UNIVERSITY FOR DEVELOPMENT STUDIES

EVALUATING THE EFFECT OF ROCK PHOSPHATE AND TRIPLE SUPERPHOSPHATE SUBSTITUTION AND OTHER NUTRIENTS ON COWPEA PERFORMANCE IN GHANA'S GUINEA SAVANNA AGROECOLOGY

AYAABA ADAKUDUGU ATONGI

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BY

AYAABA ADAKUDUGU ATONGI

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THESIS SUBMITTED TO THE DEPARTMENT OF CROP SCIENCE, FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

MARCH, 2026

DECLARATION

I hereby declare that this work is the result of my own research and the thesis, either in full or part, has never been presented in any other institution for a degree. All other references made from other research have accordingly been cited.

Ayaaaba Adakudugu Atongi ………………… 27/07/2026

(Student) Signature Date

Supervisor

I hereby declare that the preparation and presentation of the thesis was supervised following the guidelines on supervision of thesis laid down by the University for Development Studies.

Prof. Raphael Adu-Gyamfi ………………… 27/11/2026

(Supervisor) Signature Date

ABSTRACT

Cowpea (Vigna unguiculata L. Walp) is a crucial legume crop in Ghana, contributing significantly to food security due to its nutritional and economic value. However, productivity is hindered by low soil fertility, mainly phosphorus depletion and insufficient micronutrient use, particularly zinc and boron. The study evaluated cowpea's response to Triple Super Phosphate (TSP) and its substituted forms for Rock Phosphate (RP) in combination with potassium and micronutrients (Zn and B) in phosphorus- depleted lixisols at Nyankpala and Kokpeng in Northern Ghana. The treatments including three OCP compound fertilizers, were 16 and were laid out using randomized complete block design with 4 replications. The results, indicated significant effects ($P < 0.05$) of fertilizer treatments on growth parameters measured, chlorophyll content, root characteristics and grain yield. Notably, compound fertilizers with micronutrients NKP (14:18:18) + TE and NPS (14:31:5) + TE improved root length and nutrient uptake efficiency. Optimal grain yields (over 2,500 kg/ha in Nyankpala) were achieved with specific combinations of TSP and RP, particularly in 80% TSP + 20% RP + K + TE and 60% TSP + 40% RP + K + TE treatments. The study also found that 100% RP + K + TE outperformed 100% TSP in grain yield, indicating the efficiency of RP combined with K and the micronutrients. Economic analysis revealed that 100% RP gave a favourable marginal rate of return of 475%. Integrating phosphorus sources with K, Zn, and B can significantly enhance crop growth, improve root development, and increase grain yield in the Guinea Savanna agroecological zone. The study recommends the use of Zn, B, and rock phosphate as a cheaper P source in place of TSP for improved cowpea growth and yield. Further research on the use of rock phosphate should be conducted in Northern Ghana.

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DEDICATION

This work is dedicated to my beloved Parents, Late Chief Adakudugu Aperiga (Father) may his soul rest in perfect peace, and Mma Zinabu Atubiga (Mother)

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

A multitude of people who live in tropical and subtropical climates depend on cowpeas, an essential annual legume crop (Horn *et al.,* 2022). Regardless of having originated in sub-Saharan Africa, cowpea is currently grown in more than 100 nations (Badiane *et al.,* 2019). It is frequently considered as a substitute source of protein and energy for animals during the cold and dry seasons (Morris *et al.,* 2020). It has appreciable quantity and quality haulm that makes it suitable for mixed crop-livestock systems (Samireddy palle *et al.,* 2017).

It is crucial for human health benefits, food security, and generating revenue for local farmers and food sellers. It is essential to the assistance of all the different value chain participants, such as farmers, processors, dealers, and food sellers (Nwagboso *et al.,* 2024).

The grain has a protein content of 25%, high in carbohydrates, vitamins, and minerals, and complements a diet high in cereal in nations where cowpeas are grown as a major food crop (Morris *et al.,* 2020). People also eat the young, green leaves and pods as a vegetable (Bassi *et al.,* 2024).

Although plants only need a small quantity of micronutrients, their availability is nonetheless necessary for improved plant development and increased agricultural yield (Assunção *et al.,* 2022). Zinc is a micronutrient that is necessary for plants in modest amounts as it encourages plant growth, development, and yield in addition to supporting a number of cellular and physiological processes in plants. For many proteins and enzymes, zinc is a crucial structural, enzymatic, and regulatory element (Saleem *et al.,* 2022). However, it is crucial for several physiological and biochemical activities, including protein synthesis and the activation of enzymes that affect different cellular functions. A sufficient amount of zinc is necessary for optimal enzymes activity, effective photosynthesis and regulations of plant hormone levels such as gibberellins, cytokinin and auxins (Elsheery *et al.,* 2020; Prasad, 2022). Zinc helps in the preservation of hormone equilibrium, which in turn impacts the growth of shoots, roots and flowers in lentil plants. It is also necessary for nitrogenase activity, which is the enzyme in charge of nitrogen fixation in the nodules (Basu and Kumar, 2020; González-Guerrero *et al.,* 2014).

Boron is an essential element that plants require inlow quantities, yet it plays multiple crucial roles in plant physiology. According to Bolaños *et al.,* 2023 and Matthes *et al*., 2022), Boron has a role in the synthesis, cross-linking, and preservation of the strength and structural integrity of cell walls. In addition to improving the intake of vital minerals like calcium and magnesium and the flow of sugars and other metabolites throughout the plant it contributes to the creation and elongation of pollen tubes, which are in charge of transporting sperm cells to the ovules. This promotes the general growth and development of the plant by making it easier for nutrients to reach various plant components. Boron helps in improving plant resistance to a variety of abiotic stressors, including drought, high temperatures and nutritional imbalances (Noreen *et al*.,2018; Ramirez-Builes *et al.,* 2024; Shafi and Zahoor, 2020).

According to Razaq *et al*., (2017), phosphorus (P) is the second important element needed for plant growth and development. Rock phosphorus (RP) combined with single super phosphate (SSP) can increase crop yield and P availability. The SSP can also help long term accessible P during a crop cycle (Sarkar *et al.,* 2024). In addition, it is well recognized to be accessible, affordable and to have a less carbon footprint than other P sources (Jarvie *et al*., 2019; Oppong *et al.,* 2023; Sarkar *et al.,* 2024).

Moreover, research conducted by Chtouki *et al*. (2022) shows that, plants treated with RP showed enhanced plant growth, root nodulation, and nutrient absorption at the flowering stage.

In acidic, fertile highland soils, Evate rock phosphate (EVP) has been shown in studies by Rocha *et al.* (2024) to be 25% more effective than triple superphosphate (TSP) on a total P basis. This makes Evate rock phosphate a useful amendment that may improve food grain production.

The root system is an essential part of plants, it is responsible for anchorage of the plant to the surface on which it grows, it also helps the process of water and nutrient uptake from the soil and involved in the biotic interactions between the inhibits pathogen and pests' penetration into the plant (Ma *et al*., 2014; Radhakrishnan *et al.,* 2014). In some species, the root functions as reservoir of nutrients in addition for example, some of the cassava roots store starch. The root system also contributes to soil health which refers to the capacity of the soil to function as a living ecosystem that sustains microorganisms, plants and animals (Xue *et al.,* 2014; Saikia *et al.,* 2015).

The root system is system is also explored for soil erosion control (Ola *et al*,.2015). Some plants can absorb heavy metals and other toxic compounds from the soil and accumulate the substances in aerial parts which can then be harvested and disposed off in a process known as soil phyto-remediation (Glick, 2003). Roots are capable of actively foraging resources from their environment and their system is the interface between nutrient in the soil and the ability to achieve yield in plants (Lynch, 1995). The availability of nutrients in the soil solution determines root growth and proliferation (Akpan and Mbah, 2016).

The length of the root is related to the amount of nutrient the plant can take in, while the limit to which the root grows affect the plant productivity and yield (Lynch, 1995; Hodge *et al.,* 2009). Quantifying the morphology and spatial distribution of the rooting system (root architecture) is important as a means of determining the availability and accessibility of water and nutrients and hence improving crops and managing soils for higher crop yield (Gregory, 2009). According to Soares et al. (2017), the root architecture includes the entire root system or a large part of the rooting system of an individual plant. This character has not been measured in most crops in the humid rainforest zone of Nigeria, most especially, no study has focused on the relationship between cowpea yield and its root traits. Crop yield is a quantitative trait, and its improvement depends on selecting traits with high heritability and strong correlation with yield. The root system arises from the coordinated control of an endogenous genetic system and the action of environmental stimuli such as PH, temperature, water level microbial and chemical constituents (Paez-Gracia *et al.,* 2015). The nutrient level, health and type of substrate strongly influence the rooting traits, that is, the root growth, structure and architecture of the root system as such, a healthy root system play vital role in the crop productivity. Most plant breeding efforts fail to focus on the relationship between root system and crop yield, probably because of the underground location of the root system. Paez-Gracia *et al.* (2015) reported that, plant breeding efforts centered on the modification of root traits to increase crop yield can results in the development of more stress tolerant crops and enhance the capacity of the plant to explore the soil for better absorption of water and nutrients. The ability to improve root traits to translate into higher yields would be a remarkable accomplishment for the breeder, such as parental lines with the desirable root characters can be selected as breeding lines to be advanced through the crop improvement process.

1.2 Problem statement

Cowpea is generally adapted to poor soils and its tolerance to drought, makes its cultivation attractive to the northern parts of Ghana. Production in Ghana is increasing and consumption is also at an all–time high, raising hopes over the sustainability of a key source of plant protein for millions of Ghanaians (FAO, 2013; 2018). Despite its importance, cowpea production in northern Ghana is faced with numerous constraints such as insect pests, diseases, and soil fertility decline limiting grain yield (Anago *et al.,* 2021). The combination of these stresses can cause complete crop loss if not properly managed. In Ghana, the prevalence of zinc deficiency is about 13% to 17% among pregnant women (Gernand *et al.,* 2017, 2019).

Micronutrient deficiencies can have severe consequences on plant growth, yield, and human health (Shukla *et al.,* 2018). The inclusion of micronutrients, especially Zn and B in Triple super phosphate, Rock phosphate and Potassium fertilization regimes for cowpea cultivation is not yet a standard practice. Lack of inclusion of these micronutrients could potentially limit the growth and yield of cowpea crops, as they play an important role in plant physiological processes.

1.3 Justification

Zinc and Boron are essential micronutrients that play significant roles in plant growth and development (Naz *et al.,* 2022). Zinc is involved in protein synthesis, energy production, and the regulation of plant growth hormones. Boron, on the other hand, is vital for the stability and functionality of plant cell walls, protein synthesis, and the transport of sugars and nutrients (García-Sánchez *et al.,* 2020).

Despite their importance, the inclusion of these micronutrients in fertilization regimes, particularly those involving TSP, Rock Phosphate, and Potassium, is often overlooked. This oversight can lead to micronutrient deficiencies, negatively impacting cowpea crop health and yield. Furthermore, the soil types where cowpea is commonly grown may not naturally possess sufficient levels of these micronutrients. Therefore, the addition of Zinc and Boron in the fertilization process could be a critical factor in optimizing cowpea production Debnath *et al.,* 2018.

In conclusion, there is a compelling need for research and development efforts to investigate the effects and benefits of micronutrients including Zinc and Boron in TSP, Nitrogen, Rock Phosphate, and Potassium fertilization regimes for cowpea cultivation. Such efforts could lead to improved crop health, increased yields, and ultimately, enhanced food security Singh *et al*., 2025.

1.4 Objectives

Main Objective

The main objective of the study was to evaluate the effects of TSP, RP, K, and micronutrients (Zn and B), on the growth and yield of Cowpea.

The specific objectives of this study were to:

i. Evaluate the effect of TSP and Rock phosphate (RP) and their combined application on the growth and development of cowpea

ii. Assess the effect of TSP, RP, and K fertilization regimes on root architecture, growth, and yield of cowpea

iii. Evaluate the effect of micronutrient (Zn and B) inclusion in TSP, RP and potassium fertilization regimes on root architecture, growth and yield of cowpea

iv. Assess the economic viability of TSP, RP, potassium and micro nutrient inclusion in cowpea production

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution of cowpea

Globally, cowpea (*Vigna unguiculata* L. Walp) is one of the widely cultivated legumes. The two most cultivated subspecies are; unguiculata and sesquipedialis. Although it is known to have originated from Africa, its center of domestication remains unknown (Lush and Evans, 1981). Additionally, Summerfield *et al.*. (1974) has stated that there is a lot of uncertainty regarding the actual origin of cowpea. He stated that the contradictory views supporting Africa, Asia and South America as its origin results from the lack of concrete archaeological evidence to support these claims. Cowpea found in Asia are different from those in Africa implying that Asia could be an independent center of origin from African genotypes (Doumbia, 2012). According to Schippers (2002) cowpea remains the most popular leguminous crop with an African origin. He stated that cowpea was initially taught to have originated from India, evidence later placed its origin at Ethiopia in East Africa. Kitch *et al.*. (1998) also reported that, the widely cultivated cowpea species, *unguiculata,* is thought to be domesticated West African Neolithic, whose progenitors were the wild weed species *dekindtiana* and *meusensis*. The slave trade from West Africa is believed to have resulted in the crop reaching the southern USA early in the 18th century.

The suggestion that cowpea could have been domesticated from any part of sub-Saharan Africa resulted from the wide geographical distribution of various *dekindtiana.* However, the centre of maximum diversity of cultivated cowpea is found in West Africa, in an area encompassing the savannah region of Nigeria, southern Niger, part of Burkina Faso, northern Benin, Togo, and the north western part of Cameroon (Ng and Marechal, 1985). Carbon dating of cowpea (or wild cowpea remains from the Kintampo rock shelter in central Ghana) has been carried out (Flight, 1976), and is the oldest archaeological evidence of cowpea found in Africa, as this shows the existence of gathering (if not cultivation) of cowpea by African hunters or food gatherers as early as 1500 BC.

2.2 Botany and taxonomy

The cowpea is classified as a Dicotyledonea and is found in the Fabales order, Fabaceae family, subfamily *Faboideae*, tribe *Phaseoleae*, subtribe *Phaseolinae*, genus *Vigna*, and section Catiang (Marechal, 1978; Verdcourt, 1970). Under *V. unguiculata* subspecies *unguiculata*, which is further classified into four cultigroups—*Unguiculata*, *Biflora*, *Sesquipedalis*, and *Textilis*—all cultivated cowpeas are categorized (Marechal, 1978; Ng and Marechal, 1985). The three subspecies *dekindtiana*, tenuis, and *stenophylla* identified by Marechal *et al.* (1978) were kept in the nomenclature and classification scheme suggested by Padulosi (1993). However, var. protracta and var. pubescens were raised to the status of two distinct subspecies due to their very unique hairy qualities in pods and other plant parts, as well as their morphology of flowers, pollen, grains, and leaves, as well as their root systems.

More than 15,000 accessions from 90 different nations are kept in storage at the International Institute of Tropical Agriculture (IITA) (Boukar *et al.,* 2015).

Molecular characterisation is becoming increasingly popular in cowpea breeding lately. The complicated evolutionary history of cowpea can understood by using simple sequence repeat markers, as demonstrated by the work of Quenum *et al.* (2024) for the molecular characterization of cowpea subspecies. According to the research conducted by Quenum *et al.* (2024), SSRs were unable to distinguish between the closest groupings subspecies of cowpea *alba*, subspecies *tenuis,* and the perennial groups from subspecies *unguiculata* but an array of 11 SSR markers was able to correctly identify the primary subspecies. The SSR markers supported the unique position of the annual subspecies unguiculata in relation to the several perennial subspecies in the infraspecific phylogeny of cowpea. This study confirmed that subsp. *protracta* is the oldest subspecies, implying that the species originated in southern

Africa. All hybrid taxa, including subsp. *alba*, subsp. *tenuis*, subsp. *pubescens*, and the BWA group of subsp. *unguiculata*, belong to a single group that is obviously different from subsp. *unguiculata*.

2.3 Morphology and biology of cowpea

Cowpeas are herbaceous, warm-season annual legumes. It has twining stems of varied heights and bushiness (Onuminya *et al.,* 2023). The trifoliate leaves grow alternately, with petioles of 2 to 12 cm long. Cowpea leaves have a larger diversity of shapes and sizes than regular beans. Plant growth habit is classified as upright to semi-erect, prostrate (trailing type) or ascending, and indeterminate to determinate depending on the genotype (Opoku Gyamfi *et al.,* 2022). Nevertheless, most cowpea accessions have an indeterminate growth behaviour. The root nodules are smooth and spherical, about 5 mm in diameter, and abundant on the main taproot and its branches, but sparse on the smaller roots (Chaturvedi *et al.,* 2011). Cowpea has a powerful taproot system, with roots measuring up to 95 inches deep after 8 weeks of sowing. The blooms are prominent, self-pollinating, and grow on short pedicels. The corollas can be white, dirty yellow, pink, pale blue, or purple (Kay, 1979). Flowers emerge in axillary racemes on stalks with peduncles ranging in length from 15 to 30 cm. Typically, a single peduncle has two to three pods; but, under ideal growth conditions, a single peduncle might contain four or more. Cowpea's large peduncles distinguish it from other legumes and make hand picking easier (Singh *et al.,* 2023). A physical assessment for cowpea variety identification is the foliaceous stipules. Pandey and Dhanasekar (2004) study's findings indicate that temperature and humidity are key environmental variables influencing shattering, and that tolerance to shattering is more widespread in cowpeas suited for drier climates (Lo *et al.,* 2021).

2.4 Soil and climatic requirements for cowpea production

Cowpea production begins with proper site selection. Well-drained sandy loam soils are suitable for rain-fed cowpea, while inland depressions or areas along lake shores are suitable for dry-season production using residual moisture (Nevhulaudzi., 2019).

Cowpea grows primarily under humid conditions and it is tolerant to heat and drought conditions, and also sensitive to frost which germinates rapidly at temperatures around 25/18 °C; colder temperatures slow germination (Nevhulaudzi., 2019). Cowpea can be grown under rain fed conditions as well as by using irrigation or residual moisture along river or lake flood plains during the dry season, with the minimum and maximum temperatures between 28 and 30°C (night and day) during the growing season (Dugje *et al.,* 2009). Cowpea does not tolerate excessively wet conditions or waterlogging and should not be grown on poorly drained soil (Dugje *et al.,* 2009). Most of the crop grown in agro-ecological zones requires an annual rainfall ranging between 500 and 1200 mm; however, with the development of extra-early and early maturing cowpea varieties, the crop can thrive in the regions with an annual rainfall less than 500 mm. The crop requires well-drained sandy loam soils with pH of 6 to 7 which is tolerant to drought and well adapted to a wide range of soils, including sandy and even poor soils (Dugje *et al.,* 2009).

2.5 Importance and uses of Cowpea

Cowpea is a vital grain legume widely consumed in Africa and other developing regions, especially among low-income populations. It plays a significant role in addressing protein-energy malnutrition in high-risk areas (Lado *et al.,* 2018). Enhancing domestic production requires coordinated efforts across the value chain, including adherence to quality standards, development of export markets, and strategies to improve household income and nutrition (Nwagboso *et al.,* 2024).

Globally, cowpea is consumed by both humans and animal. It is nutritionally rich, containing proteins, fats, carbohydrates, vitamins, fiber, and minerals, and these are found in seeds, leaves and the pods (Abebe and Alemayehu, 2022). Cowpea is drought-tolerant and contributes to soil fertility by fixing up to 80% of nitrogen. However, anti-nutritional factors can limit its use for humans and non-ruminants unless treated. Ruminants can safely consume up to 30% cowpea seed in their diet, while chicken rations can include up to 15% cowpea hulls.

Cowpea contains 18–25% protein (including essential amino acids), 1.4–2.7% lipids, 6% fiber, water-soluble vitamins (thiamine, riboflavin, niacin), and iron levels comparable to fish and lean meat. Its calcium content is 7% higher than beef, making it an essential food for low-income groups (Lado *et al.,* 2018). Cowpea farming supports smallholder farmers and traders by improving food security and increasing household incomes by up to 17% (Manda *et al.,* 2020). Dual-purpose cowpea varieties provide both food and livestock fodder, further boosting earnings (Faye *et al.,* 2024; Kebede and Bekeko, 2020).

