**UNIVERSITY FOR DEVELOPMENT STUDIES**

# UPTAKE AND EFFICIENCY OF NITROGEN, PHOSPHORUS AND POTASSIUM IN MAIZE PRODUCTION AS INFLUENCED BY NEEM (*Azadirachta indica* L.) SOIL AMENDMENTS IN THE GUINEA SAVANNAH ECOLOGICAL ZONE OF GHANA

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**SEPTEMBER, 2023**

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**FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES**

**DEPARTMENT OF CROP SCIENCE**



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**BY**

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**THESIS SUBMITTED TO THE DEPARTMENT OF AGRONOMY OF THE FACULTY OF AGRICULTURAL, FOOD AND CONSUMER SCIENCES, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN CROP SCIENCE**

**SEPTEMBER, 2023**

## DECLARATION

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere. References made from other research work have accordingly been cited

MAS-UD MUSTAPHA

Candidate's Signature.......................... Date: 23/09/2023

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

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## ABSTRACT

The cultivation of maize (*Zea mays* L.) in northern Ghana is synonymous with fertilizer application, but efficient nutrient uptake and utilization are major factors that influence yield parameters and grain yield. The impact of neem cake (NC) and its oil as soil amendments on nutrient uptake and efficiency of Nitrogen (N), Phosphorus (P), and Potassium (K), as well as growth, yield components and yield of maize, was investigated. The trial was conducted at two locations, Tamale Technical University and the University for Development Studies farms in Tamale and at Nyankpala close to Tamale, respectively in northern Ghana in 2021 cropping season. This was a 2 × 3 × 3 factorial experiment with treatment arranged in a Randomized Complete Block Design with three replications. Treatments that were applied included NC with 0, 200, and 400 kg/ha, neem oil (NL) with 0, 10, and 20 l/ha, and NPK at 0 and 250 kg/ha with fertilizer grade 15:15:15, the latter and in situ nutrient in soil supported as sources of NPK. The study found increasing the rate of NC from 200 to 400 kg/ha combined with 250 kg NPK/ha increased plant height, shoot dry weight, LAI, uptake and efficiency of uptake of NPK, grain yield, and harvest index (HI) of maize. Plant height, shoot dry weight, LAI, N, P, and K uptake and uptake efficiency, grain yield and HI of the crop diminished with increasing NL rate, beginning with 10 l NL/ha to 20 l NL/ha merged with 250 kg NPK/ha. The results showed combining 250 kg NPK/ha with 10 l/ha NL boosted N uptake for maize by 7.3 % (from 150.4 kg/ha to 161 kg/ha) over the approved NPK rate in maize. P uptake in maize increased by 6.8% (from 54.5 kg/ha to 58.2 kg/ha) with 250 kg NPK/ha combined with 10 l/ha NL. When 250 kg NPK/ha was combined with 400 kg/ha NC, the percentage increase for P uptake was 28% (from 47.7 kg/ha to 61.1 kg/ha) over the control. Incorporation of 250 kg NPK/ha gave uptake efficiency of 0.036 kg N/kg, 0.056 kg P/kg, and 0.048 kg K/kg as maximum entries. NC at 400 kg/ha recorded an economic yield of 1172 kg/ha. Grain yield was positively correlated with N, P and K uptake and N uptake efficiency, but not with P and K uptake efficiency, respectively with r = 0.91**, 0.82**, and 0.85**; and 0.20*, 0.01, and 0.03. The combined data analysis showed only location by NPK interaction on the majority of parameters, which was likely due to differences in the baseline soil fertility status. The study revealed 250 kg NPK/ha combined with 400 kg NC/ha manifested explicit role for optimum N, P and K uptake and efficiency, growth and yield of maize in the Guinea savannah ecological zone of Ghana. 10 l/ha NL combined with 250 kg NPK/ha also

was another most economical treatment and are therefore recommended for optimum N, P and K uptake and efficiency, growth and grain yield of maize in the Guinea savannah ecological zone of Ghana.

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## DEDICATION

I dedicate this thesis to Almighty God, for seeing me through this study and to my family and friends.

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# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 BACKGROUND

Globally, amongst the numerous cereal crops in the agricultural industry, one of the most important is maize (*Zea mays* L.). It is utilized both for man's food and also used to feed animals. No other cereal has such immense potential in food security, earning it the title "Queen of Cereals" (Dwivedi *et al.*, 2022). Although Scientists have developed varieties with higher proportions of nutrients, the maize grain has the composition of 9% protein, 4% oil, 70% starch, and 2.7% crude fiber. Maize protein "Zein" contains abundance of two important amino acids, Tryptophan and lysine (Scheiterle & Birner, 2018), which are noted for building proteins that improves human health.

