.T., 2011), organic matter was determined using the loss-on-ignition procedure (Schulte, E.E. and Hoskins, B., 2011), and available phosphorus and potassium were tested using the Mehlich 3 (ICP) method (Wolf and Beegle, 2011). The cation exchange capacity (CEC) was measured using the summation method as described by Ross and Ketterings (2011).

Appendix 2: Oven-Drying Technique for Determining Dry Matter Content of Potato Tubers

The oven-drying technique for determining the dry matter content of potato tubers follows established methods as recommended by the International Potato Center (CIP, 2010), and has been validated in research by Woolfe (1992) and Tumwegamire *et al.* (2014).

To begin, a sample of three to five marketable tubers per plant or plot is selected after harvest. From each tuber, slices approximately 2 cm thick are cut from the midsection. These slices are then mixed together, and a composite sample weighing approximately 100 g is taken.

The fresh weight (FW) of the composite sample is immediately recorded using a digital balance. Following this, the sample is placed in a clean, labelled aluminum or porcelain dish and dried in a hot air oven at a temperature of 65–70°C for 72 hours or until constant weight is achieved. Constant weight is defined as a weight change of less than 0.1 g across two measurements. After drying, the sample is removed from the oven and allowed to cool in a desiccator for 30 minutes to prevent moisture absorption.

Once cooled, the dried sample is weighed to obtain the dry weight (DW), and this value is recorded in grams. The dry matter content is then calculated using the following formula:

Dry Matter Content (%) = (Dry Weight (g) / Fresh Weight (g)) × 100.

Appendix 3: Gravimetric Determination of Ash Content in Crop Samples

The ash content of the crop was determined gravimetrically using the dry oxidation method, also known as dry ashing, as described in method 923.03 of AOAC (1990). The procedure involved burning the samples in a muffle furnace at a high temperature of 500ºC for a specified duration.

To begin, six grams of the sample were used, distributed across three crucibles, each containing two grams of sample. The sample was placed into a dried and pre-weighed porcelain crucible. The crucibles were then placed in the muffle furnace and heated in an air atmosphere at temperatures above 500°C to burn away the organic material.

After the burning process, the crucibles were removed from the furnace and allowed to cool to room temperature in a desiccator. Once cooled, the crucibles were re-weighed. The weight of the ash residue remaining in the crucible was considered the filler unless the residue was less than 1%. Residues under 1% were typically the result of additives that did not burn off during the process.

The ash content of the sample was calculated using the following formula:
% Ash = (Weight of Ash / Weight of Original Sample) × 100

A magnified optical examination of the ash residue was performed to determine whether the ash was mineral. The total ash content was expressed as the percentage of ash content in the original sample, based on the weight of the ash and the original sample weight.

Appendix 4: Determination of Beta Carotene (Vitamin A) Content in Sweet Potato Tubers Using HPLC

The beta carotene (vitamin A) content in the tubers was determined using the protocol outlined in the AOAC (1989) method. The procedure involved mashing the tubers to prepare approximately 2.00 g of sample extracts. The extracts were then purified and diluted to a standard volume of 25 mL in a mobile phase, which was composed of methanol, dichloromethane, and water in the ratio of 79:18:3.
The prepared extracts were filtered through a 0.45-micron Millipore filter to remove any particulate matter. A 30 µL portion of the filtered extract was injected into a high-performance liquid chromatography (HPLC) system (Hitachi, model L4000H), equipped with a pump (L6000) and an RP C18 column (25 cm x 4.5 mm). The flow rate was set at 1 mL/min, and a UV/Visible detector was used to monitor β-carotene at a wavelength of 450 nm, as described by Echessa *et al*. (2013). This method allowed for the accurate determination of beta carotene content in the tuber samples.

Appendix 5: Determination of Calcium Content in Sweet Potato Tubers Using Atomic Absorption Spectroscopy (AAS)

The calcium content in the sample tuber was determined by first processing the tuber to obtain a homogeneous mixture. Approximately 2.00 g of the sample was weighed and subjected to digestion using a strong acid mixture, specifically nitric acid (HNO_3), in a microwave digestion system. This digestion method efficiently breaks down the sample matrix, releasing calcium ions into the solution (Cameron & Lichtenstein, 2017).

After digestion, the sample was filtered through a 0.45-micron Millipore filter to remove any undissolved particles. The filtrate was collected in a clean container, and its volume was adjusted to 100 mL by adding deionized water. This ensures that the sample is standardized and prepared for accurate analysis by Atomic Absorption Spectroscopy (AAS) (Singh *et al*., 2015).

A series of calcium standards with known concentrations (e.g., 0.1, 0.5, 1.0, 2.0 mg/L) were prepared using a calcium standard solution. These standards were used to create a calibration curve, which is essential for quantifying calcium levels in the sample. The calibration curve establishes a relationship between absorbance and concentration, ensuring the accuracy of the analysis (Meena & Rani, 2018).

The prepared sample extract was then introduced into the Atomic Absorption Spectrometer (AAS) (e.g., Hitachi L4000H model), where it was aspirated into a flame or graphite furnace, depending on the detection mode (flame or furnace AAS). The AAS instrument used a specific wavelength of light (e.g., 422.7 nm for calcium) to measure the amount of light absorbed by calcium atoms in the flame. This absorption is directly proportional to the calcium concentration in the sample (Patel *et al*., 2019). The flow rate of the flame was adjusted (typically around 1.0-2.0 L/min) to ensure optimal atomization of the sample. The calcium hollow cathode lamp was used as the light source, and the detector recorded the absorption, which was then correlated to the concentration of calcium in the sample.

The AAS system was calibrated using the prepared standards to obtain a calibration curve. The calcium concentration in the sample was determined by comparing the absorbance readings to the calibration curve. This calibration ensures that the relationship between absorbance and concentration is accurate, enabling reliable determination of calcium content in the sample.

The final calcium concentration in the sample was automatically calculated by the AAS system based on the calibration curve. The result was expressed in mg/kg, providing valuable information on the calcium concentration in the potato tubers. This method is widely used for the determination of calcium content in various biological and environmental samples (Ramakrishna *et al*., 2020).