In Ghana, cowpeas are a staple in traditional dishes like waakye, beans with gari, porridge, and apapransa often fortified with Moringa leaves (Glover-Amengor *et al.*. 2017). Internationally, cowpeas are used in weaning foods such as a sweet potato–cowpea–banana (PCB) flour blend, which is high in vitamin A and offers nutritional benefits for children (Olaniran *et al.,* 2024; Okwunodulu *et al.,* 2019). Increasing cowpea flour in such mixes enhances overall nutrient levels, although it slightly reduces carbohydrate content.

2.6 Cowpea production level

Given their potential for large-scale production, cowpeas have enormous economic significance, and approximately, 6.5 million metric tons of cowpea are produced each year nationwide, totaling over 14.4 million hectares (Dutta *et al.,* 2020).

According to Boukar *et al.* (2016), the projected production of cowpeas is likely to increase from 9.8 million tons in 2020 to 12.3 million tons by 2030. According to research, the worldwide cowpea market is currently valued at over USD 6.3 billion, and by 2050, it is projected to expand to USD 10.5 billion (Transparency Market Research, 2020).

2.7 Biotic factors that affect cowpea production

Cowpea productivity is low due to a variety of biotic and abiotic factors. Limitations in Africa include salinity, drought, excessive demand for synthetic pesticides from farmers, the effects of climate change, declining soil nutrients, microbial infestations, and pest problems (Boukar *et al.* 2016). Furthermore, Rasche *et al.* (2023) discovered that the main obstacles to greater yield were insect pests, *Striga*, drought, and limited access to fertilizers.

Biotic factors that affect cowpea production is fungi infestation. Among the fungi that can harm leaves and stems are rusts, anthracnose, powdery mildew, southern blight, Cercospora leaf spot, and stem rot. Fusarium wilt, damping off, and charcoal rot all affect the vasculatures of plants and their roots. The primary bacteria disease of this crop is bacterial blight. Cowpeas are susceptible to numerous viruses, some of which are transmitted by seeds and others only by insects. A study conducted by Ogunsola *et al.*. (2021) revealed three viruses that are endemic in West Africa. They include: the Southern Bean Mosaic Virus (SBMV), the Cucumber Mosaic Virus (CMV), and the Bean Common Mosaic Strain (BCMV-BICM). Salem *et al.* (2010) also highlighted the Cowpea Aphid-Borne Mosaic Virus (CABMV). The most devastating insects include bean flies as seedling pests, flea beetles, leaf miners, pod borers, and pod bugs or leaf defoliators as mature plant pests, and pulse beetles or bruchids as insects of stored seed (Mahesha *et al.,* 2022). Aphids and leafhoppers are particularly significant as vectors.

2.8 Abiotic factors that affect cowpea production

A major abiotic factor affecting the production of the crop is drought stress (Siddique 2020). In low rainfall areas, cowpea productivity, growth, development and reproductive ability are greatly affected (Daryanto *et al.,* 2017). This usually results in significant reduction in grain yield and biomass output (Ghonaim *et al.,* 2021). Drought-resistant breeding could be advanced by evaluating and characterizing cowpea genotypes in-depth utilizing physiological, biochemical, and molecular techniques (Mekonnen *et al.,* 2022).

Another constraint in cowpea production is low soil fertility. Phosphorus is essential for cowpea production in many tropical African soils but low availability of phosphorus poses a challenge in its production (Singh *et al.,* 2011). The primary source of N in agro-ecosystems is the symbiotic N_2 fixation process through legume-rhizobium symbiosis. Legumes rely on symbiotic N_2 fixation for production, which is influenced by a variety of environmental factors, water availability, and mineral nutrients, particularly phosphorus (Ohyama, 2017). As a result, cowpeas need inoculation and single super phosphate, which contain more phosphorus than nitrogen. Furthermore, it is needed in significant amounts in developing cells, such as the tips of shoots and roots, where there is a high metabolism and rapid cell division, which increases yield (Kyei-Boahen *et al.,* 2017).

2.9 Effect of primary and micronutrients on the growth and yield of cowpea

2.9.1 Effects of Phosphorus (P)

Recent studies have revealed significant effects of phosphorus on cowpea growth and yield. In tropical soils, phosphorus is important and influences crop production.

Global production of rock phosphate is mostly produced in Morocco, China, and the United States, in which they own almost 80% of the deposits that may be used. Rock phosphate (RP) is an excellent option for direct soil application and has been reported to be a less expensive fertilizer that is within the means of low-income nations (Hazzoumi *et al.,* 2022).

Phosphorus adsorption in these soils is influenced by several variables, such as temperature, clay surface potential, and soil acidity (Hanyabui *et al..,*2020). Furthermore, it was shown that the primary mechanism of P adsorption in tropical soils is precipitation. To enhance P solubility and availability in heavily depleted soil, fertilization techniques such as adding organic manure, crop residues, rock phosphate, water soluble P fertilizers and phosphorus solubilizing organisms are highly recommended (Hanyabui *et al.,* 2020). The mineralogy of the clay fraction influences how well phosphate fertilizers work in tropical soils, aluminum minerals have a major role in P acquisition (Lemos *et al.,* 2022). It has been reported that humic acid complexed phosphate fertilizers can prevent P immobilization in soils underscoring the significance of soil management techniques in improving P availability (Zavaschi *et al.,* 2020). Phosphorus adsorption dynamics are influenced by soil properties such as organic matter concentration, PH and clay content; organic matter is particularly important for optimizing the effectiveness of phosphate fertilization (Vinha *et al.,* 2021).

Studies conducted in India demonstrated the benefit of phosphate fertilizers on cowpea (Vaishnavi *et al.*2023; Zote and Dawson, 2023). Results from Nikhitha *et al.* (2023) and Bawa, (2020) showed that treatments with higher phosphorus levels improved the number of nodules per plant, plant dry weight, number of pods per plant, harvest index, stover yield and seed yield. Phosphorus levels ranging from 50 to 90 kg/ha exhibited superior growth indices and enhanced yield. Moreover, these treatments showed increased gross returns, net returns and benefit-cost ratios, emphasizing the significance of phosphorus management for optimizing cowpea production.

During the fifth or sixth weeks after sowing, phosphorus is crucial for the growth of the leaves and stems of cowpea. Plants treated with P had greater leaf area, higher shoot dry weight, and were taller overall. P was more readily absorbed throughout the flowering stage and at the start of pod development, indicating that P is required for pod formation. (Karikari and Arkorful, 2015). In the same study Karikari and Arkorful (2015) indicated that phosphorus application is not dependent on varietal differences, but rather cowpea dry matter production and partitioning among above ground parts depends on cowpea variety but not phosphorus fertilization. For maximum cowpea yield, appropriate timing and phosphorus application amounts are critical (Atakora *et al.,* 2014). According to Bawa and Yussif (2015), the application of phosphorus in combination with particular cowpea varieties such as Valenga and DPC, as well as the best possible row spacing, can greatly enhance the yield of biomass from the shoots, roots, and nodules.

A major challenge in cowpea production especially in West Africa is phosphorus deficiency (Bawa, 2020). Cowpea is noted for its high nutritional content and ability to fix nitrogen to increase fertility (Mogale *et al.,* 2023). A study conducted by Nadeem *et al.* (2017) revealed the importance of phosphorus application for root development, nodulation, plant height, leaf area index, stem girth, number of nodules per plant, number of branches per plant, total dry matter, pod yield, and the available soil nutrient status, which includes pH, N, P, K, organic carbon, and NPK content in the plant.

Phosphorus is essential for cowpea productivity as it affects rhizobium-legume symbiosis functions. Phosphorus is an essential for legumes and rhizobia to form a functional symbiotic relationship and for nodulation, which aids symbiotic nitrogen fixation (Sinharoy *et al.,* 2024). Phosphorus deficiency is one of the main factors impeding legume-rhizobia symbioses particularly in calcareous and acidic soils. When there is a P shortage, phosphatases help to improve nodule permeability to O_2 and consume organic P for N_2 fixation (Drevon *et al.,* 2015).

2.9.2 Effect of Potassium (K)

According to Zörb *et al.* (2014), potassium (K) is essential for the production of turgor, primary metabolism, long-distance transport, and crop tolerance to pests and diseases, as well as high light, cold, salinity, and drought. Again, potassium reduces water stress and promotes development, both of which are critical functions in cowpea physiology. Studies show that under inadequate moisture conditions, potassium fertilizer use improves cowpea shoot growth, root responsiveness, water relations, and photosynthetic rates (Ma *et al.*. 2021).

Furthermore, it has been demonstrated that potassium enhances physiological parameters in cowpea plants under water constraint, including photosynthetic absorption of CO_2, translocation, transpiration rates, stomata closure and opening, chlorophyll content, and water-use efficiency (Rawat *et al.,* 2022).

The different phonological periods of plants affect their potassium needs (Tighe-Neira *et al.,* 2018). They further categorized the functions of potassium into the Calvin and Benson cycle (CO_2 fixation, sugar generation, and transport) and the Hill reaction (synthesis of NADPH and ATP with ionic equilibrium, electron transport, and proton motive force). Furthermore, Tränkner *et al.* (2018) highlighted and affirmed their role in phloem-loading, long-distance photoassimilate transport, photoprotection of the photosynthetic equipment, which leads to photosynthesis, and the diffusion of CO_2, a primary photosynthesis substrate, into chloroplasts. Plants that are grown in soils low in potassium have smaller leaves, less photosynthesis, wither and die. Plant growth depends on K, and a K deficit might weaken the capacity of plants to withstand biotic and abiotic stressors. According to Cakmak (2005), plants under salt stress experience K deficit, which reduces photosynthetic ability, slows plant growth, and sometimes even kills the plant. When subjected to intense light, K-deficient plants quickly turn chlorotic and necrotic. They are particularly light-sensitive. The plant's ability to biosynthesize sugar and to distribute it is restricted when there is a K deficit (Tighe-Neira *et al.,* 2018). Younger leaves progressively lose their green color and turn pale yellow as well as shrink and thin (Sindhu *et al.,* 2014). Brown patches on the tips of leaves or near the edges of adult leaves are the most noticeable sign of an extreme potassium deficit. The spots eventually turn into brown patches that spread to the veins, and large amounts of the leaves abruptly curl and fall off the plant (Zörb *et al.,* 2014).

According to Zhang *et al.* (2024), adding K can encourage a rise in plant dry weight as well as significant gains in stomatal conductance, transpiration rate, and photosynthesis rate. Increases in potassium led to increases in plant height, haulm yield, number of nodules per plant, dry weight, number of pods per plant, and seeds per pod. Particularly, treatments involving 30 kg/ha of potassium plus 100 ppm of gibberellic acid and 60 kg/ha of potassium plus 1.0 kg/ha of boron showed considerable benefits in a number of cowpea growth and yield parameters (Krishna *et al.,* 2023; Zote and Dawson, 2023).

Potassium fertilizers have been shown to considerably enhance wheat crop development in saline environments; yields peak at 100 kg K_2O/ha (Zahedi, 2016). Furthermore, studies conducted by (Ghulam *et al.,* 2019) have demonstrated the considerable effects that varied potassium levels have on wheat growth and grain production. The use of potassium at 100% results in large increases in growth, yield components, and buildup of nutrients in comparison to control plots (Ghulam *et al.,* 2019).

2.9.3 Effect of Nitrogen (N)

In cowpea production, nitrogen has a critical role in enhancing crop growth and development, stress response, and grain yield (Arun *et al.,* 2016; Zhang *et al.,* 2018). Physiologically, it is essential to the production of lipids, amino acids, nucleic acids, and chlorophyll (Bedu *et al.,* 2020; Kusano *et al.,* 2011).

The physiological and growth of cowpea depend substantially on nitrogen. Cowpea's ability to assimilate nitrogen at different growth stages is greatly influenced by nitrogen sources, including soil and atmospheric nitrogen (Masete *et al.,* 2022)

According to Alharbi *et al.* (2022), sufficient nitrate and urea applied to the soil adsorbed by plant roots was translocated and digested leading to notable plant growth in terms of number of leaves, stem height, leaf area, shoot moisture content, net assimilation rate, and plant dry weight.

Furthermore, it has been discovered that applying nitrogen fertilizer enhances the physiological responses of cowpeas and the ultrastructure of chloroplasts for efficient photosynthesis.

Absorbed nitrogen is known in its transformation into amino acids and hydrolysis into ammonia, which subsequently joined forces with organic acids through amination or transamination to produce the corresponding amino acids and proteins.

Also, increased plant height, branch count, nodule count, plant dry weight, crop growth rate, test weight, number of pods and seeds per plant, seed yield, and harvest index can result from applying nitrogen, especially when combined with phosphorus solubilizing inoculants (Chattha *et al.,* 2017; Shanko *et al.,* 2020). Bandeira *et al.* (2019), found that while nodulation was limited with increasing N rate, inoculation increased shoot dry weight, root dry weight, and total dry weight up to 30 kg ha^{-1}.

Furthermore, increased plant height, branch count, dry weight, number of pods and seeds per plant, pod dry weight, seed index, seed yield, and haulm yield can be obtained by applying nitrogen topically in combination with a plant growth regulator such as NAA (Bandeira *et al.,* 2019; Jeber and Khaeim, 2019). Again, a sufficient amount of nitrate and urea applied to the soil, absorbed by plant roots, was translocated and digested, according to Alharbi *et al.* (2022), and this led to a considerable increase in the number, stem height, leaf area, water content in the shoots, net assimilation rate, and dry weight of the plants.

Additionally, depending on the amount of nitrogen present, adding nitrogen-fixing bacteria to cowpea seeds can improve the traits of the plant, including nodulation (de Silva *et al.,* 2012). According to Jemo *et al.* (2017), cowpeas require up to 100 kg N ha^{-1} per season. Depending on the environment and expected output, this implies that N fertilizer application may be necessary to meet crop demand. Because plants are unable to absorb all of the nitrogen fertilizer, there are increased environmental problems as well as reduced nitrogen recovery and usage efficiency. According to Freitas *et al.* (2022), biological nitrogen fixation (BNF) is a process that is prone to drought, a prevalent environmental condition in tropical agriculture, and it declines even before transpiration and photosynthetic rates do.

Conversely, a lack of nitrogen fertilizer negatively impacts the absorption, assimilation, and synthesis of amino acids (Nunes-Nesi *et al.,* 2010). The quantity of nitrogen (N) changes the supply sugars to various organs and can have a differential effect of characteristics associated with reproductive growth and yield resulting in less flowers and larger fruits due to low N supply (de Avila Silva *et al.,* 2019). This may be due to the accumulation of organic acids, sugars and amino acids in the roots (Lin *et al.,* 2021). This, in turn, impacts the assimilation of carbon (C), eventually impeding the growth and development of plants (Zahedi, 2016). Therefore, excessive or insufficient nitrogen is unfavorable for crop growth and development. According to reports, seedling development is severely inhibited by nitrogen deficiencies (Xu *et al.,* 2024). Research by Li *et al.* (2024) indicate that, when there was a nitrogen shortage, more flavonoids were produced and release by the cowpea plant, which restricted the above ground portion of the cowpea plant.

In addition to reduced photosynthetic pigment levels, thylakoid structure and photosynthetic electron transport chain (PETC) in leaves, a lack of nitrogen (N) also disrupted nutrient balance and homeostasis in plants, inhibiting plants growth and lowering CO_2 assimilation (Huang *et al.,* 2021). Lack of nitrogen can intensify the way plant's nutritional balance is altered, influencing the ratio of components such as P, K, Mg, Ca and S in the leaves and stems (Huang *et al.,* 2021). Nevertheless, plants have developed defense mechanisms for coping with nitrogen shortage, such as enhanced photosynthetic dry matter partitioning to roots, which may have an impact on the root – shoot ratio (Qin *et al.,* 2019).

2.9.4 Effect of Zinc (Zn)

Zinc (Zn) is an important micronutrient that is necessary for several plant functions, such as respiration, photosynthesis, stress tolerance, chlorophyll production, and auxin metabolism (Shahid *et al.,* 2023). Plant height, branching, leaf count, dry matter content, effective nodule weight, and grain production are markedly enhanced by zinc. According to Upadhyay and

Singh (2016), there was no sign interaction between zinc and nitrogen on grain yield. Combining zinc sulphate with boric acid has been shown to increase plant concentration-dependent growth and yield as well as shoot, root and architecture length and architecture nodulation efficiency and growth (Kayata *et al.,* 2024): Ranjan *et al.,* 2022). These results enhanced growth, development and uptake of nutrient in plants.

Zinc (Zn^{2+}) ions promote the development of biofilms, root attachment, cell survival, and exopolysaccharide (EPS) effectiveness in beneficial bacteria like *Rhizobium leguminosarum* bv. *Trifolii* under nitrogen-stressed circumstances (Kopycińska *et al.,* 2018). During the early stages of seedling growth, faba bean drought tolerance was enhanced by an adequate zinc supply achieved by seed priming (Farooq *et al.,* 2021).

2.9.5 Effect of Boron (B)

In plants, boron can be involved either directly or indirectly in the metabolism of carbohydrates, proteins, and ribonucleic acid (RNA), as well as in the creation of cell walls and plasma membranes. Vera-Maldonado *et al.* (2024) reported that in some situations, adding Boron (B) through fertilization might increase agricultural production by minimizing the metabolic changes brought on by harmful concentrations of aluminum and heavy metals like cadmium, thereby lowering total yield losses. But depending on the plant species and variety as well as the environment, Boron's interactions with other nutrients including calcium (Ca), nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) are extremely complicated and can have antagonistic or synergistic effects.

The element takes part in a variety of ion, metabolite, and hormone transport processes because it is involved in the building and function of cell walls and membranes. Fertilization is a viable solution to the deficiency issue, while a variety of techniques may be employed to mitigate soil boron toxicity (Brdar-Jokanović, 2020). Furthermore, boron affects the metabolism of microminerals like Calcium, Magnesium, and triglycerides as well as glucose, proteins, amino acids, reactive oxygen species, and steroid hormones. The most abundant deposits of boron are found in Turkey and the United States (US), as reported by the same author. Boron is economically obtained from the minerals ulexite, borax (tincal), natural boric acid (sassolite), colemanite, and kernite.

Shireen *et al.* (2018) asserted that B is involved in the following processes; cell division and elongation, nitrogen and carbohydrate metabolism, sugar transport, cytoskeletal proteins, plasmalemma-bound enzymes, nucleic acid, ascorbic acid, polyamines, phenol metabolism and transport, and structural and functional integrity of the cell wall and membranes (Kohli *et al.,* 2023). It contributes to the growth of reproductive organs, the synthesis of biomolecules such as proteins and carbohydrates, the metabolism of phenols and auxins, the fixation of nitrogen, the resistance to disease, and the control of abiotic stress (Kohli *et al.,* 2023). As anticipated, foliar spraying with boron greatly enhanced the number of primary branches per plant, number of leaves, plant height, number of pods, length of pod, width of pod, number of seeds per pod, seed yield per plant, fresh weight of the roots, and total yield per hectare (Ullah *et al.,* 2024). Nonetheless, the lack of boron has an impact on the metabolism of carbohydrates and nucleic acids, highlighting its critical function in preserving the structure of plant membranes (Li *et al.,* 2017). Insufficiency of boron cause visible brown rings to grow on the petioles of cotton seedlings, diminishing photosynthesis in leaves and the transport function in petioles (Li *et al.,* 2017).

Findings from research indicate that, the development of brown rings on the petioles of cotton leaves is the main sign of boron deficiency. In response to a reduction in boron availability, plant growth reduces, prevent root elongation and modify leaf expansion (Haliloglu and ceylan 2023). These actions have an indirect effect on photosynthetic capacity and stomatal conductance as well as on the export of non-structural carbohydrates from leaves of fruits (Oosterhuis and Zhao 2001).

Studies on cowpea cultivation in boron-deficient soils have shown that, it negatively affects the plant, resulting in decreased biomass and seed output (Kumar *et al..,*2023; Silva *et al.*, 2021). Growth reduction, low grain yield, and abnormalities in the reproductive organs are some of the deficiency signs and symptoms of low boron in soils (Javed *et al*., 2021).

2.10 Root system architecture (RSA's) and its influence on crop productivity.

Root architecture means the spatial configuration of the root system within the soil, such as root depth, length, angle, and branching patterns. In cowpea, these traits are important because the crop is often cultivated under low-input conditions. According to Singh and Matsui (2002), deep and efficient root systems allow cowpea to access water from deeper soil layers and improve resilience to drought stress. In their studies, root traits have been associated with improved drought tolerance in cowpea, particularly under terminal drought stress (Singh and Matsui, *2002).* Cowpea varieties with deeper and more extensive root systems are better suited to terminal drought conditions, common in rainfed systems and help maintain physiological functions during late-season drought, which is critical for pod filling and seed development (Belko *et al.* 2012). Research by Belko *et al.* (2012) demonstrated that cowpea genotypes with improved rooting depth showed better performance under drought.