In Ghana, maize is an undisputedly a major staple crop that accounts for over half of the country's grain production and is planted in all agro-ecological zones (Wongnaa *et al.,* 2021). Maize is often the most popular basic grain, and output has increased since 1965 (Wongnaa *et al.,* 2021) in the country. Most of the produced maize in Ghana are consumed by households within it and that is why maize production is crucial if Ghana wants to ensure food security in a sustained manner (Abdulai *et al*., 2018). Average maize yields range between 1.2 and 1.9 metric tons (Mt) per hectare (ha), while field and institutional indicate that economic yields of "4 to 6 Mt/ha of maize are achievable in the country (FAOSTAT, 2018)

Maize is farmed and consumed by the totality of the agro-ecological zones of Ghana. This crop flourishes in loamy soils that are deep and well-drained (MoFA, 2009). The three agro-ecological zones namely: Guinea savanna, Forest savanna and Transitional zones; in the country is responsible for over 70% of the maize produced. The (5) five main regions for growing maize are North east, Savannah, Northern, Bono, Ahafo, Bono east, Ashanti, Central, and Eastern Regions (Amanor Boadu, 2012). The attainable yield of well-liked enhanced maize varieties planted in Ghana is 2.2 metric tons per hectare, which is 50% below the yield reported by (SRID-MoFA

2011). For instance, Obatanpa and Mamaba each have a 5.5 and 7.5 Mt/ha potential production, respectively (Tengan *et al.,* 2011). These figures show that there is enormous potential to raise smallholder income for significant increases in maize output.

Due to its reputation as a heavy nutrient feeder, maize typically benefits from heavier fertilizer applications (CSIR-SARI, 2011). Nitrogen is a vital nutrient for plants since it enhances enzyme and chlorophyll content of plant, which is necessary for the metabolism of energy in activities such as photosynthesis and respiration (Nasar *et al*., 2021). N losses worsen the environmental impact by boosting greenhouse gas emissions and contaminating groundwater (Coskun *et al*., 2017; Conijn *et al*., 2018).

Phosphorus is necessary for respiration and metabolism, seed germination, root growth, seed and fruit production, cell division since it is a component of nucleoprotein, which speeds up crop maturation and fruit ripening, and strengthens the structure of plants to prevent toppling. In addition to being a component of essential cellular like ATP, phospholipids, and nucleic acids, phosphorus is crucial for energy preservation and metabolic control (Marschner 1995, Raghothama 2002).

Potassium catalyses most physiological function; regulation of water; aids nitrate absorption from the soil; neutralize organic aids; strengthens plants straw and stalk against lodging, fungal and bacteria attack. Potassium contributes to charge balance, osmotic adjustment, and enzyme catalysis, which are all crucial for plant growth and development as well as cellular homeostasis (Marschner 1995, Maathuis and Sanders 1996).

## 1.2 PROBLEM STATEMENT

As one of Ghana's major producers of maize (Amanor Boadu, 2012), the Guinea savannah ecological zone also boast as a one the zones that uses more fertilizers produced from chemicals in the country (IFDC, 2019). Despite this, farmers are bedeviled with low yields with an average of only 1.9 t/ha rather than the maximum output of 6.0 t/ha (Anorvey *et al.,* 2018; MoFA, 2019). More investigation into causes of the abysmal low yields facing farmers in the northern Ghanaian agricultural sector reveals that low fertility soils support crops with low yields, and this is detrimental to the advancement of the sector (RELC, 2005). The widespread reduction in poor soil nutrient availability and uptake coupled with producing the chronically low crop yields could also be caused by continuous cropping of cereals that drastically extract and without sufficient nutrient inputs management to the soil (Sanginga, 2003).

## 1.3 JUSTIFICATION

In order to attain high growth parameters and yields from the necessary doses of fertilizers farmers apply to their farms, strategies for enhancing and maintaining agricultural production could be concentrated on how to enhance the uptake efficiency of the nutrient resources available more effectively, efficiently, and sustainably as compared to the past. Research shows that, one of the major nutrients like Nitrogen, experiences 50% loss when applied to the soils through N fertilizers and that reduces nutrient uptake and use in almost equal volumes (Coskun *et al.,* 2017; Bindraban *et al*., 2020). These nitrogen escape to the atmosphere exacerbate the negative environmental impacts by heightening the emission of greenhouse gases (nitrous oxide) and contaminating groundwater (Coskun *et al.,* 2017; Conijn *et al.*, 2018). For the above reasons and more, farmers and environmentalists are becoming more interested in increasing nutrient use efficiency (NUE) via optimizing uptake of nutrients. So that maximum expected crop yields from a recommended fartilization could be achieved, and as a result, negative impacts, for instance nitrogen losses could be reduced to the barest minimum (Neeteson *et al.*, 1999; Rahn, 2002; Burns, 2006; Agostini *et al*., 2010).

Exploiting the use of technologies for improving fertilizer uptake and utilization efficiency could be vital in achieving and sustaining maximum yields of crops and nutrient loss reduction that can potentially deteriorate environmental quality. Through moderation of soil physico-chemical parameters including pH, cation exchange capacity, nutrient uptake, and water retention capacity, organic materials like neem products could promote soil health (Iren *et al.*, 2015; Iren *et. al*., 2016). According to some studies, using both organic and inorganic nutrient sources together improve crop performance overall and nutrient uptake (Garba & Oyinlola, 2014).