Appendix 6: Determination of Magnesium Content in Sweet Potato Tubers Using Atomic Absorption Spectroscopy (AAS)

The magnesium content in the sample tuber was determined by first processing the tuber to obtain a homogeneous mixture. Approximately 2.00 g of the sample was weighed and subjected to digestion using a strong acid mixture, specifically nitric acid (HNO_3), in a microwave digestion system. This method efficiently breaks down the sample matrix, releasing magnesium ions into the solution, ensuring complete extraction of magnesium from the sample matrix (Zhang *et al*., 2018).

After digestion, the sample was filtered through a 0.45-micron Millipore filter to remove any undissolved particles. The filtrate was then collected in a clean container, and its volume was adjusted to 100 mL by adding deionized water. This step ensures that the sample is standardized and ready for accurate analysis by Atomic Absorption Spectroscopy (AAS) (Singh *et al*., 2017).

A series of magnesium standards with known concentrations (e.g., 0.1, 0.5, 1.0, 2.0 mg/L) was prepared using a magnesium standard solution. These standards were used to create a calibration curve, which is essential for quantifying magnesium levels in the sample. The calibration curve establishes the relationship between absorbance and concentration, ensuring the accuracy of the analysis (Yadav *et al*., 2020).

The prepared sample extract was introduced into an Atomic Absorption Spectrometer (AAS) (e.g., Hitachi L4000H model), where it was aspirated into a flame or graphite furnace, depending on the detection mode (flame or furnace AAS). The AAS instrument used a specific wavelength of light (e.g., 285.2 nm for magnesium) to measure the amount of light absorbed by magnesium atoms in the flame. This absorption is directly related to the magnesium concentration in the sample (Sarma *et al*., 2019). The flow rate of the flame was adjusted (typically around 1.0–2.0 L/min) to ensure optimal atomization of the sample. A magnesium hollow cathode lamp was used as the light source, and the detector recorded the absorption, which was then compared to the calibration curve to determine the magnesium concentration in the sample.

The AAS system was calibrated using the prepared magnesium standards to generate a calibration curve. The magnesium concentration in the sample was then determined by comparing the absorbance readings to the calibration curve, ensuring accurate and reliable results.

The final magnesium concentration in the sample was automatically calculated by the AAS system, and the result was expressed in mg/kg. This method is widely used for the determination of magnesium content in various biological and environmental samples (Reddy *et al*., 2021).

Appendix 7: Determination of Percentage Moisture Content in Sweet Potato Tubers Using Gravimetric Method

The percentage moisture content of the sample tuber was determined using the gravimetric method. To begin, the sample tuber was processed to obtain a homogeneous mixture. Approximately 5.00 g of the sample was weighed and placed in a pre-weighed moisture dish. The dish containing the sample was then placed in an oven set at 105°C for a specified period, typically 24 hours, to allow the moisture to evaporate. This method relies on the principle that moisture in the sample will evaporate upon heating, and the loss in weight corresponds to the amount of moisture in the sample (Chen *et al*., 2016).

After drying, the sample was removed from the oven and allowed to cool in a desiccator to prevent the absorption of moisture from the air. The weight of the sample was then recorded. The difference between the initial and final weights represents the moisture content in the sample. This difference is expressed as a percentage of the initial sample weight, calculated using the following formula:

Percentage Moisture Content = (Initial Weight - Final Weight) / Initial Weight × 100

This method provides a direct measure of the moisture content, which is essential for determining the quality and storage conditions of various food and agricultural products (Mellado *et al*., 2019).

To ensure accuracy, the process was repeated for several replicates, and the average value was calculated. The gravimetric method is widely used in food science, agriculture, and environmental studies for determining moisture content in a variety of samples, including plant tissues, soils, and food products (Yadav *et al*., 2020).

Appendix 8: National Commission of Science Technology and Innovation (NACOSTI) Research Permit

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NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **247657**

Date of Issue: **15/December/2020**

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Appendix 9: Test for model adequacy for the effect of Combined Cattle Manure and Phosphatic Fertiliser Rates on Growth Performance of Sweet Potato for two trials

Trial	Variable	Source of variation	df	SS	MS	F-value	p-value
1	Vine Girth – WK 1	Model	10	4.48499012	0.44849901	47.09	<.0001
		Error	70	0.66674568	0.00952494		
		Corrected Total	80	5.15173580			
	Vine Girth – WK 2	Model	10	6.07033086	0.60703309	54.48	<0.0001
		Error	70	0.77994568	0.01114208		
		Corrected Total	80	6.85027654			
	Vine Girth – WK 3	Model	10	7.26295556	0.72629556	111.56	<0.0001
		Error	70	0.45573333	0.00651048		
		Corrected Total	80	7.71868889			
	Vine Girth – WK 4	Model	10	10.82633086	1.08263309	87.18	<0.0001
		Error	70	0.86930864	0.01241869		
		Corrected Total	80	11.69563951			
	Vine Girth – WK 5	Model	10	13.89792346	1.38979235	164.23	<0.0001
		Error	70	0.59238272	0.00846261		
		Corrected Total	80	14.49030617			
	Vine Girth – WK 6	Model	10	15.18667901	1.51866790	159.25	<0.0001
		Error	70	0.66755309	0.00953647		
		Corrected Total	80	15.85423210			
	Vine Girth – WK 7	Model	10	17.00683457	1.70068346	179.77	<.0001
		Error	70	0.66220494	0.00946007		
		Corrected Total	80	17.66903951			
	Vine Girth – WK 8	Model	10	20.28367901	2.02836790	152.53	<.0001
		Error	70	0.93086420	0.01329806		
		Corrected Total	80	21.21454321			

	Vine Girth – WK 9	Model	10	24.56945679	2.45694568	239.04	<.0001
		Error	70	0.71949383	0.01027848		
		Corrected Total	80	25.28895062			
	Vine Girth – WK 10	Model	10	28.31496049	2.83149605	240.37	<.0001
		Error	70	0.82458272	0.01177975		
		Corrected Total	80	29.13954321			
	Vine Girth – WK 11	Model	10	32.28553827	3.22855383	343.24	<.0001
		Error	70	0.65843457	0.00940621		
		Corrected Total	80	32.94397284			
	Vine Girth – WK 12	Model	10	36.59654074	3.65965407	294.71	<.0001
		Error	70	0.86925926	0.01241799		
		Corrected Total	80	37.46580000			
	Vine Girth – WK 13	Model	10	41.45624444	4.14562444	368.66	<.0001
		Error	70	0.78715556	0.01124508		
		Corrected Total	80	42.24340000			
	Vine Girth – WK 14	Model	10	49.00985185	4.90098519	369.70	<.0001
		Error	70	0.92797037	0.01325672		
		Corrected Total	80	49.93782222			
	Vine Girth – WK 15	Model	10	48.28029630	4.82802963	440.90	<.0001
		Error	70	0.76652593	0.01095037		
		Corrected Total	80	49.04682222			
	Vine Girth – WK 16	Model	10	57.70742222	5.77074222	516.97	<.0001
		Error	70	0.78137778	0.01116254		
		Corrected Total	80	58.48880000			
	Vine Length – WK 1	Model	10	2619.674333	3473.987200	21.46	<.0001
		Error	70	854.312867	12.204470		
		Corrected Total	80	3473.987200			