According to Lynch (2001), in root traits and nutrient uptake**,** different root traits are associated with the uptake of specific nutrients. For example, shallow and highly branched roots may be more effective in acquiring immobile nutrients like phosphorus, which accumulates in the topsoil Lynch and Brown, 2001. Deeper root systems, on the other hand, are beneficial for nitrogen uptake and water absorption during drought conditions Kell *et al.,* 2011.

In nutrient-deficient soils, root traits such as lateral root density and root hair length become important for maximizing phosphorus and nitrogen uptake. Cowpea's ability to form symbiotic relationships with rhizobia also depends on root structure and nodulation efficiency, contributing to soil fertility and crop productivity (Agbicodo *et al., 2009).*

Significant genotypic variation exists among cowpea varieties for root traits. Breeding programs now include root phenotyping as part of selection strategies to improve stress tolerance. Tools such as shovelomics and root imaging are being employed to screen for beneficial root traits (Muchero *et al.,* 2009; Adu *et al.,* 2014).

Mostly under field conditions where water and nutrients are heterogeneously distributed in the soil, RSA plays a vital role via the uptake of these resources (Lynch, 1995), since RSA significantly determine exploration of distinct spatial domains in the soil (Lynch, 1995). Plant root systems perform many essential functions including water and nutrient absorption, soil anchorage and rhizosphere biotic interactions (López *et al.,* 2003; Lynch, 2013; Lynch and Brown, 2001).

Root architecture is essential for the acquisition of vital soil resources such as nitrogen and P is immobile and limiting (Lynch, 1995). Absorption of phosphorus is mostly increased by greater length and density of root hair (Lynch, 2011; Miguel *et al.,* 2015). Numerous studies have identified the importance of a deep root system in crops such as rice, millet and sorghum to absorb water from deeper soil layers in water-stressed environments (Reynolds *et al.,* 2006; Hammer *et al.,* 2009). The tap roots of most desert plants are capable of storing large amounts of water (Graham and Nobel, 1999). Roots also host many soil microbes whose proliferation inside or outside the root surface is inadvertently catalyzed by the release of C from the root cells into the rhizosphere (Gregory, 2006; Lambers *et al.,* 2009). Increased rhizodeposition may, in effect, stimulate N mineralization from the pools of recalcitrant organic soil (De Graaff *et al.,* 2009).

Coarse or tap roots anchor plants and establish root system architecture, control root system depth, and thus determine the ability of a plant to grow under a compact soil profile (Henry *et al.,* 2011). Roots also anchor the plant to prevent wind, water or other mechanical disturbances from dislocating it (Sitte *et al.,* 2002). According to Smucker (1993), root systems function in photosynthesis, respiration, and ensure a balance between the biomass below and above the soil. In epiphytic orchids and mangrove aerial roots, root respiration is particularly common.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site description

The experiment was a multi-locational trial sited at two locations. One trial was set up at the experimental field of the University for Development Studies in Nyankpala Campus (09.41277 N, 000.98855 W**),** Tolon District, while the second trial was set up at Kokpeng (09.43298 N 000.97060 W**)** in Kumbungu District, during the 2023 cropping season. Both (UDS and Kokpeng) areas experience a unimodal rainfall pattern of about 800-1000 mm, which is evenly distributed from May to October, with the peak in August and September. The average minimum and maximum temperatures are 25˚C and 35˚C, respectively (Lawson *et al.,* 2013).

3.2 Treatments and Experimental Design

The treatments consisted of 16 fertilizer regimes. The treatments included Phosphorus, which was supplied using Triple Super Phosphate (TSP). The TSP was substituted with Rock Phosphate (RP) at 20, 40, and 100%. Potassium (K), and trace elements (TE) B and Zn were added to the phosphorus serially. Three compound fertilizers introduced by OCP-Ghana were added as treatments (Table 1).

OCP (**Office Chérifien des Phosphates**) is a state-owned company founded in 1920 and headquartered in Casablanca, Morocco, with the mission of maximizing the positive impact of phosphorus.

The area was ploughed using a disc plough and harrowed. The plots were laid out using randomized complete block design (RCBD) with four replications. The plot size was 5 m x 5 m with 2 m alleys between blocks and a meter between experimental units. All treatments were randomly assigned to the experimental units. Wankai cowpea variety was planted on August 6, 2023. Three seed were planted to each hill at a distance of 60 cm x 20 cm. Each hill was thinned to two seedlings after seed emergence. Fertilizer application was done 2 weeks after planting by side placement and covered. Plots that were earmarked for rock phosphate received it on the day the seeds were planted.

Table 1: Treatments used in the study

Treatment	**Amount of fertilizer (kg/ha)**
Control	0
NPK (11:22:21) +TE	272.7 kg
NPS (14:31:5) +TE	272.7 kg
NPK (14:18:18) +TE	333.33 kg
100% TSP	131kgTSP
100%TSP+K	131kg TSP+100 kg MOP
100%TSP+K+TE	131 kgTSP+100 kg MOP+ 11.4 ZnO + 7.1 B_2O_3
80%TSP+20%RP	105 kgTSP+85 kg RP
80%TSP+20%RP+K	105 kgTSP+85 kg RP+100 kg MOP
80%TSP+20%RP+K+TE	105 kgTSP+85kg RP+100 kg MOP+ 11.4 ZnO + 7.1 B_2O_3
60%TSP+40%RP	79 kgTSP+174 kg RP
60%TSP+40%RP+K	79 kgTSP+174 kg RP+100 kg MOP
60%TSP+40%RP+K+TE	79 kgTSP+174 kg RP+100 kg MOP+ 11.4 ZnO + 7.1 B_2O_3
100%RP	200 kg RP
100%RP+K	200 kg RP+100 kg MOP
100%RP+K+TE	200 kg RP+100 kg MOP+ 11.4 ZnO + 7.1 B_2O_3

***NB:** TSP=Triple Superphosphate. RP= Rock Phosphate, K=Poatassium, TE= Zinc and Boron*

3.3 Soil Sampling and Physio-chemical analysis

Soil samples were taken at 0-25cm depth in two stages throughout the experimental stage;

Stage one was initial (Composite) sampling which was done prior to ploughing using the double or two diagonals method from each of the experimental field.

Stage two Sixteen cores were taken at 0-25cm depth after harvesting, where soil sampling was based on treatment. Similar treatments from each of the four replications were composited and sub-sampled.

Soil samples were air dried and sieved through a 2 mm (British Standard) meshed sieve. Approximately 300 g of soil sampled was sent for physio-chemical analysis at the soil chemistry laboratory of the University of Cape Coast (UCC), in the Central region of Ghana.

The standard laboratory procedures used in determining physicochemical properties of the soil samples;

Soil pH was measured in a 1:2.5 soil–water suspension using a glass electrode pH meter following the procedure described by Jackson (1973).

Soil organic carbon was determined using the Walkley and Black wet oxidation method as described by Walkley and Black (1934).

Total nitrogen was analyzed using the Kjeldahl digestion method according to the procedures outlined by the Association of Official Analytical Chemists (AOAC, 1990).

Available phosphorus in the soil was determined using the Bray I extraction method by Bray and Kurtz (1945).

Exchangeable potassium was determined using 1 N ammonium acetate (NH_4OAc) extraction at pH 7.0, following the method described by Page *et al*. (1982).

Available micronutrients including boron and zinc were determined using Atomic Absorption Spectrophotometry (AAS) following extraction procedures by Lindsay and Norvell (1978).

Soil ammonium (NH_4^+) and nitrate (NO_3^-) nitrogen were extracted using potassium chloride (KCl) solution and determined by Page *et al.,* (1982).

Effective cation exchange capacity (ECEC) was determined using the 1 N ammonium acetate (NH_4OAc) extraction method**,** where exchangeable bases were extracted from the soil and summed to estimate the ECEC **(**cmol kg^{-1}) following the procedure described by Page *et al*., (1982).

Soil texture was determined using the hydrometer method to estimate the proportions of sand, silt, and clay, following the procedure described by Bouyoucos, (1962).

3.4 Cultural practices

Weed control was carried out manually by hoeing and hand-pulling at the 2nd and 6th weeks after emergence. Insect pests were controlled by spraying K-Optimal insecticide (a broad-spectrum insecticide with active ingredients Lambda-cyhalothrin and Acetamiprid**)** 1 l/ha at two-week intervals from the 2nd to the 8th week after planting.

3.5 Data collection and Schematic presentation of field demarcation for above-ground biomass and yield data measurements

Five plants in the inner rows were tagged for growth (vegetative) parameter measurements.

Each plot was divided into two for destructive and non-destructive data collection, (Plate 1). One part, the smaller part with 3 rows, **(B**) was used for destructive data collection in parameters such as root/nodule count and above ground dry biomass measurements. The other part with four rows (**A**) was used for non-destructive data collection such as vine length, SPAD reading and branches during growth and yield measurements at harvest

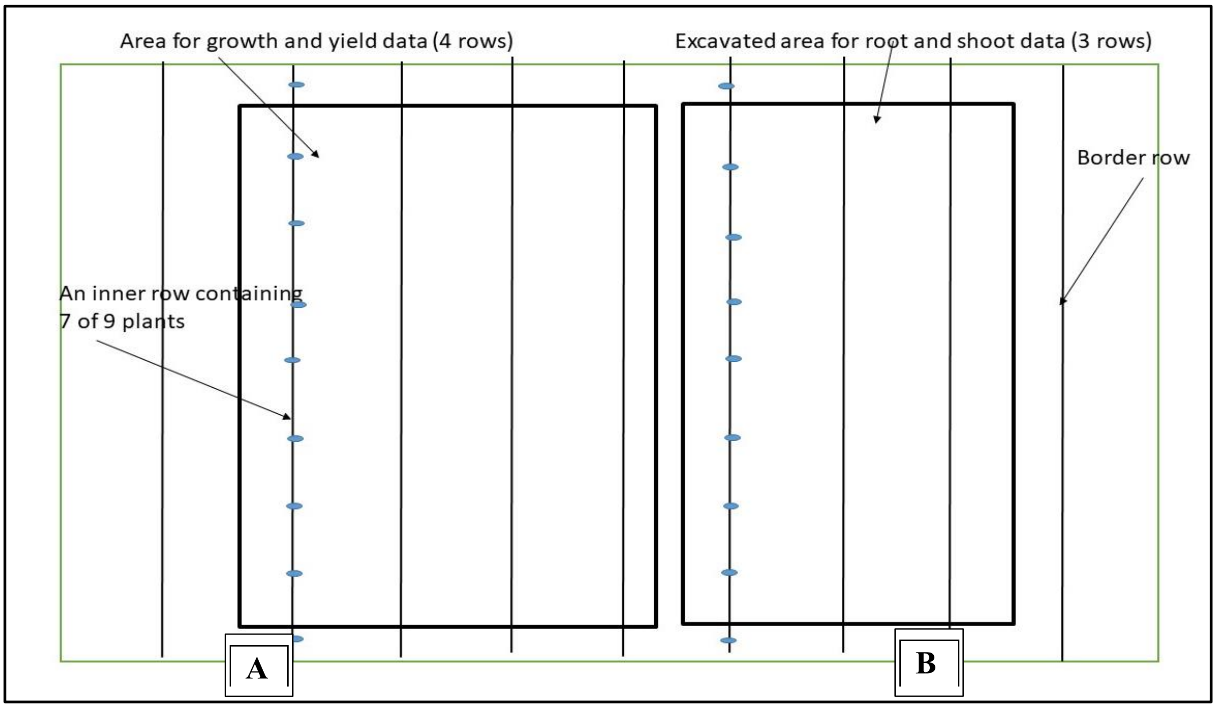

***Plate 1**: Schematic presentation of field demarcation for above-ground biomass and yield data measurements*

3.5.1 Vine length

One main vine was selected and the height was measured from the base of tagged plants to the tip of vine at the 2nd,4th, 6th and 8th weeks after planting. Means were computed and recorded in centimetres.

3.5.2 Number of branches

Number of branches borne on tagged plants were counted at the 4th, 6th and 8th weeks after planting. Means were computed and recorded.

3.5.3 Leaf Area Index (LAI)

Leaf area index (LAI) of cowpea was estimated using an indirect method as in formula 1, by multiplying the mean leaf area per leaf by the total number of leaves per plant and a constant factor of 0.37, and dividing the product by the land area occupied by the plant (Nangju and Wanki ,1980). This was done to obtain the leaf area index at the 2nd, 4th, 6th and 8th weeks after planting.

$$\text{Leaf Area Index} = \frac{\text{Leaf area (LA)} \times \text{Number of leaves} \times \text{Correction factor}}{\text{Land area covered}} \text{...........Formula 1}$$

Where:

Leaf area (LA): Mean area of a single cowpea leaf (cm²), usually measured as length × width

Number of leaves: Total leaves per plant counted

Correction factor: 0.37 is commonly used for cowpea to account for the trifoliate leaf shape

Land area covered: Ground area occupied by the plant (cm²), based on spacing ($1200 cm^2$)

3.5.4 Number of nodules and nodules weight

The number of nodules borne on three sampled plants were harvested, counted and recorded at the 5th and 8th weeks after emergence. These nodules were weighed and recorded in grams. Averages were computed and recorded.

3.5.5 Above ground dry biomass

Above-ground dry biomass data collection as well as root excavation were done at podding on part **B** of each plot ($8.28 m^2$). The shoots of five plants were cut at the soil surface and oven dried at 105 °C for 48 hours until they attained a constant weight. Averages were computed and recorded in grams as above-ground dry biomass and were later extrapolated into kg/ha.

3.5.6 Extraction of root features using SmartRoot software

The procedure employed in extracting root traits, as described by Adu *et al.* (2014), was used and it utilizes an ImageJ plugin called SmartRoot (Lobet *et al.,* 2011). An analysis tool for root images, SmartRoot monitors root objects and transmits measurements to a defined access database. The underlying wireframe model of SmartRoot uses lines to connect the vertices of images. SmartRoot uses the coordinates of connected nodes along different root system axes to describe root images using a vector representation of the root system (***Plate 2***).

The software uses an algorithm to determine the root midline close to a user-selected seed location. It then builds a segmented line to the root tip step by step by approximating the root midline.

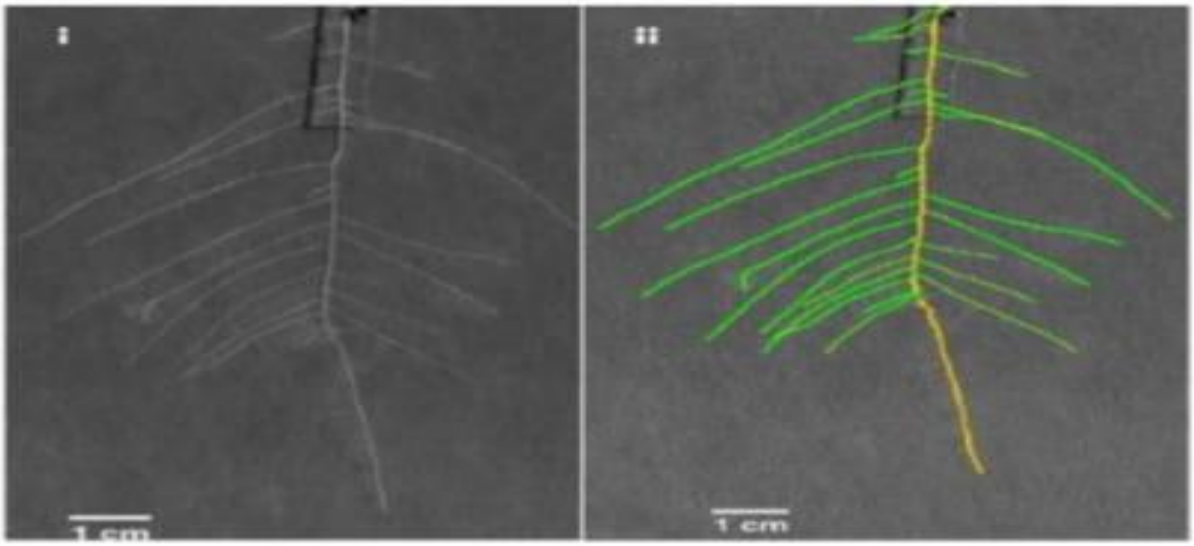

Plate 2***: Analysis of RSA by SmartRoot Software (I) original grey-scale image; (II) image traced with SmartRoot showing primary root (yellow) and lateral roots (green)***

SmartRoot can also be used to analyse developmental processes of complex root system architecture (RSA) from images across time-series (Lobet *et al.,* 2011) but the procedure could be slow by repeating the whole process for each image. The SmartRoot was used to extract root growth information by tracing all root axes (primary and lateral roots) on image (II) in plate 2. The initial tracing was then used as the starting point for the tracing of the preceding image, which is obtained by removing the portion of roots that have been created between the penultimate and the image (II).

3.5.7 Yield data measurements

Yield data were taken from the four inner rows (**Plate 1 A**) measuring 11.04 m^2. Plant population in each demarcated area was determined. In order to cater for plots with low germination and ensure uniform plant population formula 2 was used. This formula replaced plants on plots with few plants within the demarcated area for yield especially if the low number of plants is not dependent on the treatment.

$\boldsymbol{P = (A \div ab) * n}$ **.. Formula 2**

Where P is plant population, A is plot area, ab is the product of planting distance, and n is the number of plants per stand. Within this area, the number of pods per plant and grain weight per plant and hectare were determined.

3.5.8 Pod weights

Ten pods were randomly sampled after harvest from the demarcated four rows. Their weights were determined using an electronic scale (Camery) and recorded in grams.

3.5.9 Pod length and seeds per pod

Ten pods were randomly sampled from respective plots in each replication after harvest, and their lengths were measured and recorded in centimetres per pod and grams, respectively. These pods were threshed or cracked open, and the number of seeds in each pod was counted per pod; their averages were computed and recorded.

3.5.10 Hundred seed weight

After harvest, pods were dried, and 100 seeds were randomly sampled from each treatment and their weight was determined.

3.5.11 Grain yield in kg/ha

Pods were harvested from the demarcated four rows, measuring 11.04m^2. Grains obtained for each treatment were weighed after sun drying. The data collected in grams were extrapolated to kg/ha using formula 3.

$Yield = (10000\ \mathrm{m2}/11.04\ m2\ ) * plot\ yield$ **................................ Formula 3**

3.5.12 Partial Budget Analysis of cowpea

In order to conduct a comprehensive economic analysis of the various treatments, a range of analytical techniques including partial budget analysis, dominance analysis, and marginal analysis were employed to narrow on the treatment that will bring better returns. Partial budget specifically computes the variable costs and net benefits associated with each treatment in the experiment. Subsequent to the partial budget analysis, a dominance analysis was carried out. This procedure excluded treatments that result in greater additional costs with lesser net benefits in comparison to treatments that incur the same or lower additional costs from further consideration. Marginal analysis encompasses the evaluation of marginal (incremental) benefits against marginal (incremental) costs associated with transitioning from one treatment to an alternative one (Perrin *et al.,* 1976). It requires the computation of the following:

Net Benefit Analysis

The net benefits were determined through the following calculations:

$$Net\ Benefits\ (NB) = Gross\ Benefits\ (GB) - Total\ Variable\ Cost\ (TVC) \quad .... (1)$$

Where GB = Output (Yield) × Output price, and TVC = Sum of variable cost (Perrin *et al.,* 1976).

.

Marginal Rate of Return (MRR)

Change in net benefits (ΔNB) and change in total variable costs (ΔTVC) were computed and were used to compute the marginal rate of return (MRR) as shown:

$$MRR = \frac{\Delta NB}{\Delta TVC} \times 100 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

Where;

$\Delta NB = change\ in\ net\ benefits\ (marginal\ benefits)\ and\ \Delta TVC =$

$change\ in\ total\ costs\ that\ vary\ (marginal\ variable\ cost).$

3.12 Data Analysis

Data collected were subjected to Analysis of Variance using Genstat statistical package edition 16. Means were separated using Duncan Multiple rang test at 5% significance level. Partial budget Analysis was done to determine the treatment that was profitable.