By enhancing N uptake and soil health, Krupnit *et al*. (2004) established that, the use of fertilizers produced from natural and synthetic materials in their proper combination as required by crops are cost effective. Therefore, supplying nutrients through fertilizers produced from chemicals, if well complemented with readily available plant resources obtained from nature, could boost uptake of nutrients and utilization; improve NUE and promote good health of the soil and crop production in sustained manner (Singh *et al.,* 2016).

Neem and neem-cake coated urea have been shown in prior investigations to have nitrification-inhibiting capabilities (Rao *et al*., 2000, Pushpanathan *et al.*, 2005). Neem-coated fertilizers, for instance, have been shown to minimize nitrogen losses through leaching and volatilization (Sharma and Prasad, 1996). Additionally, according to Singh and Slivay (2003), fertilizer coated with NL lowers N losses in a rice plus wheat cropping system, and nitrogen is gradually taken up by the crop at the various growth stages. Naresh (2003) also revealed the neem's ability to suppress nitrification and its phenomena of raising nutrient use efficiency (NUE) in rice. For instance, Sanjay *et al*. (2015) conveyed the administration of 100% of the required amount of nitrogen along with urea coated with neem dramatically boosted nutrient holding capacity of the soil, accessibility and uptake, increasing maize grain and straw yields. Neem is a good soil conditioner, inhibits nitrification, boosts crop production over time, and has no adverse environmental effects (Lokanadhan *et al.,* 2012).

According to Dwivedi *et al.* (2022), a treatment application of 0.57 t/ha of NC, 1.66 t/ha of vermicompost, 130.5 kg/ha of urea, 5 kg/ha of zinc, and 0.5 kg/ha of boron was most effective and hence most advised for farmers. Furthermore, according to Kamal *et al*. (2021), the combined supply of NPK dispensed at 20:40:00 kg/ha and NC at a rate of 1 t/ha produced the highest yield of green gram, which could be attributed to the treatment's advantageous impacts on higher growth indices. NC at 3 t/ha along with farm yard manure should be used on the farms of spice crops like “turmeric, ginger, and large cardamom”, according to Das *et al*. (2018) who studied spice crops, in order to increase productivity.

The claim for neem and its products (oil and cake) having strong nitrification inhibition qualities (Patra *et al.*, 2006); universal availability and attainable at affordable prices promoted testing with it for improving nutrient uptake on a highly demanded and staple, such as maize. Hence the current study was undertaken to determine whether the neem products may improve the utilization of soil and applied N, P, and K and increase the economic yield in maize production.

## 1.4 OBJECTIVES OF THE STUDY

### 1.4.1 GENERAL OBJECTIVE

The overall aim was to determine the effect of neem extracts and NPK on uptake and uptake efficiency of nitrogen, phosphorus and potassium on growth, yield components and grain yield of maize in Ghana's Guinea savannah ecological zone.

### 1.4.2 SPECIFIC OBJECTIVES

1. Evaluate the impact of neem products (cake and oil) and N, P, K on the yield components and grain yield of maize.

2. Determine the effect of neem products (cake and oil) and N, P, K uptake and uptake efficiency of N, P and K in maize.

3. Determine the interaction of neem products (cake and oil) on yield of maize, uptake and uptake efficiency of N, P and K in maize.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Maize Production in Ghana

Agricultural production represents roughly 23% of the gross domestic product (GDP) of Ghana, and a quarter of all households in the nation are employed in the sector (MoFA, 2016). One of the most important cereal crops amongst the numerous cereals in the global agricultural economy is maize (*Zea mays* L.), being utilized both as human food and animal feed. In Ghana, the second-largest commodity crop after cocoa is maize and the utmost significant principal crop for food widely consumed. It accounts for in excess of 50% of all grain cultivation (MoFA, 2011a). In Ghana, maize is a significant source of calories. According to a report, in northern Ghana maize has almost completely displaced sorghum and pearl millet which were also noted as traditional staple crops (SRID-MoFA, 2011b). According to Rondon and Ashitey (2011), the average annual maize production between 2007 and 2010 was 1.5 million MT, with a yield of roughly 1.7 t/ha" (SRID-MoFA, 2011b). However, in excess of 70% of maize grain produced comes out from the three agro-ecological zones guinea savanna, forest savanna, and transitional zones, and it does best in loamy soils that are deep and well-drained.

The crop is farmed across all agro-ecological zones of Ghana (MoFA, 2005). The Northern, North east, Savannah, Bono, Bono east, Ahafo, Ashanti, Central, and Eastern Regions are home to the five main maize-growing regions (Amanor Boadu, 2012). Majority of the food and food products that is widely consumed across the country is made from made from the maize making it the most significant security food crop. In 2005, its per capita consumption was 43.8 kg/head (MoFA, 2011a). In Northern Ghana, nitrogenous fertilizer is often used more frequently since the crop which is widely produced is maize noted to heavily feed on nutrient (CSIR-SARI, 2011). For decades, 250 kg/ha of N, P, K 15-15-15 compound fertilizer with 125 kg/ha of ammonium sulphate as a topdressing rate of chemical fertilizer have been suggested for Ghana's maize production (Kombiok *et al.,* 2012). In Ghana, 954000 acres of maize were planted in 2009, yielding 1,620,000 t of grain (MoFA, 2009). In the nation as a whole, maize consumption accounts for 62% of the totality of grain produced. The poultry industry as well as the brewing industry both utilize maize as a most significant resource in production (GAIN, 2011).