	Vine Length – WK 2	Model	10	6944.257279	694.425728	88.09	<.0001
		Error	70	551.845501	7.883507		
		Corrected Total	80	7496.102780			
	Vine Length – WK 3	Model	10	10156.07792	1015.60779	148.56	<.0001
		Error	70	478.55759	6.83654		
		Corrected Total	80	10634.63551			
	Vine Length – WK 4	Model	10	18574.67860	1857.46786	180.34	<.0001
		Error	70	720.96686	10.29953		
		Corrected Total	80	19295.64545			
	Vine Length – WK 5	Model	10	23914.63880	2391.46388	243.17	<.0001
		Error	70	688.42332	9.83462		
		Corrected Total	80	24603.06212			
	Vine Length – WK 6	Model	10	32193.25887	3219.32589	268.44	<.0001
		Error	70	839.49493	11.99278		
		Corrected Total	80	33032.75380			
	Vine Length – WK 7	Model	10	33072.62265	3307.26227	360.92	<.0001
		Error	70	641.43184	9.16331		
		Corrected Total	80	33714.05449			
	Vine Length – WK 8	Model	10	39247.17026	3924.71703	569.57	<.0001
		Error	70	482.34878	6.89070		
		Corrected Total	80	39729.51903			
	Vine Length – WK 9	Model	10	46979.01881	4697.90188	716.17	<.0001
		Error	70	459.18299	6.55976		
		Corrected Total	80	47438.20180			
	Vine Length – WK 10	Model	10	55083.47221	5508.34722	660.21	<.0001
		Error	70	584.03032	8.34329		
		Corrected Total	80	55667.50254			

	Vine Length – WK 11	Model	10	57199.73932	5719.97393	779.28	<.0001
		Error	70	513.80207	7.34003		
		Corrected Total	80	57713.54140			
	Vine Length – WK 12	Model	10	60948.24159	6094.82416	737.52	<.0001
		Error	70	578.47720	8.26396		
		Corrected Total	80	61526.71879			
	Vine Length – WK 13	Model	10	65592.98883	6559.29888	627.97	<.0001
		Error	70	731.16852	10.44526		
		Corrected Total	80	66324.15735			
	Vine Length – WK 14	Model	10	66704.61249	6670.46125	665.98	<.0001
		Error	70	701.11886	10.01598		
		Corrected Total	80	67405.73135			
	Vine Length – WK 15	Model	10	71751.44480	7175.14448	689.78	<.0001
		Error	70	728.15056	10.40215		
		Corrected Total	80	72479.59536			
	Vine Length – WK 16	Model	10	77125.70516	7712.57052	956.54	<.0001
		Error	70	564.40699	8.06296		
		Corrected Total	80	77690.11216			
	Number of Leaves – WK 1	Model	10	519.5308642	51.9530864	10.70	<.0001
		Error	70	339.7530864	4.8536155		
		Corrected Total	80	859.2839506			
	Number of Leaves – WK 2	Model	10	1674.444444	167.444444	41.99	<.0001
		Error	70	279.111111	3.987302		
		Corrected Total	80	1953.555556			
	Number of Leaves – WK 3	Model	10	3071.012346	307.101235	76.90	<.0001

	Error	70	279.530864	3.993298		
	Corrected Total	80	3350.543210			
Number of Leaves – WK 4	Model	10	5064.419753	506.441975	143.05	<.0001
	Error	70	247.827160	3.540388		
	Corrected Total	80	5312.246914			
Number of Leaves – WK 5	Model	10	8874.518519	887.451852	258.44	<.0001
	Error	70	240.370370	3.433862		
	Corrected Total	80	9114.888889			
Number of Leaves – WK 6	Model	10	11566.74074	1156.67407	319.70	<.0001
	Error	70	253.25926	3.61799		
	Corrected Total	80	11820.00000			
Number of Leaves – WK 7	Model	10	13874.79012	1387.47901	327.66	<.0001
	Error	70	296.41975	4.23457		
	Corrected Total	80	14171.20988			
Number of Leaves – WK 8	Model	10	20110.04938	2011.00494	602.41	<.0001
	Error	70	233.67901	3.33827		
	Corrected Total	80	20343.72840			
Number of Leaves – WK 9	Model	10	25031.16049	2503.11605	627.49	<.0001
	Error	70	279.23457	3.98907		
	Corrected Total	80	25310.39506			
Number of Leaves – WK 10	Model	10	30567.45679	3056.74568	839.80	<.0001
	Error	70	254.79012	3.63986		
	Corrected Total	80	30822.24691			
Number of	Model	10	34829.53086	3482.95309	806.98	<.0001

	Leaves – WK 11						
		Error	70	302.12346	4.31605		
		Corrected Total	80	35131.65432			
	Number of Leaves – WK 12	Model	10	38506.79012	3850.67901	880.73	<.0001
		Error	70	306.04938	4.37213		
		Corrected Total	80	38812.83951			
	Number of Leaves – WK 13	Model	10	44032.66667	4403.26667	1344.02	<.0001
		Error	70	229.33333	3.27619		
		Corrected Total	80	44262.00000			
	Number of Leaves – WK 14	Model	10	49529.40741	4952.94074	2242.71	<.0001
		Error	70	154.59259	2.20847		
		Corrected Total	80	49684.00000			
	Number of Leaves – WK 15	Model	10	53228.00000	5322.80000	1435.52	<.0001
		Error	70	259.55556	3.70794		
		Corrected Total	80	53487.55556			
	Number of Leaves – WK 16	Model	10	61704.71605	6170.47160	1631.23	<.0001
		Error	70	264.79012	3.78272		
		Corrected Total	80	61969.50617			
2	Vine Girth – WK 1	Model	10	5.56460494	0.55646049	749.44	<.0001
		Error	70	0.05197531	0.00074250		
		Corrected Total	80	5.61658025			
	Vine Girth – WK 2	Model	10	7.33420741	0.73342074	688.26	<.0001
		Error	70	0.07459259	0.00106561		
		Corrected Total	80	7.40880000			