CHAPTER FOUR

RESULTS

4.1 Soil analysis

The initial pre-planting and after harvest soil properties of both areas (Nyankpala and Kokpeng) are shown in tables 2 and 3.

The initial soil at Nyankpala was slightly acidic (pH 6.12) and classified as sandy loam. After harvesting, soil pH varied among fertilizer treatments, ranging from 5.85 to 8.22, with lower pH values generally observed under NPK compound fertilizer and TSP fertilizer treatments. Available boron (B) increased from an initial value of 31.92 µg g^{-1} to higher values across all fertilizer treatments after harvest, with the highest values recorded under combined TSP, RP, K, and TE treatments (Table 4). Zinc (Zn) concentrations after harvest were generally lower than the initial value (1.53 µg g^{-1}), although treatments involving RP combinations recorded relatively higher Zn levels.

Organic carbon (%OC) and total nitrogen (TN) contents declined slightly from initial values (0.76 % OC and 0.08 % N) after harvesting across most treatments, with higher residual values observed under RP-based and TE (Zn and B) amended treatments as shown above (Table 2).

Available phosphorus (P µg g^{-1}) increased markedly in fertilized plot compared with the initial values of 8.51 µg g^{-1} particularly in fertilizer treatments involving TSP either alone or in combination with RP and K. Exchangeable potassium increased in K amended fertilizer treatments relative to the initial value (0.147 cmol kg^{-1}), while lower values were recorded treatment without K application.

Effective cation exchange capacity (ECEC) increased from an initial value of 3.482 cmol kg-1 to higher values across fertilized treatment (plots), with the highest ECEC recorded in combined RP, K and TE treatments (Table 2). Ammonium and nitrate nitrogen, which were not detected in the initial soil, were present after harvesting across all fertilizer treatments, with values varying significantly among treatments.

The initial soil at Kokpeng was slightly acidic (pH 6.13) and sandy loam in texture. After harvesting, soil pH ranged from 5.80 to 6.32 across fertilizer treatments (*Table 3*). Available boron (B) increased substantially from the initial value of 17.03 µg g^{-1}, with the highest concentrations observed under NPK compound fertilizer and TSP based fertilizer treatments. Zinc (Zn) levels after harvest were generally lower than the initial concentration (0.741 µg g^{-1}), though moderate increases were observed in treatments supplemented with trace elements (Zn and B).

Available phosphorus (Pµg g^{-1}) increased in all fertilized plots relative to the initial value of 4.51 µg g^{-1}, with higher post-harvest values observed under TSP and RP based fertilizer treatments (*Table 3).*

Exchangeable potassium increased in K-amended treatments compared with the initial value (0.151 cmol kg^{-1}), while non-K treatments recorded lower residual K levels. ECEC increased from the initial value of 4.294 cmol kg^{-1} across most fertilizer treatments. Ammonium and nitrate nitrogen, which were absent in the initial soil, were detected after harvest, with significant variation among fertilizer treatments (*Table 3*).

Table 2: Initial soil and effects of fertilizer treatments on the post-harvest soil physical and chemical properties at Nyankpala

Fertilizer Treatment	pH (1:2.5) water	Avail. B (ug/g)	Zn (ug/g)	OC %	N %	P (ug/g)	K (cmol/kg)	ECEC (cmol/kg)	NH_4 (ug/g)	NO_3 (ug/g)	SOIL TEXTURE
Initial soil sample	**6.12**	**31.92**	**1.53**	**0.76**	**0.08**	**8.51**	**0.147**	**3.482**	__	___	Sandy Loam
Post-harvest											
Control	6.09	58.72	1.223	0.703	0.080	2.002	0.127	4.110	2.431	3.055	
NPK (14:31:5) +TE	5.94	57.10	0.502	0.681	0.071	3.262	0.089	3.996	3.159	4.985	
NPK (14:18:18) +TE	5.92	97.00	0.485	0.638	0.070	1.717	0.114	3.912	3.227	5.847	
NPK (11:22:21) +TE	5.85	85.54	0.387	0.630	0.058	1.425	0.111	3.825	3.633	3.818	
100TSP	5.88	56.21	0.441	0.607	0.065	8.410	0.112	4.302	3.912	5.220	
100TSP+K	5.99	102.07	0.509	0.694	0.062	3.305	0.129	4.228	3.234	6.345	
100TSP+K+TE	8.22	52.43	0.424	0.653	0.063	1.771	0.126	4.155	5.840	4.709	
80TSP+20RP	6.09	72.45	0.507	0.774	0.068	5.616	0.146	4.347	3.493	5.306	
80TSP+20RP+K	6.02	95.49	0.582	0.796	0.068	1.916	0.145	4.121	3.934	7.562	
80TSP+20 RP+K+TE	6.02	110.20	0.763	0.965	0.089	3.716	0.308	4.864	4.931	7.596	
60TSP+40RP	6.02	71.14	0.601	0.635	0.067	2.608	0.163	3.972	5.469	7.534	
60TSP+40RP+K	6.00	76.23	0.634	0.849	0.067	18.210	0.225	4.375	3.108	5.536	
60TSP+40RP+K+TE	5.94	75.46	0.434	0.700	0.106	7.494	0.204	3.868	3.177	3.413	
100RP	6.02	85.21	0.542	0.830	0.071	2.799	0.141	4.231	3.382	8.657	
100RP+K	6.10	82.44	0.444	0.781	0.085	6.830	0.337	4.467	4.086	3.473	
100RP+K+TE	6.08	79.55	0.420	0.933	0.078	2.124	0.211	4.798	3.631	6.044	
Grand mean	**6.14**	**78.58**	**0.56**	**0.74**	**0.073**	**4.58**	**0.168**	**4.267**	**3.790**	**5.569**	
LSD(0.05)	**00**	**0.38****	**0.008****	**0.003****	**0.0118****	**0.047****	**0.0028****	**0.102****	**0.236****	**0.043****	
%CV	**00**	**0.3**	**0.9**	**0.3**	**9.7**	**0.6**	**1.0**	**1.4**	**3.7**	**0.5**	

Table 3: Initial soil and effects of fertilizer treatments on the post-harvest soil physical and chemical properties at Kokpeng

Fertilizer Treatment	**pH (1:2.5)** $_{water}$	**Avail. B(ug/g)**	**Zn (ug/g)**	**OC %**	**N %**	**P (ug/g)**	**K (cmol/kg)**	**ECEC (cmol/kg)**	**NH_4 (ug/g)**	**NO_3 (ug/g)**	**SOIL TEXTURE**
Initial soil sample	**6.13**	**17.03**	**0.741**	**0.868**	**0.078**	**4.510**	**0.151**	**4.294**	__	__	Sandy Loam
Post-harvest											
Control	6.15	92.506	0.584	0.921	0.072	1.766	0.241	4.741	5.329	3.526	
NPK (14:31:5) +TE	5.87	51.567	0.561	0.764	0.057	1.968	0.161	3.768	2.558	7.663	
NPK (14:18:18) +TE	5.99	110.866	0.581	0.698	0.068	1.794	0.187	3.830	5.686	6.386	
NPK (11:22:21) +TE	5.90	70.973	0.424	0.747	0.060	1.128	0.131	4.932	2.723	3.334	
100TSP	5.94	94.494	0.574	1.003	0.067	1.705	0.220	4.984	2.772	4.559	
100TSP+K	5.80	105.811	0.478	0.788	0.072	1.396	0.166	4.206	4.079	6.419	
100TSP+K+TE	6.32	105.052	0.647	1.163	0.080	4.472	0.382	5.311	2.825	4.194	
80TSP+20RP	6.00	72.178	0.515	0.802	0.063	1.030	0.150	4.456	6.416	6.434	
80TSP+20RP+K	6.13	63.994	0.523	1.126	0.069	2.609	0.211	5.315	3.755	4.573	
80TSP+20 RP+K+TE	6.14	86.683	0.441	0.711	0.057	3.453	0.275	4.728	5.010	3.813	
60TSP+40RP	6.00	49.941	0.401	0.751	0.066	0.604	0.151	4.905	2.866	4.522	
60TSP+40RP+K	6.19	135.150	0.334	0.605	0.072	0.468	0.153	4.021	4.047	6.950	
60TSP+40RP+K+TE	6.03	65.701	0.521	1.001	0.073	0.477	0.125	4.839	6.566	3.702	
100RP	5.98	90.704	0.477	0.646	0.066	1.054	0.164	4.082	3.430	6.217	
100RP+K	6.04	81.781	0.463	0.732	0.058	0.409	0.151	4.907	2.444	5.196	
100RP+K+TE	6.02	74.381	0.443	0.761	0.072	0.573	0.158	4.356	2.417	2.853	
Grand mean	**6.03**	**84.49**	**0.50**	**0.83**	**0.067**	**1.557**	**0.189**	**4.586**	**3.933**	**5.334**	
LSD(0.05)	**00**	**0.311****	**0.0112****	**0.007****	**0.008****	**0.112****	**0.002****	**0.002****	**0.068****	**0.055****	
%CV	**00**	**0.2**	**1.3**	**0.5**	**7.1**	**4.3**	**0.6**	**00**	**1.0**	**0.6**	

4.2 Main vine length

The location and fertilizer on vine length were significant ($P<0.05$) at the various times the growth parameter was assessed except at the 2nd week after planting (WAP). Vine length was also significantly ($P<0.05$) affected by the fertilizer treatments at all sample periods, except at 2WAP.

At 4 WAP, the compound fertilizers showed a stronger response in Kokpeng than in Nyankpala. In Kokpeng, NPS (14:31:5) + TE recorded the longest vine length, which was statistically at par with TSP+K and (80% TSP +20% RP + K) at the same location (Figure 1). In contrast, these same treatments did not show the same level of performance at Nyankpala at this stage (4 WAP). Meanwhile, 100%RP + K in Kokpeng was significantly lower than the control treatments at both experimental locations (Figure 1).

At 6 WAP, the pattern shifted in favour of Nyankpala, where the three compound fertilizers NPK (14:18:18) +TE, NPS (14:31:5) +TE and NPK (11:22:21) +TE recorded the longest vine length than all other treatments. At Kokpeng, compound fertilizers NPS (14-31-5) + TE and NPK (11:22:21) + TE recorded the shortest vine length compared to the other TSP, RP, and their combination with K and TE treatments as well as the control treatment (Figure 1).

At 8 WAP, the trend observed in 6 WAP became more pronounced. In Nyankpala, all three compound fertilizers, NPK (14:18:18) +TE, NPS (14:31:5) +TE and NPK (11:22:21) +TE continued to lead in terms of vine length and remained clearly outstanding to the other fertilizer treatment combinations and the control. However, at Kokpeng two treatments, NPK (14:18:18) +TE and NPK (11:22:21) +TE, showed superior length growth. The shortest vine lengths were recorded by the control treatments in both locations, and varied significantly from all other treatments (Figure 1).

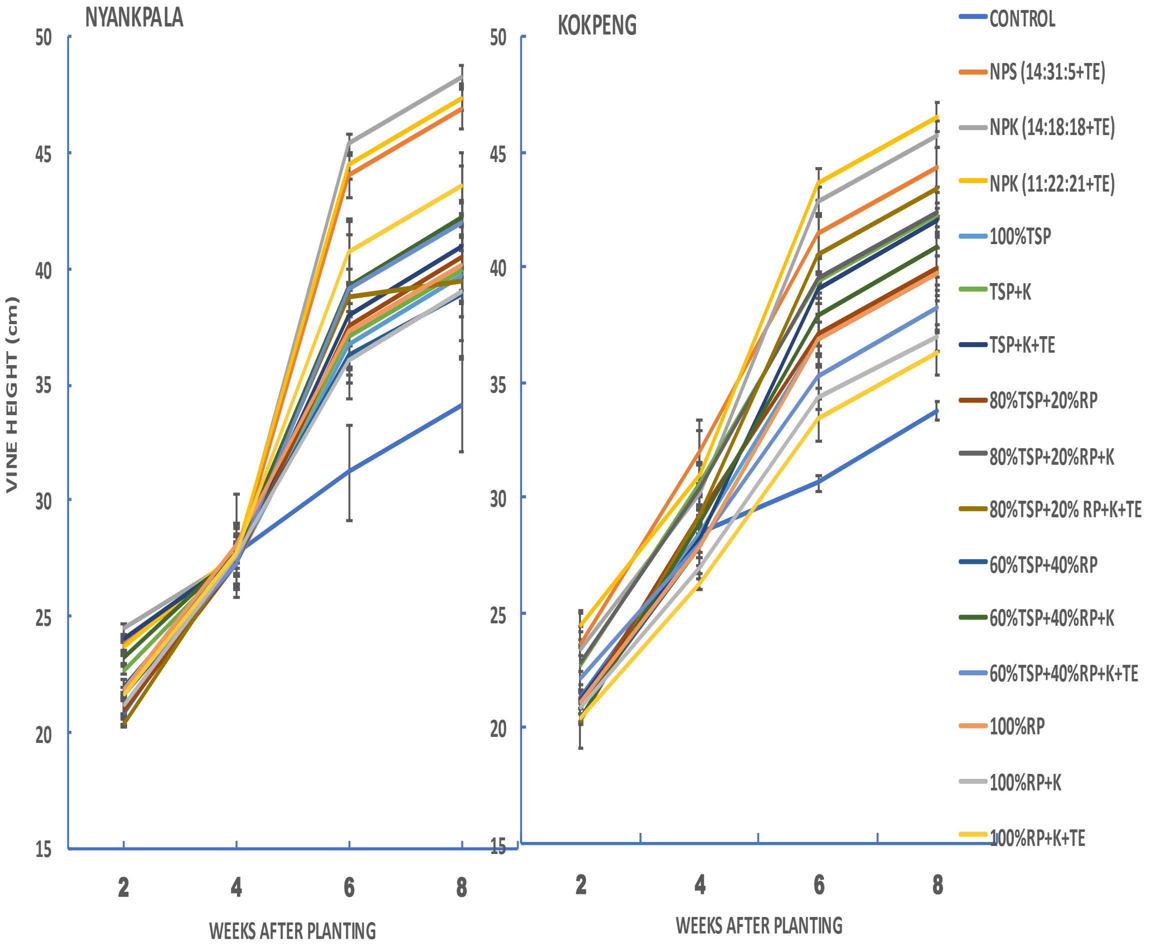

Figure 1: Effect of fertilizer treatment and Location on Vine height of Cowpea in 2,4,6 and 8 weeks after planting (WAP). Bars represent the standard error of the mean (SEM)

4.3 SPAD meter reading as an indicator of chlorophyll content

Fertilizer treatment and location were not significant in the weeks the greenery of the crop was assessed *($P> 0.05$)*. The mean effect of fertilizer treatments significantly ($P<0.001$) affected chlorophyll content of cowpea at 4 and 6 WAP, week 2 was, however, eliminated because the fertilizer treatments did not have a significant effect *($P=0.52$)*.

The three compound fertilizers NPK (11:22:21 + TE), NPS (14:31:5 + TE) and NPK (14:18:18 + TE) led in greenery of the leaves in both weeks 4 and 6 (Figure 2). The TSP and its substituted form in combination with K and the TE were not significantly different. The control recorded the lowest chlorophyll content among all the treatments.

It is worth highlighting that the main effect of the experimental locations significantly ($P<0.05$) affected chlorophyll content of cowpea at 2, 4 and 6 WAP. Except for 2 WAP, chlorophyll content of cowpea plants was higher at Nyankpala compared to Kokpeng at 4 and 6 WAP (Figure 3).

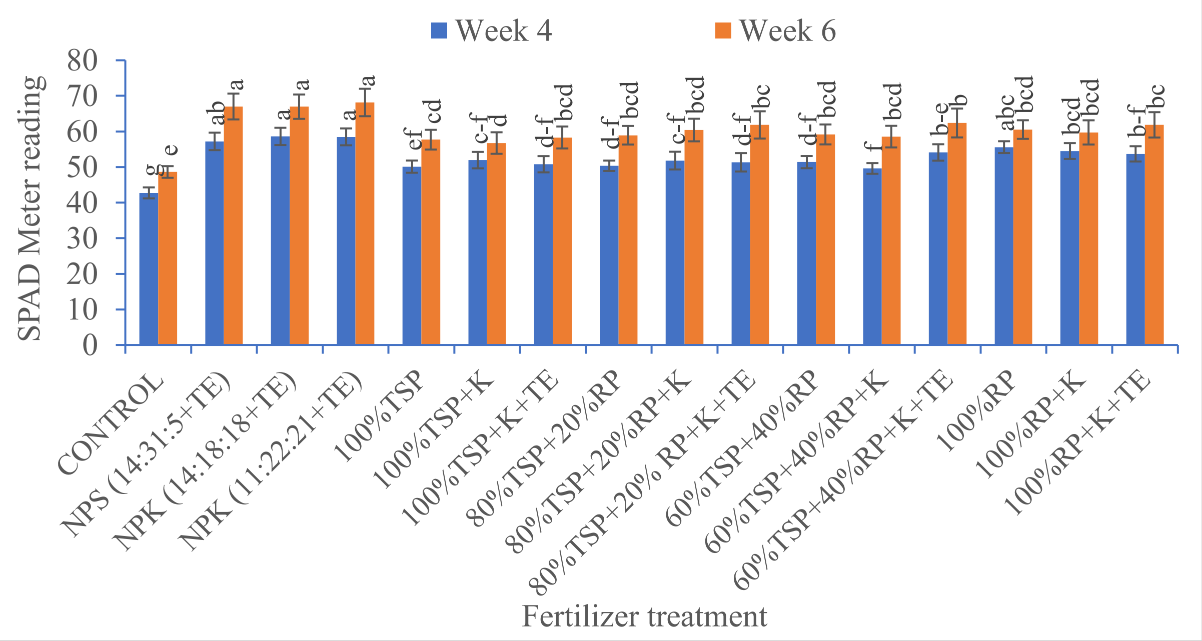

Figure 2: *Influence of fertilizer treatment on greenery of cowpea leaves at 4 and 6WAP. Bars represent SEM. Treatment means followed by the same letter(s) indicate that they were not significantly different (p <0.05) from each other*.

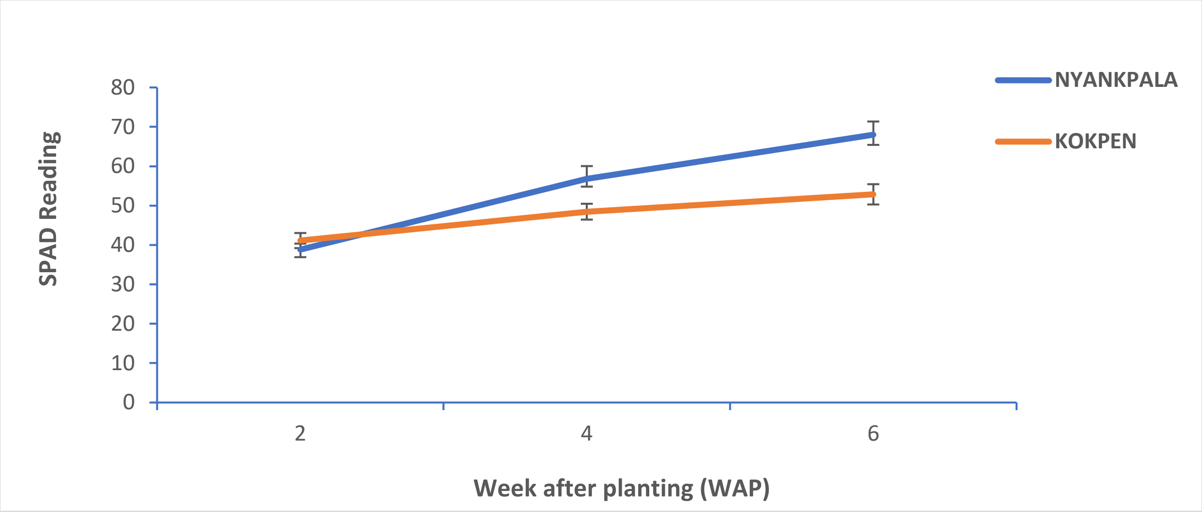

Figure 3: *Influence of experimental locations on SPAD meter reading of cowpea leaves. Error bars represent SEM*

4.4 Effect of fertilizer treatment and location on cowpea branching

The interaction between fertilizer treatment and location had a statistically significant effect ($P < 0.05$) on the number of branches per cowpea plant at 4 and 6 weeks after planting (WAP) (*Table 4*). At both experimental locations, the application of 100% RP supplemented with potassium and trace elements (TE) (100% RP + K + TE) resulted in the highest number of cowpea branches. The application of the two compound fertilizers, NPK (11:22:21) + TE and NPS (14:31:5) + TE, also produced significantly greater branching compared to the other fertilizer treatments across both experimental locations.