Farmers producing in small scale can produce maize as monocrop or as intercrop with other crops like yam and cassava (MiDA, 2010; Morris *et al.*, 1999). Ghana trade in 715,027, 830,127, and 81,708 t of wheat, rice, and maize in 2018, valued at a total of USD 684 million, due to the abysmal yield being recorded (MoFA, 2019).

### 2.1.1 Major Factors that Hinders Maize Production in Ghana

Despite the crop's importance in SSA, farmers frequently register appalling average yields of 1.9 t/ha as against corn's capable harvest of 6.0 t/ha (Anorvey *et al.*, 2018; MoFA, 2019). The scarcity of fertilizers, which results in low input and nutrient losses in maize production (WABS Consulting, 2008), and the continued decline of soil fertility are some of the factors causing the yield gap (Ranum *et al.*, 2014; Namatsheve *et al*., 2020). According to FAO (2006), developing countries have about 40-60 kg of NPK depletion per hectare. Other factors, however, have been enlisted as the primary cause of the incessant decrease in yields and they include rising temperatures, poor soils, and irregular rainfall (EPA, 2000; Abu, 2011). Fertilizer use has been hampered by a lack of physical access to fertilizers and high prices (IFDC, 2012). Photosynthesis and transpiration rates are negatively affected when N concentration is low and this usually results in lower crop yields (Ashraf *et al.*, 2016).

### 2.1.2 Nature of Soils of Northern Region

The single agricultural season (180-200 growing days), unimodal rainfall pattern, and 1100 millimetres of annual mean precipitation set apart the Ghana's Guinea savanna agro-ecological zone based in the region (SRID, 2016). Persistent agricultural land use and other land degradation factors render the soils infertile (Oppong-Anane, 2006). Nitrogen levels of the soils in many areas of the region are woefully low (Dakora *et al.*, 1987). Shorter fallow times due to population pressures have increased the burden on the previously poor soils (Dakora *et al.*, 1987; Franke *et al.*, 2004). On smallholder farms, those problems have led to widespread decreases in soil fertility and causes farmers to continue to record abysmal low crop yields. This coupled with continuous cereal-based systems that do not deliver enough nutrient inputs to the soil has made the situation more precarious (Sanginga, 2003). Northern Ghana makes up 52.7% of Ghana's population who live in extreme poverty (Ghana Statistical Service [GSS], 2014). The principal areas of Ghana where maize is grown have meagre soil levels of organic carbon, total nitrogen, exchangeable potassium, and accessible phosphorus (Okalebo *et al.,* 2003).

## 2.2 Effects of N, P and K on Maize Growth and Yield.

It is well recorded, without fertilizers, maize grain yields are terrible and uneconomical in some areas where maize is cultivated including areas such as the Guinea savannah zone (NAES, 1993; CSIR-SARI, 1996; Gholipoor *et al.,* 2013). NPK are most essential major nutrients that influence the growth of crops and their proper development. Enough supply of nitrogen improves the enzymic activities and plant chlorophyll content, which subsequently improves the plant's photosynthetic activities (Nasar *et al*., 2021). Nitrogen is linked to enzyme activities which are necessary for the metabolism of energy including photosynthesis and respiration (Marschner 1995; de Groot *et al.,* 2003b).

Phosphorus is necessary for respiration and metabolism. It is also necessary for cell division because it is a component of nucleoproteins, necessary for seed germination, root growth, and the formation of seeds and fruits, speeds up crop maturation and fruit ripening, and strengthens the structure of plants to prevent them from lodging. In addition to being a component of vital biological components like ATP, phospholipids, and nucleic acids, phosphorus is also vital for metabolism regulation and the storage of energy (Marschner 1995; Raghothama 1995).

Most physiological processes are catalyzed by potassium, which also regulates water, helps plants absorb nitrate from the soil, neutralizes organic fertilizers, and fortifies their stem and straw against fungal and bacterial attack. Due to its contributions to balancing charges, regulation of osmosis, and enzyme catalysis, potassium performs crucial roles during growth and development of plants and also as cellular homeostasis (Marschner 1995; Maathuis and Sanders 1996). Generally speaking, adding nitrogen fertilizer raises the percentage of shoot root and peanut root extract. In comparison to the control, NPK fertilizer considerably enhanced number of leaves, leaf area, plant height, fresh weight of root and shoot, and dry weight of root and shoot for maize, according to Afrida and Tampubolon (2022). Additionally, it was discovered that applying NPK considerably boosted grain yield, dry forage yield, and fresh forage yield when compared to alternative nutrition sources (Amin, 2011).