	Vine Girth – WK 3	Model	10	7.32766420	0.73276642	720.97	<.0001
		Error	70	0.07114568	0.00101637		
		Corrected Total	80	7.39880988			
	Vine Girth – WK 4	Model	10	8.26130864	0.82613086	1143.09	<.0001
		Error	70	0.05059012	0.00072272		
		Corrected Total	80	8.31189877			
	Vine Girth – WK 5	Model	10	10.65965679	1.06596568	1225.82	<.0001
		Error	70	0.06087160	0.00086959		
		Corrected Total	80	10.72052840			
	Vine Girth – WK 6	Model	10	11.90206667	1.19020667	1340.42	<.0001
		Error	70	0.06215556	0.00088794		
		Corrected Total	80	11.96422222			
	Vine Girth – WK 7	Model	10	12.56115309	1.25611531	1439.58	<.0001
		Error	70	0.06107901	0.00087256		
		Corrected Total	80	12.62223210			
	Vine Girth – WK 8	Model	10	12.34818519	1.23481852	1430.73	<.0001
		Error	70	0.06041481	0.00086307		
		Corrected Total	80	12.40860000			
	Vine Girth – WK 9	Model	10	12.72722963	1.27272296	1473.56	<.0001
		Error	70	0.06045926	0.00086370		
		Corrected Total	80	12.78768889			
	Vine Girth – WK 10	Model	10	12.57579012	1.25757901	1182.66	<.0001
		Error	70	0.07443457	0.00106335		
		Corrected Total	80	12.65022469			
	Vine Girth – WK 11	Model	10	12.45178272	1.24517827	1516.03	<.0001
		Error	70	0.05749383	0.00082134		
		Corrected Total	80	12.50927654			

Vine Girth – WK 12	Model	10	12.60107901	1.26010790	1413.47	<.0001
	Error	70	0.06240494	0.00089150		
	Corrected Total	80	12.66348395			
Vine Girth – WK 13	Model	10	12.89631852	1.28963185	1507.55	<.0001
	Error	70	0.05988148	0.00085545		
	Corrected Total	80	12.95620000			
Vine Girth – WK 14	Model	10	12.70867160	1.27086716	1563.63	<.0001
	Error	70	0.05689383	0.00081277		
	Corrected Total	80	12.76556543			
Vine Girth – WK 15	Model	10	12.53914074	1.25391407	1437.52	<.0001
	Error	70	0.06105926	0.00087228		
	Corrected Total	80	12.60020000			
Vine Girth – WK 16	Model	10	12.84835309	1.28483531	1476.61	<.0001
	Error	70	0.06090864	0.00087012		
	Corrected Total	80	12.90926173			
Vine Length – WK 1	Model	10	586.2792741	58.6279274	196.71	<.0001
	Error	70	20.8630815	0.2980440		
	Corrected Total	80	607.1423556			
Vine Length – WK 2	Model	10	1057.353230	105.735323	353.05	<.0001
	Error	70	20.964526	0.299493		
	Corrected Total	80	1078.317756			
Vine Length – WK 3	Model	10	1298.189227	129.818923	695.47	<.0001
	Error	70	13.066442	0.186663		
	Corrected Total	80	1311.255669			
Vine Length – WK 4	Model	10	1809.386694	180.938669	526.14	<.0001
	Error	70	24.072946	0.343899		
	Corrected Total	80	1833.459640			

	Vine Length – WK 5	Model	10	2704.742975	270.474298	1445.85	<.0001
		Error	70	13.094879	0.187070		
		Corrected Total	80	2717.837854			
	Vine Length – WK 6	Model	10	3435.870331	343.587033	1219.06	<.0001
		Error	70	19.729190	0.281846		
		Corrected Total	80	3455.599521			
	Vine Length – WK 7	Model	10	3899.503257	389.950326	1521.23	<.0001
		Error	70	17.943731	0.256339		
		Corrected Total	80	3917.446988			
	Vine Length – WK 8	Model	10	5154.988057	515.498806	2187.24	<.0001
		Error	70	16.497953	0.235685		
		Corrected Total	80	5171.486010			
	Vine Length – WK 9	Model	10	6330.845227	633.084523	2683.27	<.0001
		Error	70	16.515657	0.235938		
		Corrected Total	80	6347.360884			
	Vine Length – WK 10	Model	10	7491.403430	749.140343	3533.50	<.0001
		Error	70	14.840770	0.212011		
		Corrected Total	80	7506.244200			
	Vine Length – WK 11	Model	10	9248.536568	924.853657	4797.46	<.0001
		Error	70	13.494583	0.192780		
		Corrected Total	80	9262.031151			
	Vine Length – WK 12	Model	10	10562.35430	1056.23543	4344.11	<.0001
		Error	70	17.01993	0.24314		
		Corrected Total	80	10579.37422			
	Vine Length – WK 13	Model	10	12237.24374	1223.72437	4767.05	<.0001
		Error	70	17.96935	0.25670		
		Corrected Total	80	12255.21309			

	Vine Length – WK 14	Model	10	13909.61857	1390.96186	5221.07	<.0001
		Error	70	18.64891	0.26641		
		Corrected Total	80	13928.26748			
	Vine Length – WK 15	Model	10	15827.72082	1582.77208	4996.35	<.0001
		Error	70	22.17499	0.31679		
		Corrected Total	80	15849.89581			
	Vine Length – WK 16	Model	10	17870.84396	1787.08440	9442.87	<.0001
		Error	70	13.24766	0.18925		
		Corrected Total	80	17884.09162			
	Number of Leaves – WK 1	Model	10	551.3012272	55.1301227	236.51	<.0001
		Error	70	16.3165975	0.2330943		
		Corrected Total	80	567.6178247			
	Number of Leaves – WK 2	Model	10	856.2630741	85.6263074	293.20	<.0001
		Error	70	20.4429481	0.2920421		
		Corrected Total	80	876.7060222			
	Number of Leaves – WK 3	Model	10	1196.215319	119.621532	641.74	<.0001
		Error	70	13.048081	0.186401		
		Corrected Total	80	1209.263400			
	Number of Leaves – WK 4	Model	10	2147.753546	214.775355	952.57	<.0001
		Error	70	15.782775	0.225468		
		Corrected Total	80	2163.536321			
	Number of Leaves – WK 5	Model	10	3295.048272	329.504827	1548.84	<.0001
		Error	70	14.892012	0.212743		
		Corrected Total	80	3309.940284			