Conversely, the control treatment consistently resulted in the lowest number of branches in both Nyankpala and Kokpeng (Table 4). Notably, Nyankpala exhibited a marginally higher number of branches than Kokpeng across most treatments.

Table 4: Interaction effect of fertilizer treatment and Location on the Number of Branches of Cowpea at 4WAP, and 6WAP

		NUMBER OF COWPEA BRANCHES	
Location	**Treatment**	**4Weeks**	**6Weeks**
NYANKPALA	CONTROL	1.143^{mn}	2.214^{ijk}
	NPS (14:31:5) +TE	2.107^{cd}	3.571^{b-e}
	NPK (14:18:18) +TE	2^{cde}	3.5^{b-f}
	NPK (11:22:21) +TE	1.964^{cde}	3.464^{b-f}
	100%TSP	1.571^{e-m}	2.714^{e-j}
	100%TSP+K	1.464^{f-n}	2.679^{f-j}
	100%TSP+K+TE	1.964^{cde}	3.429^{b-f}
	80%TSP+20%RP	1.821^{d-j}	3.321^{b-f}
	80%TSP+20%RP+K	1.714^{d-k}	3^{d-i}
	80%TSP+20% RP+K+TE	1.75^{d-k}	3.214^{c-g}
	60%TSP+40%RP	1.75^{d-k}	3.107^{c-h}
	60%TSP+40%RP+K	1.893^{def}	3.357^{b-f}
	60%TSP+40%RP+K+TE	1.821^{d-j}	3.321^{b-f}
	100%RP	1.857^{d-h}	3.25^{c-g}
	100%RP+K	1.607^{e-l}	3^{d-i}
	100%RP+K+TE	**2.893^{a}**	**4.5^{a}**
KOKPENG	CONTROL	1.321^{k-n}	2.036^{jk}
	NPS (14:31:5) +TE	2.393^{bc}	3.929^{abc}
	NPK (14:18:18) +TE	2.107^{cd}	3.643^{bcd}
	NPK (11:22:21) +TE	1.893^{def}	3.179^{c-h}
	100%TSP	1.607^{e-l}	3.357^{b-f}
	100%TSP+K	0.536^{o}	1.786^{k}
	100%TSP+K+TE	1.857^{d-g}	3.643^{bcd}
	80%TSP+20%RP	1.393^{g-n}	3^{d-i}
	80%TSP+20%RP+K	1.393^{g-n}	2.821^{d-j}
	80%TSP+20% RP+K+TE	1.536^{e-m}	2.821^{d-j}
	60%TSP+40%RP	1.036^{n}	2.464^{g-k}
	60%TSP+40%RP+K	1.1791^{mn}	2.857^{d-j}
	60%TSP+40%RP+K+TE	1.357^{i-n}	2.714^{e-j}
	100%RP	1.357^{i-n}	2.357^{h-k}
	100%RP+K	1.679^{d-k}	3.536^{b-f}
	100%RP+K+TE	**2.607^{ab}**	**4.107^{ab}**
	Grand mean	**1.705**	**3.122**
	% C. V	**16**	**16**
	P.Value	**<.001****	**0.046***

KEYWORDS: *CV=coefficients of variation,*
(Treatment means followed by the same letter(s) (using Duncan multiple range test) indicate that they were not significantly different (P <0.05) from each other.)

4.5 Leaf area index (LAI)

The main fertilizer treatments significantly (*P<0.05*) influenced the leaf area index (LAI) of cowpea at 2, 4, 6 and 8 WAP.

Leaf area index (LAI) increased progressively across growth stages in response to fertilizer treatment application. The highest LAI values were consistently recorded under the compound fertilizer treatments such as NPK (14:18:18) + TE, NPK (11:22:21) + TE, and NPS (14:31:5) + TE. Fertilizer treatments involving partial substitution of TSP with RP supplemented with K and trace elements (Zn and B), particularly 80% TSP + 20% RP + K + TE and 60% TSP + 40% RP + K + TE, produced higher LAI, with values comparable to the compound fertilizers (Figure 4).

It was observed that, addition of K improved LAI in both TSP and RP based Fertilizer treatments, such as 100% TSP + K, 100% TSP + K + TE, 80% TSP + 20% RP + K, and 100% RP + K. Sole application of RP (100% RP) showed moderate improvement in Leaf area index, particularly when combined with K and trace elements (100% RP + K + TE) while the sole applications of TSP (100% TSP) and 40% TSP replacement with RP (60% TSP + 40% RP) showed a relatively low Leaf area index (LAI).

The control treatment consistently recorded the lowest Leaf area index (LAI) across all growth stages (Figure 4).

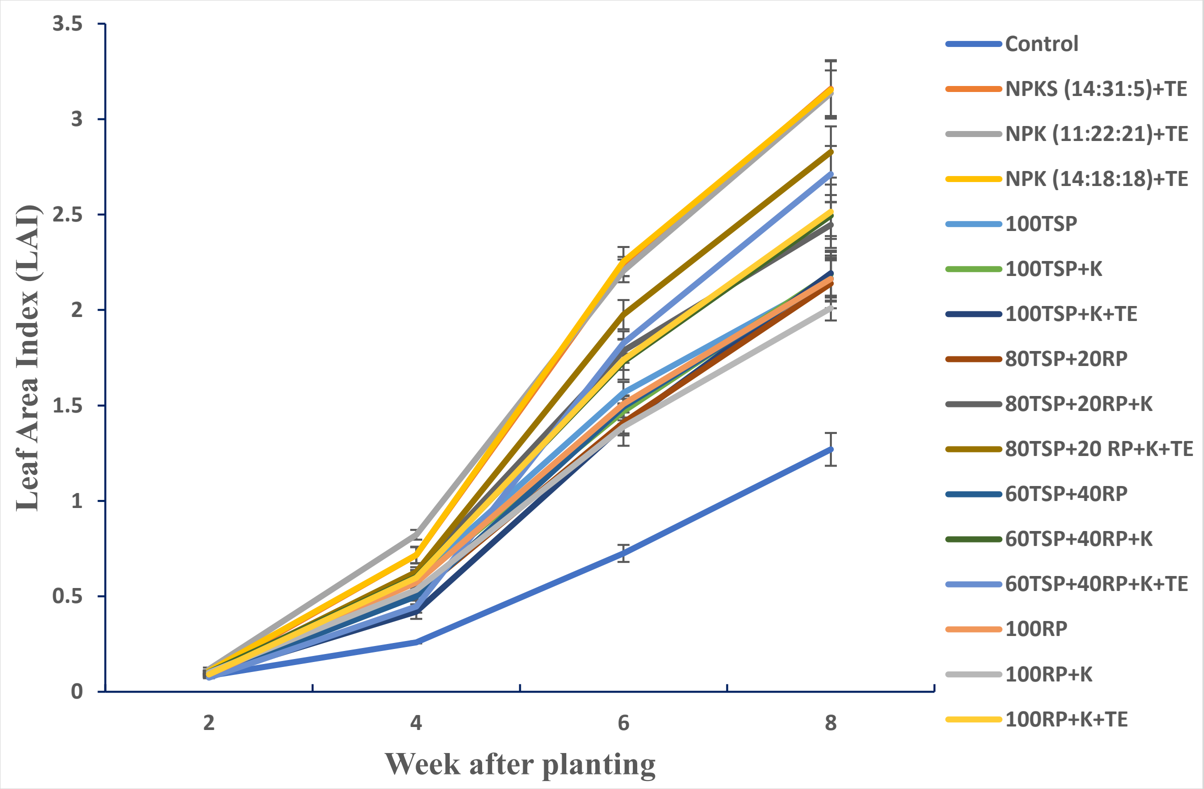

Figure 4: *Effect of fertilizer treatment on Leaf Area Index of Cowpea at 2,4,6, and 8 WAP. Bars represent SEM.*

4.6 Flowering and Maturity

The fertilizer treatments significantly *($P<0.001$)* influenced crop phonological development (*Figure 5*). The control treatment recorded the longest time to 50% flowering. Similarly, the 100% RP +K application resulted in relatively late flowering. In contrast, combined fertilizer treatments such as TSP and RP with potassium, with or without micronutrients (TE), particularly the 20% TSP replacement with RP and addition of K (80% TSP + 20% RP + K) and (60% TSP + 40% RP + K + TE), significantly reduced the number of days to 50% flowering, (Figure 5). The compound fertilizers and 100%TSP used a similar number of days to 50% flowering

Days to maturity followed a trend similar to flowering and varied significantly *($P<0.001$)* among treatments. The control treatment exhibited the longest time to maturity, and the fertilizer-treated plots, especially the compound fertilizers (NPS 14:31:5+TE) and (NPK 11:22:21+TE) and Sole TSP, 40%TSP replacement with RP (60%TSP+40%RP) and 100%RP+K fertilizer treatments, reached physiological maturity earlier *(*Figure *5).*

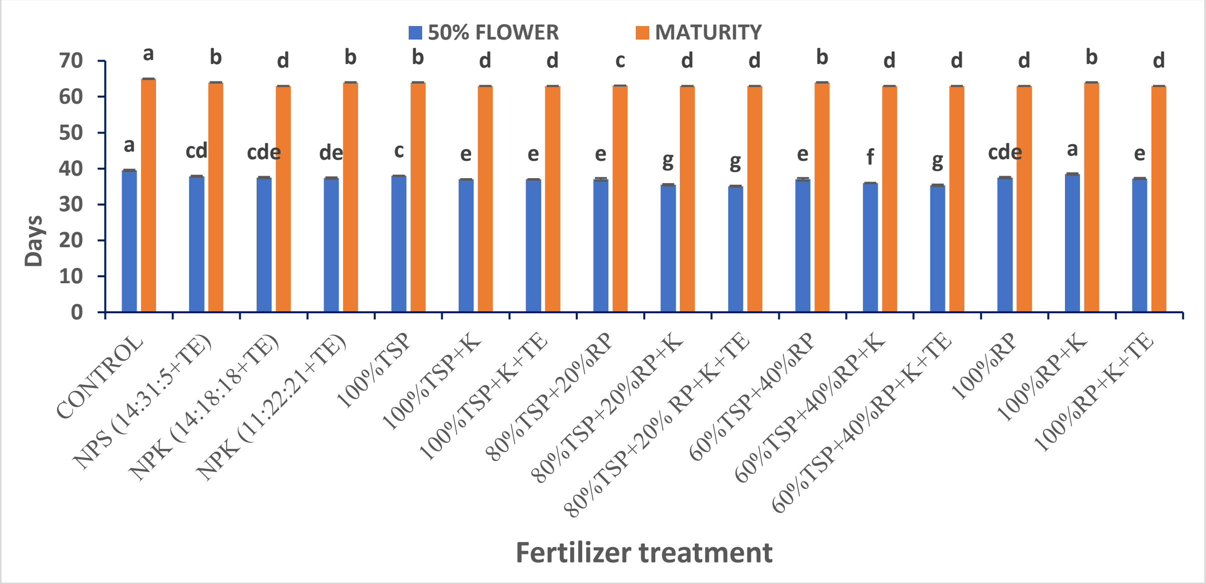

Figure 5: *Influence of fertilizer treatment on Days to 50% Flowering and 50% Maturity of cowpea. Bars represent SEM. Treatment means followed by the same letter(s) indicate that they were not significantly different (P <0.05) from each other.*

4.7 Nodule number and weight

The number of nodules recorded by the cowpea plants was significantly (*P<0.001*) affected by the fertilizer treatments. The number of nodules was highest among cowpea plants treated with compound fertilizer, NPK (11:22:21+TE), which outperformed the other two compound fertilizers, NPK (14:18:18+TE) and NPS (14:31:5+TE) (Figure 6). Replacement of part of TSP with 20% and 40% RP and with the additions of K and TE resulted in positive advancement on nodule formation more than the TSP only (Figure 6). The addition of trace elements to 100% RP+K led to substantial increment in nodulation. The plants from the control plots recorded the least number of nodules (Figure 6).

The nodules weight was significantly *($P<0.001$)* affected by fertilizer treatment and location (Figure 7). The heaviest nodules was recorded by cowpea plants treated with compound fertilizer NPK (11:22:21+TE) in Kokpeng (Figure 7). Similar response was observed at Nyankpala, though the weight was lower. Meanwhile, the 20% TSP replacement with RP coupled with K and TE combinations (80% TSP + 20% RP + K + TE) shows a significant nodule weight increase over the 100%TSP in both locations (Figure 7). 20% and 40 %TSP substitution with RP and in combination with the trace elements (Zn and B) led to substantial nodule development in both locations. The lowest nodule weight was obtained by plants from the control plots in both experimental locations (Figure 7). However, generally the nodule weight from plants in Kokpeng was higher than those from the Nyankpala experimental fields.

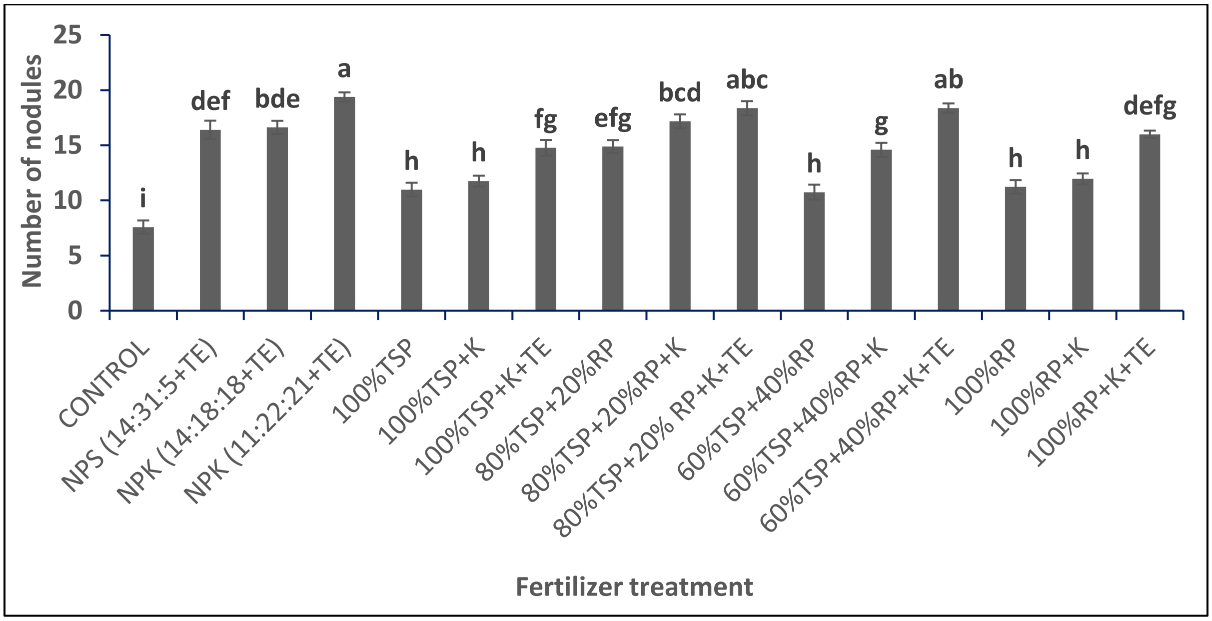

Figure 6: *Effect of fertilizer treatment on number of nodules of cowpea. Bars represent SEM. Treatment means followed by the same letter(s) indicate that they were not significantly different ($P<0.05$) from each other*

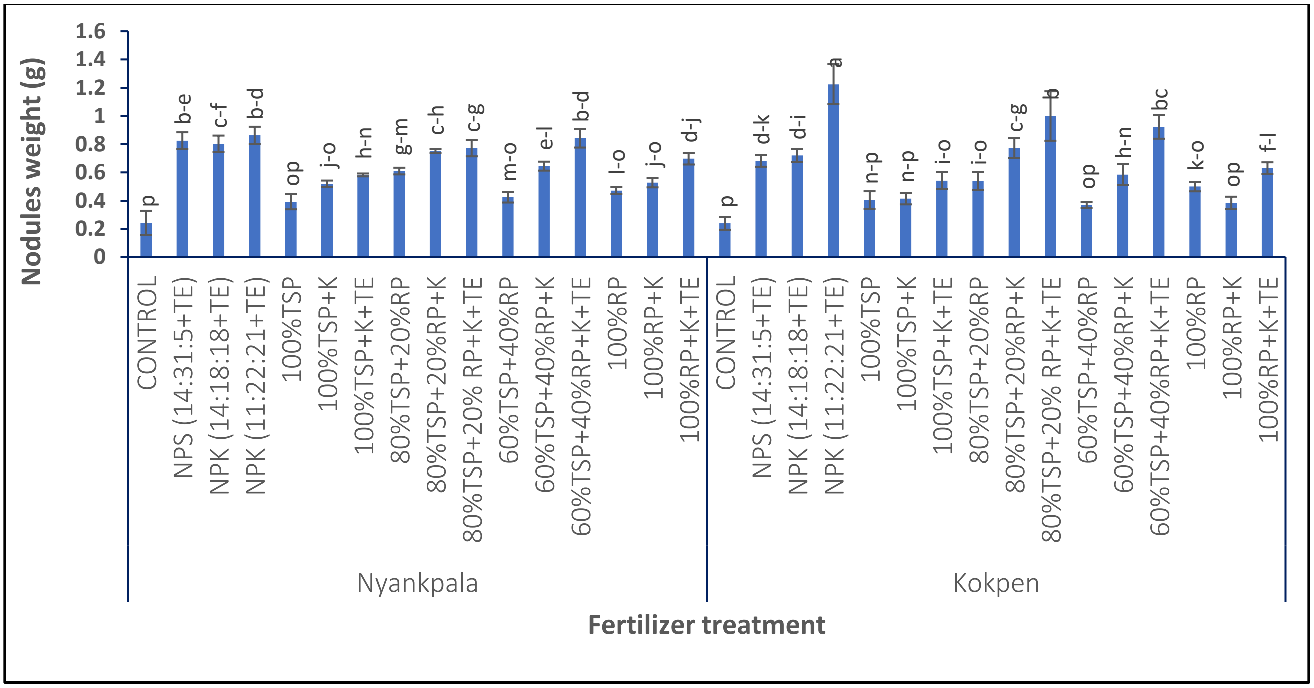

Figure 7: *Interaction effect of fertilizer treatment and location on nodule weight of cowpea. Bars represent SEM. Treatment means followed by the same letter(s) indicate that they were not significantly different (p <0.05) from each other.*

4.8 Dry shoot biomass

Dry shoot biomass of cowpea was significantly (*P<0.001*) affected by fertilizer treatment and the location where the trial was sited. The results revealed that dry total biomass was highest for plants in plots treated with compound fertilizers NPK (11:22:21+TE), NPK (14:18:18+TE), and NPS (14:31:5+TE) in both experimental locations (*Figure 8*). At Nyankpala, 100%TSP in combination with K and or the trace elements produced less biomass when compared with 80%TSP+20%RP+K, 80%TSP+20%RP+K+TE and 60%TSP+40%RP+K. At Kokpeng, 100%TSP+K+TE performed better than it did at Nyankpala. The treatment's performance was similar to the compound fertilizers (Figure 8) Plants in the control plots recorded the least fresh and dry total biomass *(*Figure 8*)*.