Due to nitrogen's ability to promote increase in the length and number of internodes, and result in a advancing the increases in plant growth and height, Gasim (2001) found an increase in plant height with NPK fertilizer as against the control and other treatments, nitrogen fertilization resulted in higher leaf area index, biomass, agronomic features, the accumulation of carbon, and its metabolism enzyme activity, according to an experiment by Chi *et al.* (2022). Nitrogen fertilizers boost all aspects of maize production, according to Diédhiou *et al.* (2022), who also highlighted that at 160 kg/ha, the highest fodder production of 5.99 tons/ha is possible. In contrast to the control for growing okra, Aboyeji (2022), who studied NPK fertilization on okra, concluded that fertilization boosted growth parameters, yield performance as well as buildup of inorganic elements and bioactive compounds. According to Valentinuz and tollenaar (2006), if nitrogen is not treated in suitable amounts, it is the main nutrient limiting plant development. Because nitrogen nutrients contain amino groups, which are responsible for the accumulation of protein, they are crucial in raising the amount of protein in food, according to Rafiq *et al.* (2010). It was also reported by Eifediyi *et al.* (2017) that, the highest yield and yield components of sesame were produced utilizing 100 kg/ha of NPK and 3 t/ha NC.



### 2.3 Botany of Neem (*Azadirachta indica* L.)

Known as the "Village Pharmacy," "Divine Tree," "Life Giving Tree," and "holy Offering of Nature," neem (*Azadirachta indica* L.) is heavily exploited and prized for its numerous beneficial benefits (Kumar & Navartnam, 2013). The United Nations has chosen this extraordinary plant as the "Tree of the 21st century" (UNEP, 2012). This wonderful neem tree, *Azadirachta indica*, is a member of Meliaceae family member and originated in India is now prized across the world as a significant source of phytochemicals. Small to medium sized and with wide and spreading branches, Azadirachta is an evergreen tree that grows quickly. Along with harsh or deteriorated soil, it can withstand extreme temperatures. The adult leaves, which are composed of a petiole, lamina, and the base that joins the leaf to the stem, are bright green in contrast to the immature leaves' reddish to purple hues (Norten and Pütz, 1999; da Costa *et al.*, 2014). Two tiny, lateral projections called stipules which resemble little leaves. Although it is an evergreen, in some situations, like prolonged dry spells, it might lose most or almost all of its leaves. The branches can spread out extensively, have a very dense roundish or oval crown, and grow up to 15-20 meters in diameter (Schmutterer, 1995). The stem is rather petite, straight, and can grow to a girth of 1.5–3.5 m. It's hard, fissured or scaly, whitish–gray to reddish–brown bark is relatively uniform in color. When exposed to air for the first time, the sapwood is grayish-white and the heartwood reddish, but following exposure, they both turn reddish-brown (Schmutterer, 1995). The average to dark green leaflets, which can amount up to 31, are around 3–8 cm long and have short petioles. The irregular, pinnate leaves are 20–40 cm long.

The tree produces supplemental white, fragrant, and periodically arranged blooms. The inflorescences typically include 150 blooms, but they can reach 250 on rare occasions. The glabrous fruits are oval-shaped drupes that range in shape from nearly round to elongated oval and are 1.4-2.8 x 1.0-1.5 cm when ripe. The young ones are green and they turn yellowish-green to yellow as they age (Schmutterer, 1995).



### 2.3.1 Constituent Elements of *Azadirachta indica* L

Azadirachtin, Epinimbin, and Diacetyl are the three primary components of melicians, often known as neem bitters, which are what give neem (*Azadirachta indica* L) its nitrification-inhibiting properties (Devakumar 2016). Neem products have an appropriate level of NPK in organic form for the growth of plants. Its natural NPK content is 100% due to its all-botanical composition, and it also contains other vital micronutrients. The compositions are: Nitrogen in the range of 2.0% to 5.0%, Phosphorus in the range of 0.5% to 1.0%, Potassium in the range of 1.0% to 2.0%, Calcium in the range of 0.5% to 3.0%, Magnesium in the range of 0.3% to 1.0%, Sulphur in the range of 0.2% to 3.0%, Zn (Zinc 15 pp (Manganese 20 ppm to 60 ppm). Both bitter limonoids and sulphur compounds are abundant in it (Schmutterer, 2002). Ibrahim *et al.,* (2018) analysis of neem samples showed that the oil contains less nitrogen, phosphorus, and potassium than the fruit, which has the greatest percentages of 3.3%, 4.1%, and 3.8% respectively. Neem contains a sizable amount of limonoids, with azadiracthin ($C35H44O16$) being the most potent. Other well-known limonoids with insecticidal and pesticidal properties include "salanin, meliantriol, and nimbin. Salannol, nimbin, nimbinin, nimbidin, nimbidiol, 3-tigloylazadirachtol (*Azadirachtin B*), and 1-tigloyl-3-acetyl-1-hydroxymeliacarpin (*Azadirachtin D*)" are a few of the other components found in neem (Morgan, 2009; Melwita & Ju, 2010).