	Number of Leaves – WK 6	Model	10	4924.090768	492.409077	1809.34	<.0001
		Error	70	19.050353	0.272148		
		Corrected Total	80	4943.141121			
	Number of Leaves – WK 7	Model	10	6222.583153	622.258315	2466.33	<.0001
		Error	70	17.661072	0.252301		
		Corrected Total	80	6240.244225			
	Number of Leaves – WK 8	Model	10	7629.804190	762.980419	3655.99	<.0001
		Error	70	14.608546	0.208694		
		Corrected Total	80	7644.412736			
	Number of Leaves – WK 9	Model	10	8703.241007	870.324101	3608.06	<.0001
		Error	70	16.885148	0.241216		
		Corrected Total	80	8720.126156			
	Number of Leaves – WK 10	Model	10	11167.05331	1116.70533	4489.65	<.0001
		Error	70	17.41103	0.24873		
		Corrected Total	80	11184.46434			
	Number of Leaves – WK 11	Model	10	13724.97176	1372.49718	5033.93	<.0001
		Error	70	19.08544	0.27265		
		Corrected Total	80	13744.05720			
	Number of Leaves – WK 12	Model	10	16178.19641	1617.81964	6876.47	<.0001
		Error	70	16.46881	0.23527		
		Corrected Total	80	16194.66522			
	Number of Leaves – WK 13	Model	10	17648.06678	1764.80668	9064.96	<.0001
		Error	70	13.62791	0.19468		

		Corrected Total	80	17661.69469			
	Number of Leaves – WK 14	Model	10	20874.29711	2087.42971	8328.73	<.0001
		Error	70	17.54411	0.25063		
		Corrected Total	80	20891.84122			
	Number of Leaves – WK 15	Model	10	24265.63169	2426.56317	15314.9	<.0001
		Error	70	11.09115	0.15844		
		Corrected Total	80	24276.72283			
	Number of Leaves – WK 16	Model	10	26046.23781	2604.62378	11114.4	<.0001
		Error	70	16.40421	0.23435		
		Corrected Total	80	26062.64202			

Appendix 10: Analysis of variance for the Combined effect of Cattle Manure and Phosphatic Fertiliser Rates on Growth Performance of Orange Fleshed Sweet Potato across the two trials

Trial	Variable	Source of variation	df	SS	MS	F-value	p-value
1	Vine Girth – WK 1	Block	2	0.00314321	0.00157160	0.16	0.8482
		Treatment	8	4.48184691	0.56023086	58.82	<.0001
	Vine Girth – WK 2	Block	2	0.00612099	0.00306049	0.27	0.7606
		Treatment	8	6.06420988	0.75802623	68.03	<.0001
	Vine Girth – WK 3	Block	2	0.01935556	0.00967778	1.49	0.2332
		Treatment	8	7.24360000	0.90545000	139.08	<.0001
	Vine Girth – WK 4	Block	2	0.02449136	0.01224568	0.99	0.3782
		Treatment	8	10.80183951	1.35022994	108.73	<.0001
	Vine Girth – WK 5	Block	2	0.00699506	0.00349753	0.41	0.6631
		Treatment	8	13.89092840	1.73636605	205.18	<.0001
	Vine Girth – WK 6	Block	2	0.00049136	0.00024568	0.03	0.9746
		Treatment	8	15.18618765	1.89827346	199.05	<.0001

	Vine Girth – WK 7	Block	2	0.01943951	0.00971975	1.03	0.3633
		Treatment	8	16.98739506	2.12342438	224.46	<.0001
	Vine Girth – WK 8	Block	2	0.00426914	0.00213457	0.16	0.8520
		Treatment	8	20.27940988	2.53492623	190.62	<.0001
	Vine Girth – WK 9	Block	2	0.00030617	0.00015309	0.01	0.9852
		Treatment	8	24.56915062	3.07114383	298.79	<.0001
	Vine Girth – WK 10	Block	2	0.00463951	0.00231975	0.20	0.8217
		Treatment	8	28.31032099	3.53879012	300.41	<.0001
	Vine Girth – WK 11	Block	2	0.00758765	0.00379383	0.40	0.6696
		Treatment	8	32.27795062	4.03474383	428.94	<.0001
	Vine Girth – WK 12	Block	2	0.00849630	0.00424815	0.34	0.7115
		Treatment	8	36.58804444	4.57350556	368.30	<.0001
	Vine Girth – WK 13	Block	2	0.01708889	0.00854444	0.76	0.4716
		Treatment	8	41.43915556	5.17989444	460.64	<.0001
	Vine Girth – WK 14	Block	2	0.02136296	0.01068148	0.81	0.4509
		Treatment	8	48.98848889	6.12356111	461.92	<.0001
	Vine Girth – WK 15	Block	2	0.02000741	0.01000370	0.91	0.4058
		Treatment	8	48.26028889	6.03253611	550.90	<.0001
	Vine Girth – WK 16	Block	2	0.01508889	0.00754444	0.68	0.5120
		Treatment	8	57.69233333	7.21154167	646.05	<.0001
	Vine Length – WK 1	Block	2	3.194600	1.597300	0.13	0.8775
		Treatment	8	2616.479733	327.059967	26.80	<.0001
	Vine Length – WK 2	Block	2	5.978588	2.989294	0.38	0.6858
		Treatment	8	6938.278691	867.284836	110.01	<.0001
	Vine Length – WK 3	Block	2	3.21905	1.60953	0.24	0.7909
		Treatment	8	10152.85886	1269.10736	185.64	<.0001