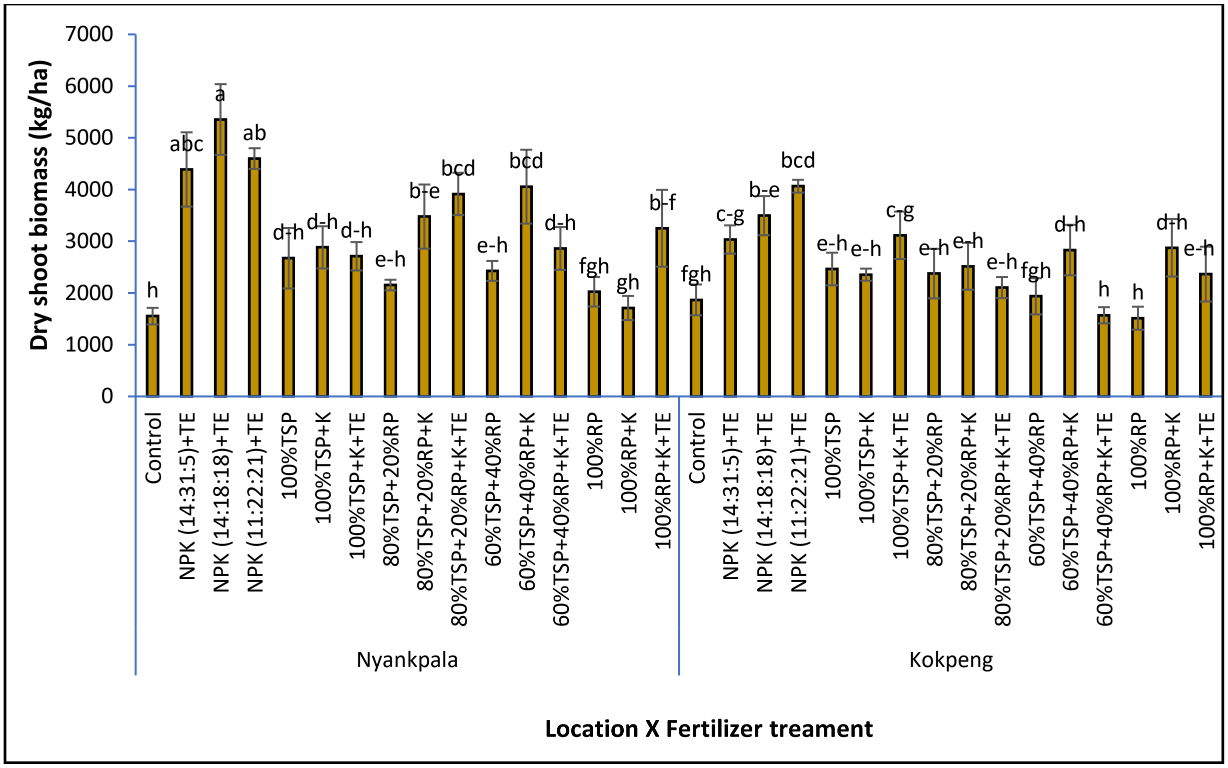

Figure 8: *Effect of fertilizer treatment and Location on Total Shoot Biomass of Cowpea. Bars represent SEM. Treatment means followed by the same letter(s) indicate that they were not significantly different (P <0.05) from each other.*

4.9 Pod length

The pod length of the cowpea was significantly *($P<0.001$)* affected by the main effect of fertilizer treatment. Substitution of 20 and 40 % of TSP with RP in addition to K and TE (60% TSP + 40% RP + K + TE) and (80% TSP + 20% RP + K + TE) was statistically superior in the longest pods to most other Fertilizer treatments, followed by 60% TSP + 40% RP + K (Figure 9). The compound fertilizer treatments, such as NPS (14:31:5) + TE, NPK (14:18:18) + TE, and NPK (11:22:21) + TE, also resulted in significantly longer pods compared to the control. Sole applications of TSP and RP (100% TSP) and (100% RP) produced shorter pod length, although improvements were observed when TSP and RP were supplemented with K and TE (100% TSP + K, 100% TSP + K +

TE, and 100% RP + K + TE). The control treatment recorded the shortest average pod length (Figure 9).

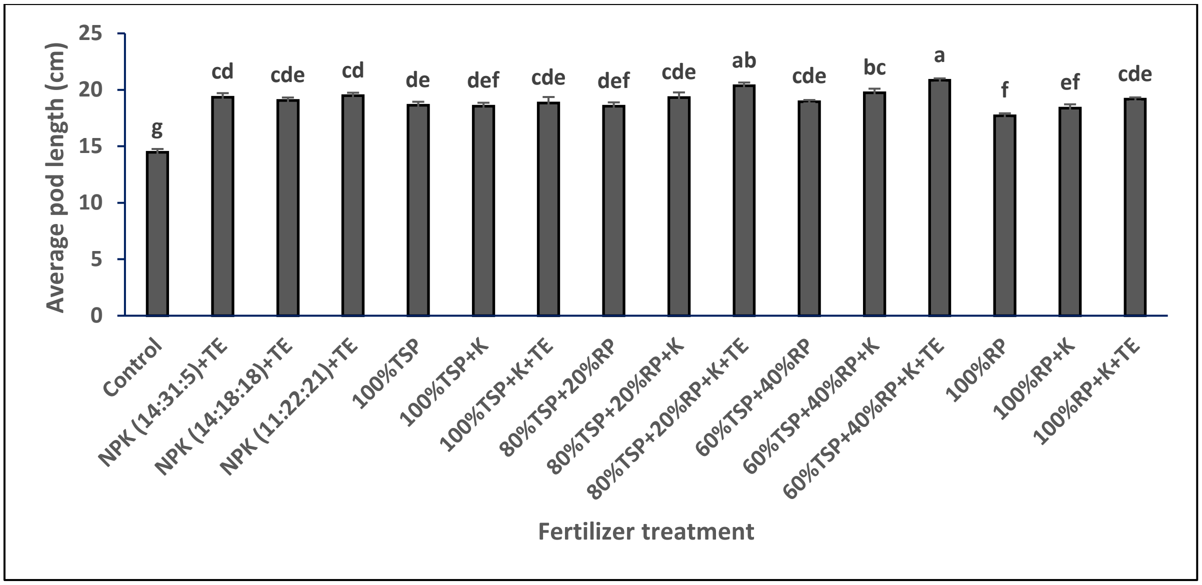

Figure 9: *Influence of fertilizer treatment on Pod length of Cowpea. Bars represent SEM. Treatment means followed by the same letter(s) indicate that they were not significantly different (P <0.05) from each other.*

4.10 Number of seeds per pod

Although the effect of the fertilizer treatments on the number of seeds per pod did not vary between the two experimental locations *($P>0.103$)* the main effect of fertilizer treatments significantly *($P<0.001$)* affected the number of seeds per pods. The 20% and 40% TSP replacement with RP in addition to K and TE, significantly increased the number of seeds better than 100% TSP and the other treatments (*Figure 10*). It was observed that mere substitution of the 20 and 40% TSP with RP (80% TSP + 20% RP) and (60% TSP + 40% RP) did not bring difference between the two treatments and 100% TSP, the difference occurred when K and the trace elements were added (*Figure 10*). However, the 100% replacement of TSP with RP was at par with the 100% TSP + K incorporated. Meanwhile, the compound fertilizer, NPK (11:22:22 +TE) outperformed the other compound fertilizers, NPS (14:31:5 +TE) and NPK (14:18:18 + TE) with the control plot recording the least number of seeds per pod (*Figure 10*).

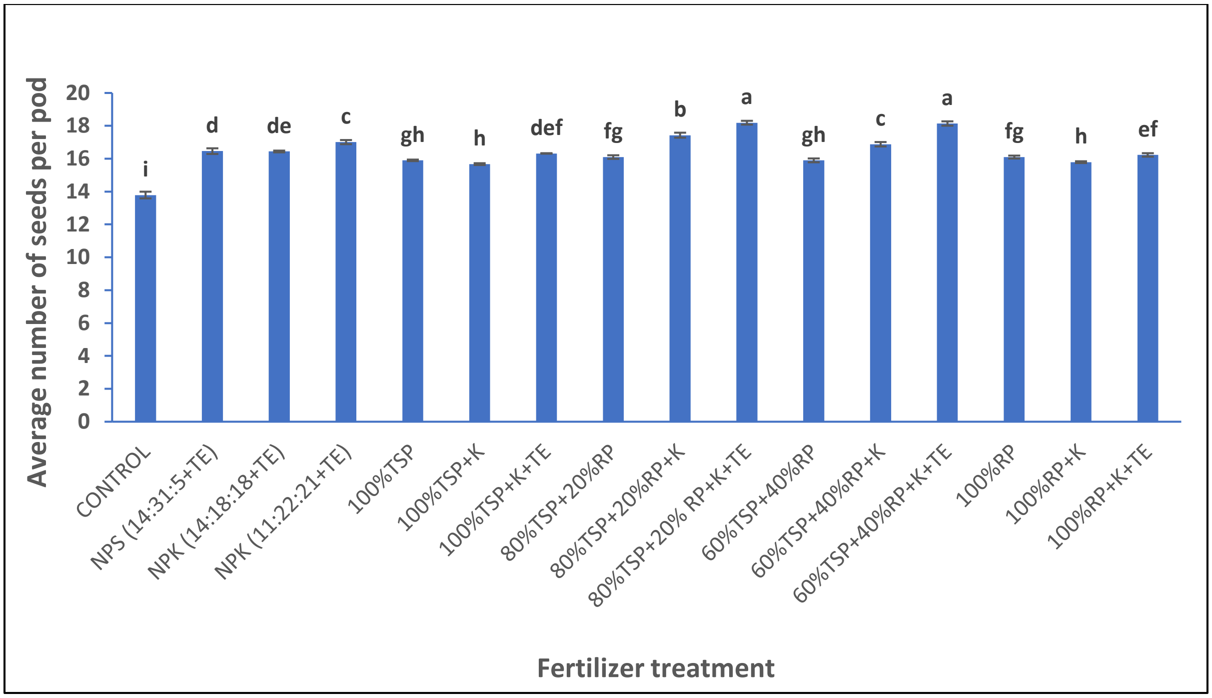

Figure 10: *Influence of fertilizer treatment on the Number of seeds per pod of Cowpea. Bars represent SEM. Treatment means followed by the same letter(s) indicate that they were not significantly different (P <0.05) from each other.*

4.11 Hundred-seed weight

The main effect of fertilizer treatment significantly *(P <0.001)* affected hundred-seed weight. Hundred- seed weight was highest in the 20% TSP substitution with RP in addition to K (80%TSP + 20% RP + K), which was, statistically similar to 40% substitution with RP in addition to K (60%TSP + 40%RP + K) (Figure 11). Apparently, the 100% TSP substitutions with RP and its K components produced seeds as dense as 100% TSP +K (*Figure 11*). The compound fertilizer, NPK (14:18:18 + TE), outperformed the other compound fertilizers, NPS (14:31:5 TE) and NPK (11:22:22 TE). Meanwhile, the least hundred seed weight among the treatments was recorded by cowpea plants from the control plots (*Figure 11*).

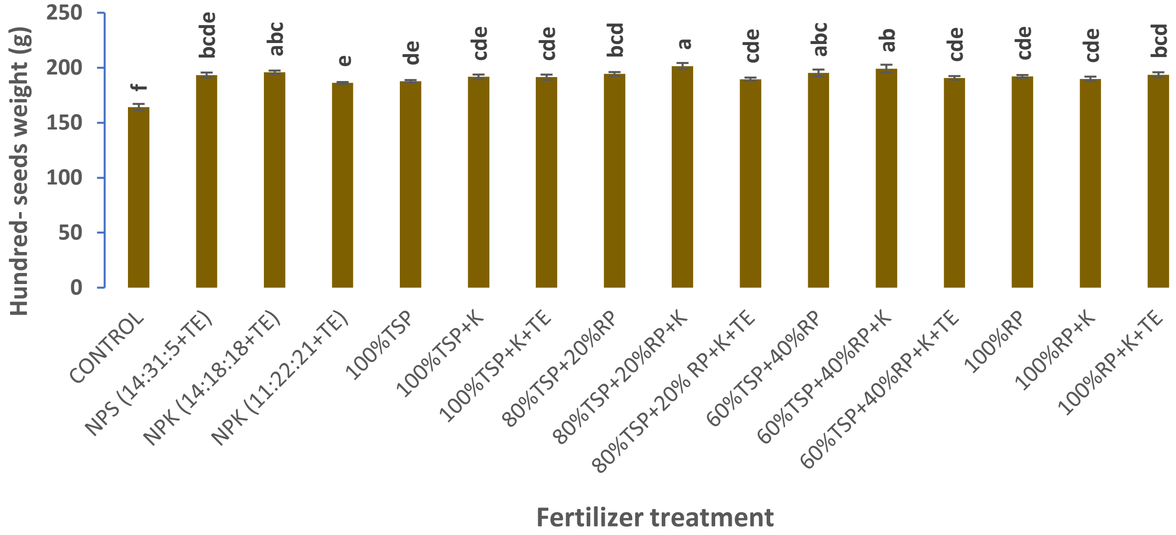

Figure 11: *Influence of fertilizer treatment on average hundred-seed weight of cowpea. Bars represent SEM. Treatment means followed by the same letter(s) indicate that they were not significantly different (p <0.05) from each other*

4.12 Grain yield

The grain yield of cowpea was significantly *(P <0.015)* affected by fertilizer treatment and the location the treatment was applied. The performance of the fertilizer treatments was generally higher in Nyankpala compared to Kokpeng (Figure 12). The highest grain yield was recorded in the 20% and 40% TSP replacement with RP in addition to K and TE (60%TSP + 40%RP + K + TE) and (80%TSP + 20%RP + K + TE) in Nyankpala. They outperformed the same treatments at the Kokpeng location (Figure 12). At Kokpeng the highest yield was recorded on plots treated with 80%TSP + 20%RP + K which was not significantly different from 80%TSP + 20%RP + K+TE and a number of treatments with 40% TSP substitution. The 100% TSP replacement with RP in combination with K and TE, that is (100%RP+K+TE) performed similarly as 100%TSP+K+TE as well as the compound fertilizers, NPK (14:18:18 + TE), NPS (14:31:5 TE) and NPK (11:22:22

TE) (Figure 12). The lowest grain yield among the fertilizer treatments was recorded in the control plots in both experimental locations (Figure 12).

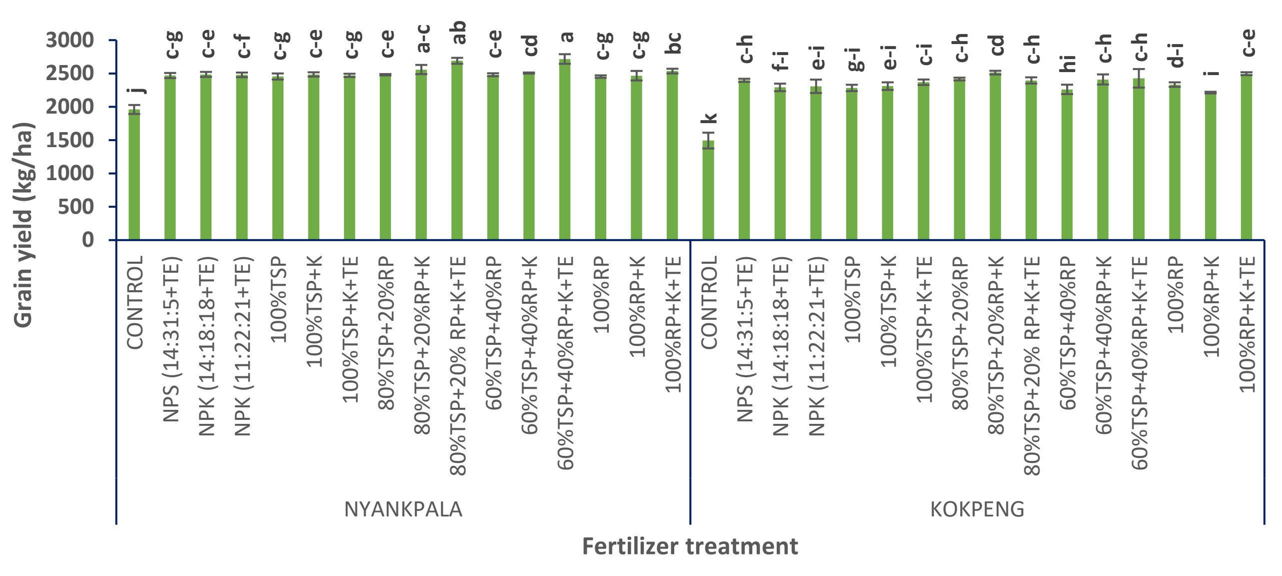

Figure 12: *Influence of fertilizer treatment and location on grain yield kg/ha of cowpea. Bars represent SEM. Treatment means followed by the same letter(s) indicate that they were not significantly different (P <0.05) from each other.*

4.13 Influence of fertilizer treatment on root architecture

4.13.1 Total root volume

Figure 13 shows clear significant *(P<.001)* differences in total root volume across the fertilizer treatments. The compound fertilizers NPS (14:31: 5) +TE, NPK (14:18:18) +TE and NPK (11:22:21) +TE produced the largest total root volumes, with noticeably higher medians and extended upper whiskers compared to all other treatments, including the control. The 100%TSP treatment resulted in moderate root volumes, while combinations such as 100%TSP+K, 80%TSP+20%RP, 80%TSP+20%RP+K, and 80%TSP+20%RP+TE recorded higher volumes than TSP alone. Rock phosphate treatments containing 40%RP, 80%RP, and 100%RP consistently produced the smallest total root volumes. Additions of K and trace elements to treatments such as 100%RP+K and 100%RP+TE improved root volume slightly but remained far below the compound fertilizer treatments (Figure 13).

A single box-whisker below represents the averages of fertilizer treatment per plot in the study area. The black horizontal line inside the box represents the median (50th percentile), the top and bottom boundaries of the box represent the 75th and 25th percentiles, while the whiskers indicate the extreme values (5% and 95%) excluding outliers. The black dots show the outliers.

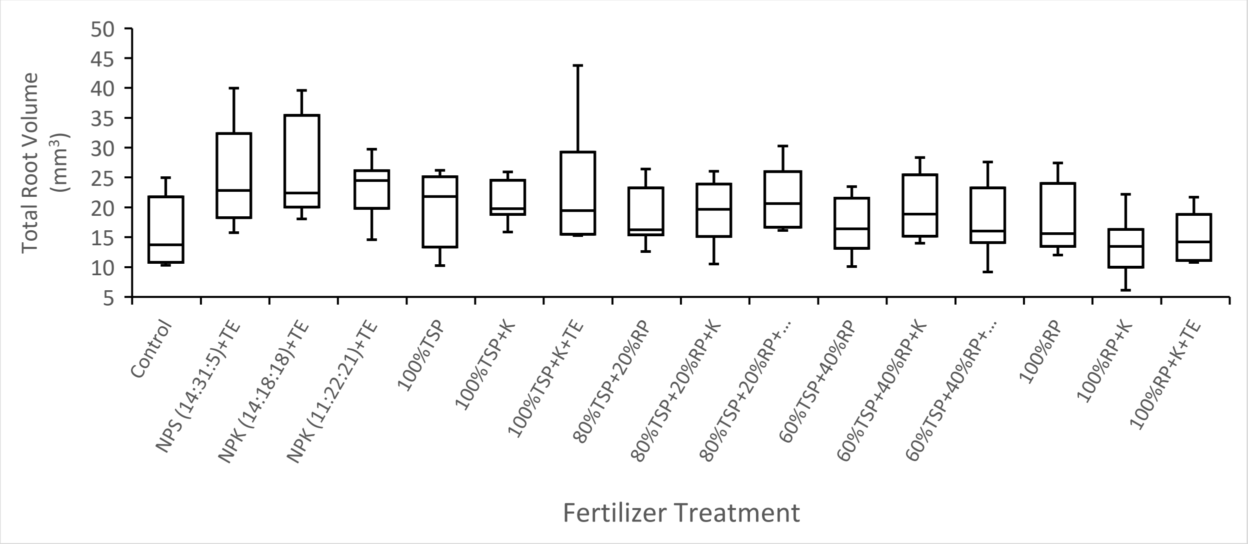

Figure 13: *Box-whisker plots as influenced by fertilizer treatment on root volume architecture of cowpea.*

4.13.2 Total root length

Total root length (Figure 14) was significantly *(P<.001)* affected by fertilizer treatments. The maximum length, which produced the longest and most extensive root systems among all fertilizer treatments, occurred under NPS (14:31:5) + TE, followed closely by NPK (14:18:18) + TE and NPK (11:22:21) +TE, clearly exceeded the untreated control plot and all P source fertilizer treatments.

The 100%TSP fertilizer treatment produced intermediate total lengths, with increases observed when TSP was combined with K and the trace elements, particularly in 100%TSP+K, 80%TSP+20%RP, 80%TSP+20%RP+K, and 80%TSP+20%RP+TE. The RP treatments, containing 100%RP, 40RP and 20RP, showed the shortest root lengths. The RP fertilizer treatments such as 100%RP+K and 100%RP+TE showed modest improvements (Figure 14).