### 2.3.2 Major Products of Azadirachta *indica* L

Bark, leaves, and seeds of neem are particularly beneficial for both medical and for agriculture (NRC, 1992; Uyovbisere and Elemo, 2007). Because it provides crucial nutrients for crop growth, it enhances the growth and production of crops (Agbenin *et al.*,1999). Neem extracts such as NL, leaf, bark, and root extracts, as well as by-products, contain antifungal, antibacterial, antiviral, antidiabetic, anthelmintic, anti-carcinogenic, anti-inflammatory, and sedative qualities (Acharya *et al.*, 2017).

### 2.3.3 Effects of neem oil (NL) of *Azadirachta indica L*

NL, which is made from the seed of the neem tree and has both therapeutic and insecticidal characteristics, has been utilized in pest management (Benelli et al., 2018). NL has more insecticidal, nematicidal, bactericidal, fungicidal, and repellant properties than other pesticides (Pascoli *et al.*, 2019). NL has a high concentration of volatile oils and fatty acids (Djenontin *et al.*, 2012), but oil derived from flowers and leaves has a lower percentage of volatile oils (0.08%), and these oils contain primarily caryophyllene at a concentration of roughly 85%. According to reports, seed oil possesses larvicidal properties against mosquito larvae (Dua *et al.*, 2009). Additionally, it has been demonstrated to be a successful insecticide against a variety of pests, including *Scirpophaga incertulas* (Madhu *et al.*, 2020), *Nilaparvata lugens* (Senthil-Nathan *et al.*, 2009), *Cnaphalocrocis medinalis* (Nathan *et al.*, 2006). Additionally, NL comprises melicians, often known as neem bitters, whose active ingredients include Epinimbin, Deacetyl, Salanin, and Azadirachtin and have been demonstrated to have a dose-dependent nitrification inhibitory effect (Devakumar and Goswami, 1992). When combined with fertilizer, neem compounds have been demonstrated to increase rice's nitrogen use efficiency (NUE) (Agarwal *et al*., 1980; Singh and Singh, 1986).

### 2.3.4 Effects of Neem Cake (NC) of *Azadirachta indica* L. on Crops

The residues after mining the NL out of the seed kernels are called NC and can be utilized as biofertilizer (Chaudhary *et al*., 2017). NC has historically been utilized as fertilizer by Indian farmers, who discovered that it had a high manurial value (NRC, 1992). NC also performs a role as a soil health booster, supplies essential nutrients for the proper growth of plant, inhibits the action of soil insect pests and bacteria, and promotes increased nutrient uptake and plant output

(Roshan & Verma, 2015). NC functions as a biofertilizer for the plant's efficient growth and development and adds organic matter to the soil while reducing nitrogen loss in the surrounding environment (Lokanadhan *et al.*, 2012). "Azadirachtin, Nitrogen (3.56%), Phosphorus (0.83%), Potassium (1.67%), Calcium (0.999%), and Magnesium (0.75%)" are all chemical components of cake (Rangiah & Godwa, 2019). 24 kg of seed cake are produced from several 50 kg of ripe neem fruits that contain 30 kg of seed kernels.

### 2.3.5 Effects of Leaves of *Azadirachta indica* L

Neem leaves contain a wide range of compounds, including "steroids, alkaloids, glycosides, tannins, flavinoids, reducing sugars, and carbohydrates" (Manikandan et al., 2008). Vermi-compost, which can increase soil fertility and serve as a pesticide, can be made from the extract, which is a good source (Chaudhary et al., 2017). A recent study found ethanolic extracts in neem leaves improved the anti-microbial performance of seaweed films, resulting in a sustainable packaging material (Kumar *et al.*, 2019). According to Bahar *et al.* (2007), the extracts were also efficient against bean aphid and reduced the number of whiteflies and aphids on cabbage (Basedow *et al.*, 2002; Zaki, 2008). Finally, the extracts of neem leaves combined with garlic bulbs were found to be effective in reducing aphids and whiteflies that damage various crops, according to Pareet (2006).

### 2.3.6 Effects of Bark of *Azadirachta indica* L

According to Xuan *et al*., (2004), bark extracts have allelopathic qualities and behave as phytotoxic materials when applied to the soil. They also hinder germination and growth in crops like rice, radish, carrot, sesame, and beans. The larva, pupa, and reported antifeedant actions on *Helicoverpa armigera* and *Spodoptera litura* were all completely killed by a nano formulation prepared from crude neem gum and obtained from neem bark at a concentration of 100 ppm (Kamaraj *et al.*, 2018).

### 2.3.7 Effects of Roots of *Azadirachta indica* L

Roots from neem trees offer antibacterial, antifungal, and antiseptic qualities (Lokanadhan *et al.*, 2012). The roots of the neem tree can also be used to isolate endophytic fungal flora (Verma *et al.*, 2011). Additionally, it was stated that root extracts are used to combat fleas and sucking insects (Lokanadhan *et al.*, 2012).