	Vine Length – WK 4	Block	2	18.64634	9.32317	0.91	0.4091
		Treatment	8	18556.03225	2319.50403	225.20	<.0001
	Vine Length – WK 5	Block	2	63.79193	31.89596	3.24	0.0450
		Treatment	8	23850.84688	2981.35586	303.15	<.0001
	Vine Length – WK 6	Block	2	10.40427	5.20214	0.43	0.6498
		Treatment	8	32182.85460	4022.85683	335.44	<.0001
	Vine Length – WK 7	Block	2	4.03836	2.01918	0.22	0.8028
		Treatment	8	33068.58429	4133.57304	451.10	<.0001
	Vine Length – WK 8	Block	2	7.24434	3.62217	0.53	0.5935
		Treatment	8	39239.92592	4904.99074	711.83	<.0001
	Vine Length – WK 9	Block	2	34.68459	17.34229	2.64	0.0782
		Treatment	8	46944.33422	5868.04178	894.55	<.0001
	Vine Length – WK 10	Block	2	19.42428	9.71214	1.16	0.3182
		Treatment	8	55064.04794	6883.00599	824.98	<.0001
	Vine Length – WK 11	Block	2	15.23068	7.61534	1.04	0.3597
		Treatment	8	57184.50864	7148.06358	973.85	<.0001
	Vine Length – WK 12	Block	2	34.75649	17.37825	2.10	0.1298
		Treatment	8	60913.48510	7614.18564	921.37	<.0001
	Vine Length – WK 13	Block	2	9.91046	4.95523	0.47	0.6242
		Treatment	8	65583.07837	8197.88480	784.84	<.0001
	Vine Length – WK 14	Block	2	9.81609	4.90805	0.49	0.6147
		Treatment	8	66694.79640	8336.84955	832.35	<.0001
	Vine Length – WK 15	Block	2	7.93882	3.96941	0.38	0.6842
		Treatment	8	71743.50598	8967.93825	862.12	<.0001
	Vine Length – WK 16	Block	2	39.88287	19.94144	2.47	0.0917
		Treatment	8	77085.82229	9635.72779	1195.06	<.0001
	Number of	Block	2	5.3580247	2.6790123	0.55	0.5783

Leaves – WK 1						
	Treatment	8	514.1728395	64.2716049	13.24	<.0001
Number of Leaves – WK 2	Block	2	18.000000	9.000000	2.26	0.1122
	Treatment	8	1656.444444	207.055556	51.93	<.0001
Number of Leaves – WK 3	Block	2	14.913580	7.456790	1.87	0.1622
	Treatment	8	3056.098765	382.012346	95.66	<.0001
Number of Leaves – WK 4	Block	2	4.172840	2.086420	0.59	0.5574
	Treatment	8	5060.246914	632.530864	178.66	<.0001
Number of Leaves – WK 5	Block	2	8.074074	4.037037	1.18	0.3146
	Treatment	8	8866.444444	1108.305556	322.76	<.0001
Number of Leaves – WK 6	Block	2	8.07407	4.03704	1.12	0.3334
	Treatment	8	11558.66667	1444.83333	399.35	<.0001
Number of Leaves – WK 7	Block	2	0.02469	0.01235	0.00	0.9971
	Treatment	8	13874.76543	1734.34568	409.57	<.0001
Number of Leaves – WK 8	Block	2	8.32099	4.16049	1.25	0.2939
	Treatment	8	20101.72840	2512.71605	752.70	<.0001
Number of Leaves – WK 9	Block	2	2.76543	1.38272	0.35	0.7083
	Treatment	8	25028.39506	3128.54938	784.28	<.0001
Number of Leaves – WK 10	Block	2	5.20988	2.60494	0.72	0.4924
	Treatment	8	30562.24691	3820.28086	1049.57	<.0001
Number of Leaves – WK 11	Block	2	11.43210	5.71605	1.32	0.2726
	Treatment	8	34818.09877	4352.26235	1008.39	<.0001

	Number of Leaves – WK 12	Block	2	13.50617	6.75309	1.54	0.2206
		Treatment	8	38493.28395	4811.66049	1100.53	<.0001
	Number of Leaves – WK 13	Block	2	2.66667	1.33333	0.41	0.6672
		Treatment	8	44030.00000	5503.75000	1679.92	<.0001
	Number of Leaves – WK 14	Block	2	2.74074	1.37037	0.62	0.5406
		Treatment	8	49526.66667	6190.83333	2803.23	<.0001
	Number of Leaves – WK 15	Block	2	16.22222	8.11111	2.19	0.1198
		Treatment	8	53211.77778	6651.47222	1793.85	<.0001
	Number of Leaves – WK 16	Block	2	2.54321	1.27160	0.34	0.7157
		Treatment	8	61702.17284	7712.77160	2038.95	<.0001
2	Vine Girth – WK 1	Block	2	0.00415802	0.00207901	2.80	0.0676
		Treatment	8	5.56044691	0.69505586	936.10	<.0001
	Vine Girth – WK 2	Block	2	0.00331852	0.00165926	1.56	0.2180
		Treatment	8	7.33088889	0.91636111	859.94	<.0001
	Vine Girth – WK 3	Block	2	0.00072099	0.00036049	0.35	0.7026
		Treatment	8	7.32694321	0.91586790	901.12	<.0001
	Vine Girth – WK 4	Block	2	0.00338765	0.00169383	2.34	0.1035
		Treatment	8	8.25792099	1.03224012	1428.28	<.0001
	Vine Girth – WK 5	Block	2	0.00041728	0.00020864	0.24	0.7873
		Treatment	8	10.65923951	1.33240494	1532.21	<.0001
	Vine Girth – WK 6	Block	2	0.00020000	0.00010000	0.11	0.8937
		Treatment	8	11.90186667	1.48773333	1675.50	<.0001
	Vine Girth – WK 7	Block	2	0.00447654	0.00223827	2.57	0.0841
		Treatment	8	12.55667654	1.56958457	1798.83	<.0001