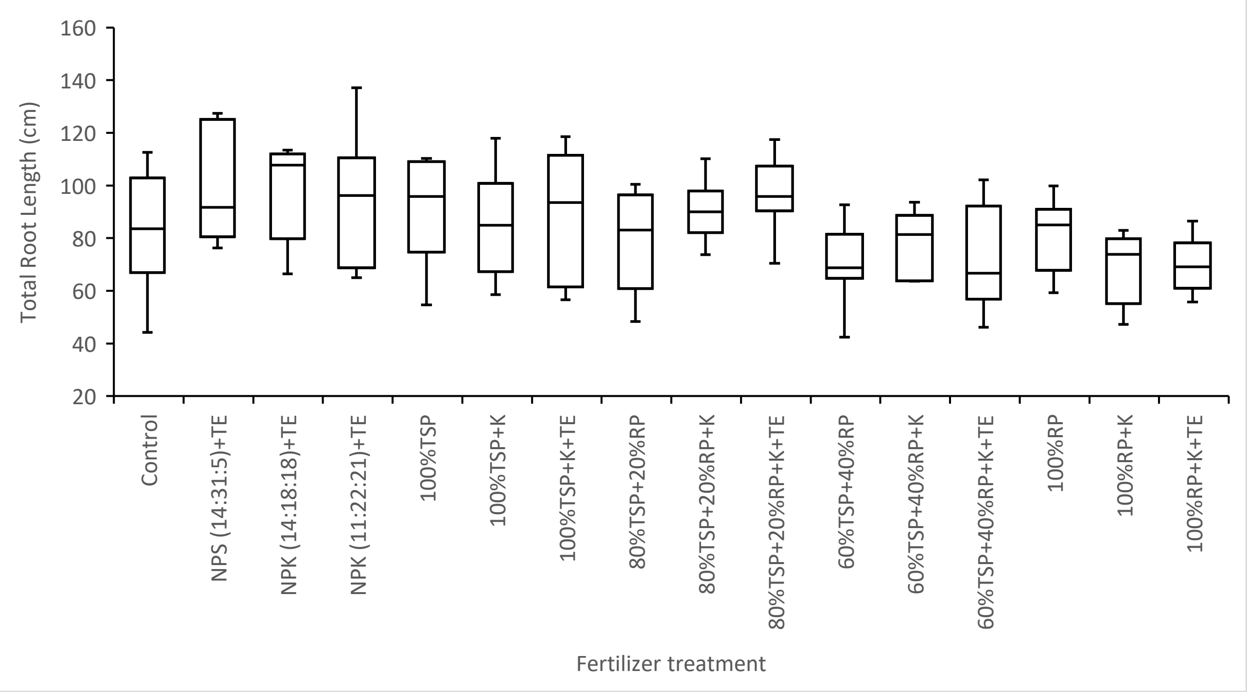

Figure 14: *Box-whisker plots as influenced by fertilizer treatment on root architecture of cowpea.*

4.14 Partial budget analysis of cowpea

Table 5 presents the partial budget analysis pertinent to all treatments applied to cowpea in the two communities. As previously noted, this analysis entails the computation of partial budget analysis which include analytical techniques such as dominance analysis and marginal analysis. The results showed that with the exception of three treatments the net benefit of all the rest were dominated by their total variable cost and were excluded in marginal rate of return analysis. The three that were not dominated were 100%RP, 80%TSP+20%RP and 80%TSP+20%RP+K in increasing order of marginal rate of returns (Table 5). The 100% TSP was dominated by 80%TSP+20%RP though the returns from it was not appreciative.

Table 5: Partial budget analysis of fertilizer treatments applied to cowpea, indicating the marginal rate of return (MRR) for cowpea production. Net benefits highlighted were dominated and were excluded in subsequent marginal analysis

Fertilizer Treatment	**Total variable cost (TVC) (GHS)**	**Revenue (GHS)**	**Net benefit (GHS)**	**ΔTVC**	**ΔNB**	**MRR**
Control	0	20716.05	20716.05			
100%RP	1280	28076.72	26796.72	1280	6080.67	475.05
TSP	1935.2	28425.54	26490.34			
80%TSP+20%RP	2102.1	29383.68	27281.58	822.1	484.86	58.98
60%TSP+40%RP	2281.8	28451.73	26169.93			
100%RP+K	2580	29496.62	26916.62			
NPS+TE (14:31:5+TE)	3194.4	29194.14	25999.74			
TSP + K	3235.2	28772.72	25537.52			
80%TSP+20%RP+K	3402.1	31050.15	27648.05	1300	366.47	28.19
60%TSP+40%RP+K	3581.8	29496.62	25914.82			
NPK(14:18:18+TE)	5164.6	28659.17	23494.57			
100%RP+K+TE	13863	30834.14	16971.18			
TSP + K+TE	14518.2	29038.46	14520.3			
80%TSP+20%RP+K+TE	14685.1	31154.34	16469.28			
60%TSP+40%RP+K+TE	14864.8	31508.06	16643.3			
NPK (11:22:21+TE)	5164.6	29358.32	24193.72			

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of fertilization on vegetative parameters

5.1.1 Vine length

The fertilization greatly enhanced the vine length of the cowpea. The inclusion of Zn and B in compound fertilizers, NPK (11:22:21), (14:18:18), and NPS (14:31:5) formulations, enhanced vine growth of the crop across the experimental locations. Compound fertilizer enhancing vine growth of cowpea has been reported by Nwokwu *et al.* (2020). They submitted that the application of NPK fertilizers at varying rates consistently enhances plant length, with optimal results typically observed at 100% recommended dose or higher. The study by Chavan *et al.* (2012), highlighted the effects of various fertilizer treatments, including NPK and micronutrients (Zinc and Boron) on the growth and yield of crops such as cowpea (*Vigna unguiculata*).

TSP with potassium combined and when 20% of it was substituted with Rock phosphate also improved vine growth. This shows that partial substitution of TSP with low cost phosphorus source is not detrimental to the growth of the crop. These findings conform to the study by Akinremi *et al.* (2017), who observed that TSP + RP + K combination supplies a sustained release of phosphorus, which supports long-term root development and overall growth, while potassium aids in water regulation and stress tolerance. When combined, these fertilizers ensure that cowpea plants have the necessary nutrients to support robust growth, leading to taller plants with better yield.

5.1.2 Leaf chlorophyll content measurements

SPAD meter readings are increasingly recognized as a reliable non-destructive method for estimating chlorophyll content in crops. The SPAD-502 chlorophyll meter correlates well with chlorophyll concentrations, demonstrating a strong linear (r = 0.8) and potential for rapid assessment in various plant species (Nurbaiti *et al.,* 2025). The study of chlorophyll content in cowpea reveals a significant insight into the effects of various nutrient formulations.

Research shows that chlorophyll concentration is closely linked to the physiological and metabolic status of plants, which can be influenced by nutrients availability and uptake (Jones *et al..,* 2007).

In this study, NPK compound fertilizers and the addition of micronutrients like Zinc and Boron significantly improved the chlorophyll content in cowpea. This improvement would likely be associated with better plant health, enhanced growth, and potentially increased yields. The optimal proportion of nitrogen, phosphorus, potassium and or Sulphur in the one compound fertilizer, NPS+TE (14:31:5 + Zn, B), facilitated the synthesis of chlorophyll, an essential component for the process of photosynthesis (Manu *et al.,*2020).

In a study by Sebetha *et al*. (2010), the comparative analysis of different compound fertilizers formulations such as NPS 14:31:5 and NPK 14:18:18 containing trace elements ZN and B indicates that these fertilizers and micronutrients can yield similar chlorophyll development, highlighting the importance of tailored nutrient management in cowpea production.

Results from this research show that lack of nitrogen affected the greenery of the crop. The effect on 100% TSP, and its substituted forms in combination with K had less pronounced effect on the plant greenness when compared with the compound fertilizers which had nitrogen. Increased nitrogen levels enhance photosynthesis nitrogen use efficiency in soyabean by optimizing nitrogen allocation to photosynthetic components, such as carboxylation and electron transport systems (Xu *et al..,* 2025). Optimizing nitrogen application can enhance phosphorus use efficiency, suggesting that balanced fertilization strategies are essential for sustainable agriculture (Hu *et al..,*2023). Phosphorus, a crucial macronutrient for plant growth, significantly influences photosynthesis and chlorophyll formation. According to Singh and Reddy's (2015) phosphorus deficiency causes declines in photosynthesis measurements and chlorophyll fluorescence, indicating a reduction in chlorophyll levels. Efficient phosphorus utilization is therefore crucial for maximizing crop yields, as phosphorus is a limiting nutrient alongside nitrogen (Ebbisa 2022).

5.1.3 Leaf Area Index (LAI)

The widest LAI was consistently observed in plots treated with compound fertilizers, particularly NPK (11:22:21 +TE), NPK (14:18:18 +TE). These fertilizers, with balanced ratios of nitrogen, phosphorus, and potassium or Sulphur along with essential trace elements (TE), promoted vigorous vegetative growth, resulting in more expansive leaf canopies.

Nitrogen, in particular, is a key driver of leaf expansion and chlorophyll synthesis, directly contributing to LAI (Imas and Megan, 2007).

Interestingly, treatments involving partial substitution of Triple Superphosphate with Rock phosphate, specifically 20% and 40% RP combined with K and TE (Zn and B), were statistically at par with the best-performing treatments. This suggests that using both readily available and slow-release P sources, can effectively support leaf development when complemented with K and micronutrient. Studies by Biswas *et al.* (2015) and Kumar *et al.* (2019) support this finding noting improved vegetative growth and nutrient use efficiency in legumes under combined TSP and RP applications.

Conversely, plots treated with 100% TSP or with K and TE were not among the top treatments that improved LAI. Their performances were similar to 100% substitution of TSP with rock phosphate. This clearly indicates that TSP substitution with rock phosphate was not harmful to leaf production.

5.1.4 Cowpea branching

The superior performance of the 100% Rock Phosphate combined with potassium and trace elements (100% TSP + K + TE) in promoting early branching is consistent with the known role of phosphorus in stimulating lateral shoot formation in legumes (Giller, 2001; Reddy *et al.,* 2010). According to Nziguheba *et al.* (2010), rock phosphate, despite being generally insoluble, becomes more accessible in acidic or biologically active soils, particularly when it is administered in finely powdered form or in conjunction with other nutrients and organic matter. The inclusion of TE (Zinc and Boron) and potassium most likely improved overall plant vigour and nutrient uptake efficiency, which in turn promoted branching and vegetative development.

The compound fertilizers, NPK (11:22:21 + TE) and NPS (14:31:5 + TE), also produced significantly high numbers of branches, further supporting the importance of tailored nutrient application in cowpea production. These fertilizer formulations supply essential nutrients including nitrogen, phosphorus, and sulphur as in NPS (14:31:5 + TE). In some compound fertilizers, they also provide potassium and important micronutrients such as zinc (Zn) and boron (B), which play key roles in various enzymatic and physiological processes in legumes (Singh et al., 2020). Micronutrients play a synergistic role in enhancing nitrogen fixation, chlorophyll synthesis, and metabolic activity, all of which influence vegetative growth and branching (Alloway, 2008).

The control treatment, which received no external nutrient input, consistently produced the lowest number of branches at both Nyankpala and Kokpeng, underscoring the poor inherent fertility of the soils. This result aligns with findings by Vanlauwe *et al.* (2011), who highlighted that legume productivity is strongly constrained by low soil fertility in sub-Saharan Africa, especially phosphorus deficiency. Cowpea is particularly responsive to phosphorus fertilization due to its relatively shallow root system and high P requirement for nodule development and biological nitrogen fixation (Dakora *et al.,* 2013).

While Nyankpala exhibited slightly greater branching than Kokpeng across most fertilizer treatments, this difference may be attributed to site-specific soil characteristics, including differences in percentage nitrogen (0.08%), (0.078%) or inherent phosphorus availability(8.51ug/g) (4.510ug/g) in Nyankpala and Kokpeng respectively. Location x Fertilizer treatment interactions are common in field experiments, as soil chemical and physical properties can significantly influence nutrient availability and plant response (FAO, 2019).

By 8th WAP, the fertilizer treatment x location interaction was no longer significant, although the main effect of fertilizer treatment remained significant. This suggests that the influence of fertilizer type on cowpea branching persisted through later stages of vegetative growth, independent of location. The compound fertilizers, NPK (11:22:21 + TE), NPS (14:31:5 + TE), and NPK (14:18:18 + TE) continued to support higher branching, likely due to their sustained nutrient release and balanced formulation.

Fertilizer treatments involving partial substitution of TSP with RP at 20% and 40% replacement levels, combined with K and TE, also performed well. This indicates the potential of RP as a sustainable alternative to TSP, especially when combined with other nutrients that enhance P availability and uptake (Chien *et al.,* 2009). The TSP, though highly soluble, can rapidly be fixed in the soil, whereas RP provides a slow and prolonged release of phosphorus. The use of RP in combination with TE and K may thus provide a more sustained nutrient supply conducive to prolonged vegetative development, as evidenced by branching patterns at 8 WAP.

Overall, the results demonstrate the importance of balanced fertilization incorporating macro- and micronutrients for optimizing cowpea growth. The consistent poor performance of the control emphasizes the necessity for soil fertility management to enhance productivity in nutrient-depleted soils, particularly in rain-fed farming.

5.2 Effect of fertilization on nitrogen fixation and yield parameters

5.2.1 Nodulation and nodule weight

This study clearly showed how fertilizer formulations can effectively promote biological nitrogen fixation through nodule formation. Compared to other compound fertilizer combinations like NPK (14:18:18 + TE) and NPS (14:31:5 + TE), cowpea plants treated with NPK (11:22:21 + TE) produced the largest amount of nodules in terms of number. This suggests that the specific nutritional balance in NPK (11:22:21), perhaps as a result of its ideal ratio of potassium to phosphorus and the presence of trace elements (zinc, and boron), produced a more favourable environment for nodulation. Since P promotes root growth and the energy-intensive process of nitrogen fixation, its significance in legume nodulation is well documented (Graham *et al.,* 2003). This may also be explained by the recognized effects of micronutrients on rhizobial colonization and nod gene expression (Giller, 2001; Singh *et al.* 2011).

Partial replacement of TSP with RP, specifically up to 40% and 20% substitution levels, also led to a significant increase in the number of nodules when supplemented with K and TE. These results suggest that RP, despite its lower solubility compared to TSP, can still effectively contribute to nodulation when used in combination with other nutrients, especially in acidic or phosphorus-deficient soils (Chien *et al.,* 2011). The findings of the study align with studies by Ofori *et al.* (2018), who reported enhanced nodulation and biomass in cowpea under RP and TSP blends in the Guinea savannah of Ghana. Furthermore, the lowest nodule numbers were observed in control plots, indicating that unfertilized soils lacked the nutrient sufficient to support rhizobial infection and nodule initiation.

The heaviest nodules were recorded from plants treated with NPK (11:22:21 + TE) at the Kokpeng experimental site, reinforcing the superior performance of this fertilizer combination. Consequently, a significant improvement in nodule weight was also observed with the treatment comprising 80%TSP + 20%RP + K + TE, outperforming the 100%TSP treatment in both Kokpeng and Nyakpala. The synergistic effect of macronutrients (P and K) and micronutrients in this formulation likely promoted both nodule formation and growth, a phenomenon supported by the findings of Emmanuel *et al.* (2021), who noted increased nodule biomass in cowpea when P was applied in conjunction with K and Zn.

Interestingly, across both experimental sites, Kokpeng consistently produced heavier nodules than Nyankpala, suggesting that site-specific soil characteristics such as texture, pH, organic matter content, and indigenous rhizobial populations might have influenced the overall efficacy of the treatments. This site effect aligns with earlier findings by Aslam *et al.* (2015) and Ahiabor and Hirata (2003), who observed that environmental factors, including soil fertility status and microbial diversity, significantly affect the performance of legumes in terms of nodulation and nitrogen fixation.

5.2.2 Pod length of cowpea

The significant differences in average pod length of cowpea among fertilizer treatments indicate that nutrient source, balance, and availability strongly influenced reproductive development. The superior performance of the blended treatment 60% TSP + 40% RP + K + TE, which produced the longest pods, suggests a synergistic interaction between soluble and sparingly soluble phosphorus sources. Triple superphosphate supplies readily available phosphorus for early growth, while rock phosphate (RP) provides a gradual release of phosphorus that can sustain crop demand during flowering and pod elongation stages (Marschner *et al.,* 2012; Chien *et al.,* 2011) and as much as what was witnessed in 80%TSP+20%RP+K+TE and 60%TSP+40%RP+K+TE. Cowpea, a leguminous crop, has a high phosphorus demand during flowering and pod development stages (Rao *et al.,* 2014). This required that phosphorus is available throughout the vegetative and reproductive phases which was met by the fast-release of TSP and slow-release of 20 and 40% rock phosphate in combination with potassium and the trace elements. Replacing 20% and 40% of TSP with RP together with Zn and B resulted in longer pod lengths, agrees with what was reported by Gandhi *et al.* (2007). This improved phosphorus nutrition, according to Raghothama *et al.* (1999), is critical for root proliferation, flower initiation, and ultimately pod elongation in legumes such as cowpea. The combined application of zinc and boron (TE) has been found to have synergistic effects on cowpea growth and pod development. Both zinc and boron contribute to enhancing the plant's reproductive potential, which leads to longer pods. A study by Yadav *et al.* (2017) demonstrated that the joint application of zinc and boron resulted in a significant increase in cowpea pod length compared to individual nutrient applications. This enhancement is believed to be due to their complementary roles in improving cell division, elongation, and nutrient mobilization to reproductive tissues.

5.2.3 Number of seeds per pod and hundred-seed weight

One important yield factor for cowpeas is the number of seeds per pod, which indicates how well reproductive processes like pollination, fertilization, and nutrient allocation work during seed development. Fertilizer treatment was found to be a significant factor in the study, although the variance in seed number per pod did not change between locations.

The treatments involving partial substitution of TSP with RP (80%TSP+20%RP and 60%TSP+ 40%RP along with K and TE recorded the highest seed numbers per pod. This suggests a synergistic effect of combining fast- and slow-release phosphorus sources, ensuring both immediate and sustained phosphorus availability throughout pod development. This finding aligns with the observations of Biswas *et al.* (2015)**,** who reported that integrated phosphorus management**,** particularly the combination of soluble and insoluble phosphorus sources, improved phosphorus use efficiency, root growth, and yield attributes in legumes. Moreover**,** Kumar *et al.* (2019) observed increased seed numbers in pigeon pea when RP was combined with bioavailable phosphorus and micronutrients, suggesting a broader applicability in legumes.

Potassium and trace elements (Zn, B, Fe) are known to enhance seed development by enhancing enzymatic activity, photosynthate transport, and reproductive tissue development. For example, Zinc and boron, as cited by Yadav *et al.* (2017)**,** improved cell division and nutrient mobilization, which are essential during seed setting. In this study, the inclusion of K and TE likely enhanced nutrient partitioning to developing seeds, resulting in higher seed numbers in the 80%TSP+20%RP and 60%TSP+ 40%RP treatments.

The higher number of seeds per pod observed under NPK (11:22:21 + TE) compared with NPS (14:31:5 + TE) and NPK (14:18:18 + TE) is likely due to its more balanced nutrient composition, particularly its potassium content. Balanced NPK fertilization supports reproductive development and assimilate translocation, thereby enhancing yield components such as seed number per pod Tsige *et al.* (2022). Potassium plays an important role in enzyme activation, transport of carbohydrate, and pod filling, which are critical for legume seed development.

According to a study by Swaroop *et al.* (2001), a balanced application of 80 kg P_2O_5 (TSP), 120 kg K_2O (K), and 20 kg N (with Rhizobium inoculation) significantly improved the yield of green pods, which is correlated with an increase in seeds per pod.

In contrast, treatments with 100% RP or 100% TSP alone, though moderately effective, did not surpass the partially substituted RP treatments, indicating that balanced nutrient synergy is more critical than relying solely on one phosphorus source. The control plot recorded the least number of seeds, underscoring the significant role of external nutrient supply in enhancing cowpea reproductive performance, especially in nutrient-depleted soils.