### 2.3.8 Neem as Nitrification Inhibitor

According to several studies, neem (*Azadirachta indica* L.), a plant belonging to the Meliaceae family, may have the ability to operate as a nitrification inhibitor. This means that it may help to delay the activity of the bacterial that causes denitrification, hence reducing the wasteful seepage of nitrate from the soil (Musalia *et al*., 2000; Mohanty *et al.*, 2008). Neem prevents nitrification by slowing the nitrobacteria's activity, which delays the initial stage of the translation of ammonium to nitrate. NUE (nitrogen use efficiency) is improved as a consequence of the gradual release of N from fertilizers (Motavalli *et al.*, 2008). Ammonia monooxygenase (AMO), an enzyme produced by the Nitrosomonas bacterium, is primarily responsible for $NO_3^-$ inhibition (Subbarao *et al.*, 2006). As a result of these inhibitors, more nitrogen is available to plants as $NH_4^+$, which slows down the nitrification process (Singh and Verma, 2007). NIs also lessen $NO_3^-$ leaching and $N_2O$ emission (Kumar *et al.*, 2000).

Neem product effects on urease activity, urea transformation in soils, and wheat production were investigated by Shivay *et al. (*2000). When the rice crop was in the tillering stage, prilled urea treatment had a larger concentration of NH3 -N than the other neem product treatments, but by the time it was in the booting and harvesting stages, the concentration had dropped. The coating of neem (products) caused a gradual change of NO2 -N, and neem outperformed the other goods in this experiment. When neem products were used instead of prilled urea in treatments, the urease activity was noticeably decreased. NL coating has demonstrated its excellence in increasing grain production and N use efficiency. Comparing NOCU to PU, urease activity was dramatically decreased (Murthy *et al.*, 2015).

The nitrogen usage efficiency (NUE) measures a plant's capacity to absorb nitrogen and convert available nitrogen into a useful component. Because grain crops need the most nitrogen to have a higher economic yield, the NUE is reported as being below 50% in cereal crops such as wheat (Ghafoor *et al.*, 2021). The N fertilization is delicate and needs to be in line with the crop's requirements (Slafer and Savin, 2018; Rahman *et al.*, 2019). A typical type of nitrogen (N) is nitrate, which is present in cell vacuoles and is reduced in the cytoplasm via nitrate and nitrite reductase activity. Chlorophyll, which is crucial for photosynthesis, was present in this process. When N is easily obtainable in the soil solution and the plant needs N at that moment, there are two crucial factors to consider (Ghafoor *et al*., 2021).

Naresh (2003) was the first to describe the qualities of neem that prevent nitrification and its phenomenon of boosting NUE in rice. Neem products (Rao *et al.,* 2000) and neem-cake coated urea exhibit nitrification-inhibiting properties, according to researchers at the Indian Agricultural Research Institute (IARI), New Delhi (Pushpanathan *et al.,* 2005). Researchers from IARI examined NL and a urea-NL mixture with 10% by weight of urea, using rice, and they noted that it out performed prilled urea (Desai *et al*., 2014) According to Sharma and Prasad (1996), neem-coated fertilizers have been found to reduce nitrogen losses by leaching and volatilization. The nitrification process may be inhibited by urea coated with NL, which would increase the availability, absorption, and efficiency of nutrients. This could be attributed to improvements in Ca, Mg, and S availability, absorption, and efficiency in soil as a result of armament from sources (Sujatha *et al.*, 2008). Fertilizer with coating of neem products lowers ammonia and nitrous oxide emissions as well as nitrate leakage into groundwater. It was discovered that urea coated in NL lasted longer in soil than PU and more successfully met the plant's needs for N. (Khandey *et al.,* 2017). NL is used in coating urea and that reduces N losses while also ensuring slow release of N to crops throughout their life cycles (Singh *et al.,* 2003). When used as a soil modification or mix with the soil, neem seed enhances the soil with organic matter and also reduces the wastage of nitrogen by suppressing nitrification. Additionally, it controls nematodes in the soil. (Roshan and Verma, 2015).

### 2.3.9 Neem Products Effects on Nutrient Uptake

Yield per nutrient intake is referred to as nutrient usage efficiency. In order for crops to absorb and use nutrients for maximum yields, the following three fundamental processes in plants must take place. nutrient absorption, assimilation, and utilization. The quantity of nutrients needed to replenish nutrients exported for the grain production of 12.0 mg/ha is quantified by maize grain nutrient status (Bender *et al.,* 2013). In their study on nitrogen mineralization and the relative efficacy of neem and neem coated urea for wheat and rice, Datt *et al.* (2007) found increased N, P, and K uptake with neem coated urea over pure urea, as well as a comparable trend for yield.