Vine Girth – WK 8	Block	2	0.00020741	0.00010370	0.12	0.8870
	Treatment	8	12.34797778	1.54349722	1788.38	<.0001
Vine Girth – WK 9	Block	2	0.00109630	0.00054815	0.63	0.5331
	Treatment	8	12.72613333	1.59076667	1841.80	<.0001
Vine Girth – WK 10	Block	2	0.00098765	0.00049383	0.46	0.6304
	Treatment	8	12.57480247	1.57185031	1478.20	<.0001
Vine Girth – WK 11	Block	2	0.00219506	0.00109753	1.34	0.2694
	Treatment	8	12.44958765	1.55619846	1894.71	<.0001
Vine Girth – WK 12	Block	2	0.00086173	0.00043086	0.48	0.6188
	Treatment	8	12.60021728	1.57502716	1766.72	<.0001
Vine Girth – WK 13	Block	2	0.00154074	0.00077037	0.90	0.4110
	Treatment	8	12.89477778	1.61184722	1884.21	<.0001
Vine Girth – WK 14	Block	2	0.00170617	0.00085309	1.05	0.3555
	Treatment	8	12.70696543	1.58837068	1954.27	<.0001
Vine Girth – WK 15	Block	2	0.00020741	0.00010370	0.12	0.8881
	Treatment	8	12.53893333	1.56736667	1796.87	<.0001
Vine Girth – WK 16	Block	2	0.00155802	0.00077901	0.90	0.4131
	Treatment	8	12.84679506	1.60584938	1845.54	<.0001
Vine Length – WK 1	Block	2	0.1768296	0.0884148	0.30	0.7442
	Treatment	8	586.1024444	73.2628056	245.81	<.0001
Vine Length – WK 2	Block	2	0.283785	0.141893	0.47	0.6246
	Treatment	8	1057.069444	132.133681	441.19	<.0001
Vine Length – WK 3	Block	2	0.482225	0.241112	1.29	0.2813
	Treatment	8	1297.707002	162.213375	869.02	<.0001
Vine Length – WK 4	Block	2	1.210299	0.605149	1.76	0.1796
	Treatment	8	1808.176395	226.022049	657.23	<.0001

Vine Length – WK 5	Block	2	1.142943	0.571472	3.05	0.0535
	Treatment	8	2703.600032	337.950004	1806.55	<.0001
Vine Length – WK 6	Block	2	1.384365	0.692183	2.46	0.0931
	Treatment	8	3434.485965	429.310746	1523.21	<.0001
Vine Length – WK 7	Block	2	0.055536	0.027768	0.11	0.8975
	Treatment	8	3899.447721	487.430965	1901.51	<.0001
Vine Length – WK 8	Block	2	0.259091	0.129546	0.55	0.5796
	Treatment	8	5154.728965	644.341121	2733.91	<.0001
Vine Length – WK 9	Block	2	0.253188	0.126594	0.54	0.5871
	Treatment	8	6330.592040	791.324005	3353.95	<.0001
Vine Length – WK 10	Block	2	0.007607	0.003804	0.02	0.9822
	Treatment	8	7491.395822	936.424478	4416.87	<.0001
Vine Length – WK 11	Block	2	0.129128	0.064564	0.33	0.7165
	Treatment	8	9248.407440	1156.050930	5996.74	<.0001
Vine Length – WK 12	Block	2	1.24590	0.62295	2.56	0.0844
	Treatment	8	10561.10840	1320.13855	5429.50	<.0001
Vine Length – WK 13	Block	2	0.24050	0.12025	0.47	0.6279
	Treatment	8	12237.00324	1529.62541	5958.69	<.0001
Vine Length – WK 14	Block	2	0.71845	0.35922	1.35	0.2663
	Treatment	8	13908.90012	1738.61252	6526.01	<.0001
Vine Length – WK 15	Block	2	0.77270	0.38635	1.22	0.3015
	Treatment	8	15826.94812	1978.36852	6245.13	<.0001
Vine Length – WK 16	Block	2	1.31232	0.65616	3.47	0.0367
	Treatment	8	17869.53164	2233.69146	11802.7	<.0001
Number of Leaves – WK 1	Block	2	0.0832914	0.0416457	0.18	0.8368
	Treatment	8	551.2179358	68.9022420	295.60	<.0001

Number of Leaves – WK 2	Block	2	0.1471185	0.0735593	0.25	0.7780
	Treatment	8	856.1159556	107.0144944	366.44	<.0001
Number of Leaves – WK 3	Block	2	1.146719	0.573359	3.08	0.0524
	Treatment	8	1195.068600	149.383575	801.41	<.0001
Number of Leaves – WK 4	Block	2	0.058714	0.029357	0.13	0.8781
	Treatment	8	2147.694832	268.461854	1190.69	<.0001
Number of Leaves – WK 5	Block	2	0.717277	0.358638	1.69	0.1927
	Treatment	8	3294.330995	411.791374	1935.63	<.0001
Number of Leaves – WK 6	Block	2	0.859558	0.429779	1.58	2261.28
	Treatment	8	4923.231210	615.403901	2261.28	<.0001
Number of Leaves – WK 7	Block	2	0.307795	0.153898	0.61	0.5462
	Treatment	8	6222.275358	777.784420	3082.76	<.0001
Number of Leaves – WK 8	Block	2	0.193588	0.096794	0.46	0.6308
	Treatment	8	7629.610602	953.701325	4569.87	<.0001
Number of Leaves – WK 9	Block	2	0.320452	0.160226	0.66	0.5179
	Treatment	8	8702.920556	1087.865069	4509.91	<.0001
Number of Leaves – WK 10	Block	2	0.83983	0.41992	1.69	0.1923
	Treatment	8	11166.21348	1395.77668	5611.63	<.0001
Number of Leaves – WK 11	Block	2	0.86223	0.43111	1.58	0.2130
	Treatment	8	13724.10953	1715.51369	6292.02	<.0001
Number of Leaves – WK 12	Block	2	0.17334	0.08667	0.37	0.6932

		Treatment	8	16178.02307	2022.25288	8595.50	<.0001
	Number of Leaves – WK 13	Block	2	0.06607	0.03303	0.17	0.8443
		Treatment	8	17648.00071	2206.00009	11331.2	<.0001
	Number of Leaves – WK 14	Block	2	0.04336	0.02168	0.09	0.9172
		Treatment	8	20874.25376	2609.28172	10410.9	<.0001
	Number of Leaves – WK 15	Block	2	0.09763	0.04882	0.31	0.7358
		Treatment	8	24265.53405	3033.19176	19143.5	<.0001
	Number of Leaves – WK 16	Block	2	1.46601	0.73300	3.13	0.0500
		Treatment	8	26044.77180	3255.59647	13892.3	<.0001

Appendix 11: Test for model adequacy for Yield and Yield Components of Orange Fleshed Sweet Potato for two trials