The highest hundred-seed weight was observed in the treatments substituting 20 and 40% of TSP with RP, along with potassium. This effect was similar to the treatment with 60%TSP+40%RP suggesting that a partial substitution of TSP with RP, rather than full replacement, provides an optimal phosphorus release pattern that supports efficient seed filling and dry matter accumulation. These findings align with those of Biswas *et al.* (2015)**,** who highlighted that integrated phosphorus management improves phosphorus use efficiency and seed development in legumes. In contrast, the full substitution of TSP with RP and its associated components did not improve hundred seed weight and performed similarly to the sole TSP treatment, indicating that P alone may not be sufficient for optimal seed development but its availability to match P need at seed development. Among the compound fertilizers tested, NPK (14:18:18 + TE) with balance nutrient composition was similar to 100- seed weight obtained in the 20 and 40% substituted TSP treatments. These findings further support the relevance of balanced nutrient combinations and strategic phosphorus sourcing in enhancing seed quality traits in legume crops (Kumar *et al.,* 2019; Yadav *et al.,* 2017).

5.2.4 Dry shoot biomass

The compound fertilizers showed superior performance in Nyankpala and this suggests that a balanced supply of essential macronutrients alongside trace elements such as zinc and boron, plays a pivotal role in enhancing vegetative growth and biomass accumulation in cowpea.

Nitrogen is essential for chlorophyll formation and vegetative development, phosphorus is crucial for energy transfer and root development, while potassium regulates water balance and enzyme activation. The inclusion of micronutrients such as Zn and B further supports metabolic processes and reproductive growth (Marschner, 2012; Fageria *et al.,* 2009). The observed increase in biomass with the compound fertilizers aligns with findings by Okeleye *et al.* (2004), Ali *et al.* (2021), who reported improved growth and yield attributes in legumes when supplied with balanced NPK fertilizers enriched with micronutrients. The comparable performance of the compound fertilizers further confirms the positive influence of tailored fertilizer blends. Phosphorus-rich blends like NPS (14:31:5+TE) likely supported early root establishment and nodulation, which are vital for legume crops such as cowpea that depend on biological nitrogen fixation (Dakora and Keya, 1997). Adequate potassium, as seen in the NPK (14:18:18+TE) treatment, may have contributed to improved photosynthate translocation, thereby boosting biomass *(*Zhao *et al.,* 2001*).*

Although treatments with 100% Triple Superphosphate and its RP substituted forms with potassium (with or without TE) resulted in appreciable biomass yields, they were generally lower than those recorded for the compound NPK blends. This could be attributed to the lack of nitrogen in TSP, a critical macronutrient that directly influences vegetative growth. These findings are consistent with the results of Ayeni *et al.* (2010), who highlighted the limited performance of phosphate-only fertilizers in the absence of balanced N and K supplementation.

The lowest biomass observed in control plots (no fertilizer application) highlights the natural nutrient limitations of the experimental soils. This is consistent with evidence that multiple nutrient deficiencies are common in smallholder soils across sub-Saharan Africa and can substantially limit legume growth and biomass in the absence of external inputs**,** with deficiencies in phosphorus, potassium, magnesium, sulphur, and micronutrients frequently constraining production when nutrients are not supplied Baijukya *et al.,* (2021). Similar to this, Ali *et al.* (2021) found that boron and zinc synergistically increased fresh shoot biomass, indicating that these micronutrients are essential for cowpea growth and production when fertilization regimens are balanced.

5.2.5 Grain Yield

Cowpea grain yield was significantly influenced by Fertilizer treatment and location, with Nyankpala outperformed Kokpeng in terms of cowpea grain yield across the majority of fertilizer treatments despite Kokpeng having higher soil organic carbon (OC). This demonstrates that soil OC alone was insufficient to enhance crop yield, as yield response is strongly controlled by interacting soil chemical and physical properties such as pH, nutrient availability, and soil structure (Brady and Weil, 2017; Havlin *et al.,* 2014).

The Phosphorus fertilizer combinations that produced the highest grain yields at Nyankpala were 60%TSP+40%RP+K+TE and 80%TSP+20%RP+K+TE. This shows that when P fertilizer is combined with K and the trace elements (TE), Zn and B, partial replacement of TSP with RP may have advantages, agronomically. Grain filling in legumes and reproductive development depends on these micronutrients (Singh *et al.,* 2011). According to Chien *et al.* (2011), the higher performance of the TSP-RP mixture also raises the possibility that RP helped enhance nutrient availability throughout critical growth stages by promoting a delayed but persistent phosphorus release. This observation is supported by Ofori *et al.* (2018), who discovered that in phosphorus-deficient soils in the Guinea Savanna, RP combined with soluble P sources such as TSP enhanced crop performance and phosphorus utilization efficiency. Similarly, studies conducted in semi-arid West Africa showed that when RP was used in the right soil pH range and in conjunction with other nutrients, it supplied sufficient P nutrition (Bationo *et al.,* 2012).

Interestingly, the study found that 100% replacement of TSP by RP, when supplemented with K and TE**,** performed similarly as 100% TSP though at par with two compound fertilizer treatment such as NPK (14:18:18 + TE) and NPS (14:31:5 + TE) at both experimental sites. This is highly relevant result, indicating that rock phosphate often considered less effective in the short term can match the performance of more soluble phosphorus fertilizers when used as part of a balanced nutrient management. It also demonstrates the importance of nutrient synergy**,** where phosphorus becomes more plant-available in the presence of potassium and certain micronutrients that support root growth and enzyme activation (Chien *et al.,* 2009). This finding aligns with those of Abdul-Razak *et al.* (2021), who reported that RP, when fortified with K and Zn, significantly improved cowpea grain yield and nodulation under savanna conditions in Ghana. Likewise, a long-term study in Burkina Faso showed that RP had a residual effect on subsequent cropping seasons, making it a potentially sustainable alternative to TSP (Bationo and Waswa, 2011). The untreated control plots recorded the lowest grain yields at both sites. This reinforces the notion that native soil nutrient reserves are insufficient to support optimal cowpea productivity, particularly under continuous cultivation systems with minimal organic matter return (Sanginga *et al.,* 2003).

5.2.6 Influence of fertilizer treatment on cowpea root system architecture (RSA)

Across all panels in figure 13, fertilizer treatments significantly influenced cowpea root system architecture, with compound fertilizers consistently outperforming single-source phosphorus treatments. The wider lateral root spread (*Panel A*), greater total root volume (*Panel B*), thicker roots (*Panel C*), and longer root systems (*Panel D*) observed under NPK and NPS fertilizers supplemented with trace elements indicate enhanced soil exploration and nutrient foraging capacity. These traits are central to efficient phosphorus acquisition in cowpea, particularly under low-P conditions typical of tropical soils (Adu *et al.* 2019; Mohammed *et al.,* 2021). Root volume and length, which integrate multiple architectural traits, have been shown to strongly correlate with nutrient uptake efficiency and biomass production (Ogbonnaya *et al.* 2003; Mohammed *et al.,* 2021). In contrast, RP-only treatments consistently exhibited restricted lateral spread, reduced root volume, thinner roots, and shorter root systems, reflecting the low solubility and slow P release associated with rock phosphate (Krasilnikoff *et al.* 2003; Adu *et al.,* 2016). Although combining RP with potassium or trace elements led to modest improvements, these treatments remained inferior to compound fertilizers, underscoring those micronutrients and secondary nutrients cannot fully compensate for inadequate phosphorus availability (Bonser *et al.* 1996; Alloway, 2008). In short, the results confirm that balanced nutrient supply, rather than reliance on single P sources, is critical for optimizing cowpea root architecture and enhancing nutrient acquisition in phosphorus-limited soils (Lynch, 1995; Adu *et al.,* 2019).

5.2.7 Economic Analysis

The partial budget analysis revealed that the treatments that included the trace elements were not profitable. They might have improved grain yield but the monetary increment in yield did not commensurate the cost of the nutrients. 100% and 20% substitution of the Triple super phosphate with Rock phosphate reduced cost and brought positive marginal returns. The addition of potassium, though positive in terms of marginal rate of return, it reduced the MRR. The cost of TSP and the compound fertilizer affected its net benefit and MRR. The addition of trace elements (Zn and B) and Potassium may have health benefit to the consumer but to the farmer it is a drain on his profit.

Assuming that every farmer expects 100 % return in addition to the interest on loan taken for farming, in Ghana about 40% at the time of the study, then Marginal Rate of Return above 140% will be acceptable to farmers and only 100% Rock phosphate exceeded the 140% marginal rate of return. The 20% substitution brought positive marginal rate of return but the quantum was not appreciable. In economic terms, farmers will be better off if they use rock phosphate in cowpea production.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusions

Triple Superphosphate (TSP) significantly boosted vegetative growth, chlorophyll content, biomass, and grain yield of cowpea.

Rock Phosphate (RP) supported gradual phosphorus release and sustained cowpea growth, Pod length, and weight, proving it a viable alternative to TSP in acidic savannah soils.

Again, combining RP with TSP improved root traits, nutrient uptake, vegetative growth, and yield compared to using either phosphorus source alone.

Incorporating K into TSP-RP enhance cowpea root development, biomass accumulation, and grain yield, promoting balanced nutrient supply and better crop performance.

Zinc and boron improved root proliferation, nutrient uptake, and yield, highlighting the importance of balanced macro- and micronutrient fertilization.

Integrated nutrient management combining TSP, RP, K, and Zn and B increased profitability and marginal rates of return, making it economically viable for smallholder cowpea farmers.

6.2 Recommendations

Integrated phosphorus fertilization, involving the combined use of Triple Superphosphate (TSP) and Rock Phosphate (RP), should be promoted for cowpea production in phosphorus-deficient soils to enhance nutrient availability and improve crop growth and yield.

Potassium (K) fertilization should be incorporated into cowpea nutrient management strategies to improve root architecture, plant growth, and grain yield.

Balanced fertilization (TSP, RP, and K) with micronutrients, particularly zinc (Zn) and boron (B), is recommended to enhance nutrient uptake efficiency, optimize root development, and maximize cowpea productivity.

Rock phosphate (RP) should be encouraged as a cost-effective alternative phosphorus source for smallholder farmers due to its sustained nutrient release.

Future studies should explore the effect of TSP RP, K, Zn, and B on root traits and their effect on soil biological processes and nutrient use efficiency in cowpea.

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APPENDIX

Appendix 1: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on plant length

Plant length (cm) 2- Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	12.685	4.228	2.79	
REPS.*Units* stratum					
TREATMENT	15	66.513	4.434	2.93	<.001
LOCATION	1	69.504	69.504	45.94	<.001
TREATMENT.LOCATION	15	78.200	5.213	3.45	0.100
Residual	93	140.706	1.513		
Total	127	367.608			

Appendix 2: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on plant length

Plant length (cm) 4-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	75.728	25.243	6.18	
REPS.*Units* stratum					
LOCATION	1	16.083	16.083	3.94	0.050
TREATMENT	15	766.023	51.068	12.51	<.001
LOCATION.TREATMENT	15	95.712	6.381	1.56	<.001
Residual	93	379.569	4.081		
Total	127	1333.114			

Appendix 3: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on plant length

Plant length (cm) 6-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	64.931	21.644	3.35	
REPS.*Units* stratum					
TREATMENT	15	1311.694	87.446	13.54	<.001
LOCATION	1	29.338	29.338	4.54	0.036
TREATMENT.LOCATION	15	167.871	11.191	1.73	0.050
Residual	93	600.791	6.460		
Total	127	2174.625			

Appendix 4: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on plant length

Plant length (cm) 8-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	60.921	20.307	3.00	
REPS.*Units* stratum					
LOCATION	1	20.608	20.608	3.05	0.084
TREATMENT	15	1293.047	86.203	12.74	<.001
LOCATION.TREATMENT	15	203.458	13.564	2.00	0.023
Residual	93	629.334	6.767		
Total	127	2207.368			

Appendix 5: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Chlorophyll content

Chlorophyll 2-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	280.906	93.635	9.96	
REPS.*Units* stratum					
LOCATION	1	170.201	170.201	18.11	<.001
TREATMENT	15	220.975	14.732	1.57	0.098
LOCATION.TREATMENT	15	132.804	8.854	0.94	0.522
Residual	93	874.209	9.400		
Total	127	1679.095			

Appendix 6: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Chlorophyll content

Chlorophyll 4-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	355.30	118.43	8.89	
REPS.*Units* stratum					
LOCATION	1	2240.31	2240.31	168.11	<.001
TREATMENT	15	1861.48	124.10	9.31	<.001
LOCATION.TREATMENT	15	158.13	10.54	0.79	0.684
Residual	93	1239.33	13.33		
Total	127	5854.56			

Appendix 7: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Chlorophyll content

Chlorophyll 6-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	376.23	125.41	9.38	
REPS.*Units* stratum					
LOCATION	1	7338.66	7338.66	548.95	<.001
TREATMENT	15	2607.67	173.84	13.00	<.001
LOCATION.TREATMENT	15	278.90	18.59	1.39	0.168
Residual	93	1243.27	13.37		
Total	127	11844.73			

Appendix 8: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on the Number of Cowpea branches

Number of Branches 4-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	0.22577	0.07526	1.01	
REPS.*Units* stratum					
LOCATION	1	2.07207	2.07207	27.70	<.001
TREATMENT	15	20.20918	1.34728	18.01	<.001
LOCATION.TREATMENT	15	3.74936	0.24996	3.34	<.001
Residual	93	6.95791	0.07482		
Total	127	33.21429			

Appendix 9: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on the Number of Cowpea branches

Number of Branches 6-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	2.2428	0.7476	3.01	
REPS.*Units* stratum					
LOCATION	1	1.4389	1.4389	5.79	0.018
TREATMENT	15	34.4042	2.2936	9.23	<.001
LOCATION.TREATMENT	15	6.7167	0.4478	1.80	0.046
Residual	93	23.1194	0.2486		
Total	127	67.9220			

Appendix 10: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Cowpea plant Leaf Area Index

Leaf Area Index 2-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	0.0029410	0.0009803	6.38	
REPS.*Units* stratum					
LOCATION	1	0.0016641	0.0016641	10.83	0.001
TREATMENT	15	0.0103755	0.0006917	4.50	<.001
LOCATION.TREATMENT	15	0.0040454	0.0002697	1.76	0.053
Residual	93	0.0142912	0.0001537		
Total	127	0.0333171			

Appendix 11: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Cowpea plant Leave Area Index

Leave Area Index 4-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	0.040432	0.013477	2.48	
REPS.*Units* stratum					
LOCATION	1	0.001515	0.001515	0.28	0.599
TREATMENT	15	2.075095	0.138340	25.45	<.001
LOCATION.TREATMENT	15	0.235829	0.015722	2.89	<.001
Residual	93	0.505440	0.005435		
Total	127	2.858311			

Appendix 12: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Cowpea plant Leave Area Index

Leave Area Index 6-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	0.17482	0.05827	1.37	
REPS.*Units* stratum					
LOCATION	1	0.32256	0.32256	7.58	0.007
TREATMENT	15	20.89698	1.39313	32.75	<.001
LOCATION.TREATMENT	15	0.45436	0.03029	0.71	0.766
Residual	93	3.95557	0.04253		
Total	127	25.80429			

Appendix 13: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Cowpea plant Leave Area Index

Leave Area Index 8-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	5.26894	1.75631	19.12	
REPS.*Units* stratum					
LOCATION	1	0.83067	0.83067	9.04	0.003
TREATMENT	15	38.61702	2.57447	28.02	<.001
LOCATION.TREATMENT	15	0.93414	0.06228	0.68	0.800
Residual	93	8.54464	0.09188		
Total	127	54.19541			

Appendix 14: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on days to 50% flowering of Cowpea

Days to 50% flowering

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REPS stratum	3	10.1250	3.3750	14.35	
REPS.*Units* stratum					
LOCATION	1	0.1250	0.1250	0.53	0.468
TREATMENT	15	161.8750	10.7917	45.88	<.001
LOCATION.TREATMENT	15	0.8750	0.0583	0.25	0.998
Residual	93	21.8750	0.2352		
Total	127	194.8750			

Appendix 15: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on days Cowpea plants attain maturity

Days to Maturity

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REPS stratum	3	0.023438	0.007813	1.00	
REPS.*Units* stratum					
LOCATION	1	0.007813	0.007813	1.00	0.320
TREATMENT	15	46.742188	3.116146	398.87	<.001
LOCATION.TREATMENT	15	0.117188	0.007813	1.00	0.462
Residual	93	0.726562	0.007813		
Total	127	47.617188			

Appendix 16: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on number of Cowpea nodules counted

Number of Nodules counted at 5-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	20.854	6.951	2.60	
REPS.*Units* stratum					
LOCATION	1	1.072	1.072	0.40	0.528
TREATMENT	15	1362.004	90.800	33.96	<.001
LOCATION.TREATMENT	15	42.464	2.831	1.06	0.405
Residual	93	248.626	2.673		
Total	127	1675.020			

Appendix 17: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on weight of nodules (g)

Weight of Nodules (g) at 5-Weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	0.36669	0.12223	9.71	
REPS.*Units* stratum					
LOCATION	1	0.00018	0.00018	0.01	0.906
TREATMENT	15	5.55659	0.37044	29.43	<.001
LOCATION.TREATMENT	15	0.53384	0.03559	2.83	0.001
Residual	93	1.17044	0.01259		
Total	127	7.62773			

Appendix 18: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Above-ground dry biomass kg/ha

Above-ground dry biomass kg/ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	5286549.	1762183.	2.57	
REPS.*Units* stratum					
LOCATION	1	11417230.	11417230.	16.68	<.001
TREATMENT	15	79374632.	5291642.	7.73	<.001
LOCATION.TREATMENT	15	21033617.	1402241.	2.05	0.020
Residual	93	63673141.	684657.		
Total	127	180785168.			

Appendix 19: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on the number pod per plant of Cowpea

Number Pod per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	4.5877	1.5292	1.58	
REPS.*Units* stratum					
LOCATION	1	17.0139	17.0139	17.59	<.001
TREATMENT	15	296.9852	19.7990	20.47	<.001
LOCATION.TREATMENT	15	7.8958	0.5264	0.54	0.909
Residual	93	89.9540	0.9672		
Total	127	416.4366			

Appendix 20: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Cowpea pod length (cm)

Pod Length (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	5.9599	1.9866	2.84	
REPS.*Units* stratum					
LOCATION	1	16.5384	16.5384	23.61	<.001
TREATMENT	15	231.4424	15.4295	22.02	<.001
LOCATION.TREATMENT	15	4.6271	0.3085	0.44	0.963
Residual	93	65.1510	0.7005		
Total	127	323.7188			

Appendix 21: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on number of seeds per pod

Number of Seeds per Pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	6.72523	2.24174	46.31	
REPS.*Units* stratum					
LOCATION	1	0.13133	0.13133	2.71	0.103
TREATMENT	15	130.50180	8.70012	179.71	<.001
LOCATION.TREATMENT	15	0.72742	0.04849	1.00	0.460
Residual	93	4.50227	0.04841		
Total	127	142.58805			

Appendix 22: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on thousand seeds weight (g) of Cowpea

Hundred Seeds weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	6.75	2.25	0.06	
REPS.*Units* stratum					
LOCATION	1	85.15	85.15	2.22	0.139
TREATMENT	15	7966.83	531.12	13.86	<.001
LOCATION.TREATMENT	15	720.94	48.06	1.25	0.247
Residual	93	3562.91	38.31		
Total	127	12342.58			

Appendix 23: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on Cowpea development and Yield

Grain Yield (kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	96254.	32085.	2.64	
REPS.*Units* stratum					
TREATMENT	15	4962819.	330855.	27.25	<.001
LOCATION	1	1370992.	1370992.	112.92	<.001
TREATMENT.LOCATION	15	454096.	30273.	2.49	0.004
Residual	93	1129169.	12142.		
Total	127	8013329.			

Appendix 24: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on the total root length (cm)

Total Root Length (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	1307.9	436.0	1.21	
REPS.*Units* stratum					
LOCATION	1	0.5	0.5	0.00	0.970
TREATMENT	15	13098.6	873.2	2.43	0.005
LOCATION.TREATMENT	15	2299.2	153.3	0.43	0.968
Residual	93	33423.5	359.4		
Total	127	50129.7			

Appendix 25: Influence of NPK, Phosphorus source and some essential elements (Zn and B) on the Root Volume (mm^3)

Root Volume (mm^3)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	163.96	54.65	1.91	
REPS.*Units* stratum					
LOCATION	1	971.57	971.57	33.91	<.001
TREATMENT	15	1577.36	105.16	3.67	<.001
LOCATION.TREATMENT	15	314.56	20.97	0.73	0.746
Residual	93	2664.37	28.65		
Total	127	5691.82			