Trial	Variable	Source of variation	df	SS	MS	F-value	p-value
1	Days to maturity	Model	10	2779.604938	277.960494	123.17	<.0001
		Error	70	157.975309	2.256790		
		Corrected Total	80	2937.580247			
	Tuber Diameter	Model	10	10.66407901	1.06640790	10.97	<.0001
		Error	70	6.80615309	0.09723076		
		Corrected Total	80	17.47023210			
	Tuber Dry Matter	Model	10	131.2572963	13.1257296	16.34	<.0001
		Error	70	56.2215037	0.8031643		
		Corrected Total	80	187.4788000			
	Tuber Weight	Model	10	3.75222963	0.37522296	22.66	<.0001
		Error	70	1.15897037	0.01655672		
		Corrected Total	80	4.91120000			
2	Days to maturity	Model	10	1058.000000	132.250000	83.04	<.0001
		Error	70	28.666667	1.592593		

		Corrected Total	80	1086.666667			
	Tuber Diameter	Model	10	9.06046667	0.90604667	103.84	<.0001
		Error	70	0.61075556	0.00872508		
		Corrected Total	80	9.67122222			
	Tuber Dry Matter	Model	10	126.5102227	12.6510223	18.79	<.0001
		Error	70	47.1264289	0.6732347		
		Corrected Total	80	173.6366516			
	Tuber Weight	Model	10	5.24118519	0.52411852	284.91	<.0001
		Error	70	0.12877037	0.00183958		
		Corrected Total	80	5.36995556			

Appendix 12: Analysis of variance for Yield and Yield Components of Orange Fleshed Sweet Potato for two trials

Trial	Variable	Source	Df	SS	MS	F-value	p-value
1	Days to maturity	Block	2	2.691358	1.345679	0.60	0.5536
		Treatment	8	2776.913580	347.114198	153.81	<.0001
	Tuber Diameter	Block	2	0.20440247	0.10220123	1.05	0.3550
		Treatment	8	10.45967654	1.30745957	13.45	<.0001
	Tuber Dry Matter	Block	2	0.8614741	0.4307370	0.54	0.5873
		Treatment	8	130.3958222	16.2994778	20.29	<.0001
	Tuber Weight	Block	2	0.03842963	0.01921481	1.16	0.3193
		Treatment	8	3.71380000	0.46422500	28.04	<.0001
2	Days to maturity	Block	2	0.0000000	11.18603		
		Treatment	8	691.7777778	115.2962963	72.40	<.0001
	Tuber Diameter	Block	2	0.00246667	0.00123333	0.14	0.8684
		Treatment	8	9.05800000	1.13225000	129.77	<.0001
	Tuber Dry Matter	Block	2	1.1000222	0.5500111	0.82	0.4459
		Treatment	8	125.4102005	15.6762751	23.29	<.0001
	Tuber Weight	Block	2	0.00320741	0.00160370	0.87	0.4227
		Treatment	8	5.23797778	0.65474722	355.92	<.0001

Appendix 13: Test for model adequacy for Quality variable of Orange Fleshed Sweet Potato mineral elements for two trials

Trial	Variable	Source of variation	df	SS	MS	F-value	p-value
1	Ash Content	Model	10	53.75196790	5.37519679	67.42	<.0001
		Error	70	5.58068642	0.07972409		
		Corrected Total	80	59.33265432			
	Beta Carotene	Model	10	3167.110323	316.711032	28.78	<.0001
		Error	70	770.199746	11.002854		
		Corrected Total	80	3937.310069			
	Calcium	Model	10	13550.47616	1355.04762	184.02	<.0001
		Error	70	515.46020	7.36372		
		Corrected Total	80	14065.93636			
	Magnesium	Model	10	22254.34838	2225.43484	259.63	<.0001
		Error	70	600.00051	8.57144		
		Corrected Total	80	22854.34888			
	Moisture Content	Model	10	3643.045501	364.304550	40.72	<.0001
		Error	70	626.186975	8.945528		
		Corrected Total	80	4269.232477			
2	Ash Content	Model	10	155.7445503	15.5744550	15461.0	<.0001
		Error	70	0.0705138	0.0010073		
		Corrected Total	80	155.8150641			
	Beta Carotene	Model	10	23558.80252	2355.88025	724026	<.0001
		Error	70	0.22777	0.00325		
		Corrected Total	80	23559.03029			
	Calcium	Model	10	14479.47476	1447.94748	379.72	<.0001

		Error	70	266.92089	3.81316		
		Corrected Total	80	14746.39565			
	Magnesium	Model	10	11196.97016	1119.69702	1400.93	<.0001
		Error	70	55.94767	0.79925		
		Corrected Total	80	11252.91782			
	Moisture Content	Model	10	1787.669331	178.766933	191.19	<.0001
		Error	70	65.450798	0.935011		
		Corrected Total	80	1853.120128			

Appendix 14: Analysis of variance for Quality variable of Orange Fleshed Sweet Potato mineral elements for two trials

Trial	Mineral element	Source	Df	SS	MS	F-value	p-value
1	Ash Content	Block	2	0.02333580	0.01166790	0.15	0.8641
		Treatment	8	53.72863210	6.71607901	84.24	<.0001
	Beta Carotene	Block	2	0.02333580	0.01166790	0.15	0.8641
		Treatment	8	53.72863210	6.71607901	84.24	<.0001
	Calcium	Block	2	10.98454	5.49227	0.75	0.4781
		Treatment	8	13539.49162	1692.43645	229.83	<.0001
	Magnesium	Block	2	22.27094	11.13547	1.30	0.2793
		Treatment	8	22232.07744	2779.00968	324.22	<.0001
	Moisture Content	Block	2	5.112402	2.556201	0.29	0.7523
		Treatment	8	3637.933099	454.741637	50.83	<.0001
2	Ash Content	Block	2	0.0016057	0.0008028	0.80	0.4547
		Treatment	8	155.7429446	19.4678681	19326.0	<.0001
	Beta Carotene	Block	2	14.715054	7.357527	0.67	0.5156
		Treatment	8	3152.395269	394.049409	35.81	<.0001
	Calcium	Block	2	22.37207	11.18603	2.93	0.0598

	Treatment	8	14457.10269	1807.13784	473.92	<.0001
Magnesium	Block	2	4.96202	2.48101	3.10	0.0511
	Treatment	8	11192.00813	1399.00102	1750.39	<.0001
Moisture Content	Block	2	0.391825	0.195912	0.21	0.8115
	Treatment	8	1787.277506	223.409688	238.94	<.0001