According to Meena *et al.* (2013), applying 2.7 t ha-1 of vermicompost and 75% of the recommended fertiliser dose enhanced maize N, P, and K uptake . Due to low nutrient levels in the soil pool, the treatment in which no nutrients were supplied resulted in minimal dry matter buildup. NC treatment occasioned higher N, P, and S'Uptake in spinach than urea, charcoal, or animal manure. Improved soil organic matter, soil Cation Exchange Capacity, total Nitrogen, available N, P and K uptake, plant height and tiller production, and rice yield were all seen with neem compost at 15 tons per hectare (Juniarso *et al.,* 2018). Additionally, it was discovered that the maximum nutrient uptake of 99.91 kg/ha was considerably achieved with the supply of zinc sulphate at 25 kg/ha, NC at 200 kg/ha, azotobacter at 2 kg/ha, and fertilizer at 150% of the prescribed dose. 50% of the prescribed dose of fertilizer treatment combinations showed the lowest nutrient absorption (Kamlakannan *et al.,* 2019). According to Ghosh *et al*. (2020), the usage of organic manure boosts the crop's access to nitrogen while also enhancing the nutritional state of the soil. Ram *et al*. (2020) discovered that N uptake was maximum in the vermicompost or FYM treatments that was combined with chemical fertilizers than in the sole fertilization.

The uptake of N, P, and K has been reported to be greatly improved by the supply of neem coated urea. To boost the effectiveness of nitrogen utilization, urea and NC are traditionally mixed together in India (Agostini, 2010). Although it has long been known that neem products can increase NUE in crops when combined with urea (Khandey *et al.,* 2017). Sanjay *et al.* (2015) used three different organic manures namely; FYM, vermicompost, and poultry manure with fertilizers and neem-coated urea, to study the impact of different organic manures and fertilizers on yield and uptake of nutrient in maize. The findings showed that fertilizer produced with neem-coated greatly boosted availability of nutrient and uptake. In terms of nitrogen utilization efficiency and N uptake, Upadhyay and Tripathi (2000), Kumar *et al.* (2011), and Kumar *et al.* (2007) discovered that neem coated fertilizer was superior than regular fertilizer. Additionally, vermicompost enhanced the soil's organic carbon content, creating a more favorable rhizosphere for maize to absorb nutrients

(Sharma *et al.*, 2019). Cocoa seedlings in unfertilized soil have low growth and yield responses, according to Moyin-Jesu and Atoyosoye (2002). Additionally, the soil N, P, K, Ca, and Mg values for the crops in control treatments were the lowest. Meena *et al*. (2019) discovered that applying neem coated urea (NCU) at recommended dose of 125% N (RDN) with a 50:25:25 split schedule at the basal (B), active tillering (AT), and panicle initiation (PI) stages resulted in higher P and K uptake and distribution to leaf, stem, and panicle at harvest compared to the supply of prilled urea at 100% RDN with the same split schedule (current practice) on rice.

### 2.3.10 Neem Products Effects on Nutrient Uptake Efficiency

Compost+NOCU+PK fertilizers, according to Sanjaykumar *et al*. (2015), considerably increased grain yield (8626 kg/ha), as well as maize's uptake of N (210.8 kg/ha), P (65.4 kg/ha), and K (205.8 kg ha-1). The COMPOST+NOCU+PK fertilizers treatment had the highest N, P, and K use efficiency, measuring 34.5, 59.9, and 118.1 kg grain per kilogram of N, P, and K applied, respectively. The soil's available N, P, and K levels were significantly greater in the compost+NC+PK fertilizers enrichment approach than they were in the RPP (154.8 kg/ha, 33.7 kg/ha, and 161.4 kg/ha, respectively). According to Abdul Rehman *et al.* (2021), applying 100% and 75% RNCU to wheat resulted in the highest levels of N, P, and K uptake , as well as the highest levels of agronomic use efficiency (AUE) (17.33 and 21.30 kg/kg), nitrogen use efficiency (30.31 and 31.75 kg/kg), nitrogeN uptake efficiency (NUptE) (1.04 and 1.09 kg/kg), and nitrogen productive efficiency (NPE) Ghafoor *et al.* (2021) investigated the effects of urea coating with secondary nutrients, NL, and microorganisms on the efficiency of fertilizer use and wheat production using studies on cabbage and baby corn. in calcareous soils and reduced N losses under arid environments. It was revealed that neem-coated and sulfur-coated fertilizers showed better results than monotypic urea.

Utilizing coated fertilizers greatly enhanced wheat phenology, growth, and nutrient uptake efficiency. In a field experiment, Jadon *et al*. (2018) grew corn on a Vertisol. The treatments included regular fertilizer (100% RDs), neem coated urea (NCU) and pine oleoresin coated urea (RCU) at 100% and 75% recommended doses (RDs), respectively (without any fertilizers). At 100% RDs, RCU and NCU increased grain yield by a respective 30.1% and 25.4% over conventional fertilizer. In comparison to treatments using regular fertilizer, coated fertilizer applied treatments had significantly higher agronomic efficiency, nutrient uptake efficiency, and partial factor productivity. Hussain *et al.* (2021) demonstrated that the application of 100% RDN through neem coated urea resulted in the maximum Agronomic Efficiency (AEN) (29.8), Physiological Efficiency (PEN) (103.8), Apparent Recovery Efficiency (AREN) (59%) and Agro Physiological Efficiency (APEN) (50.30). (T7). Addition of 75% RDN through neem coated urea in rice production outputted the highest Partial Nutrient Balance (PNBN) (1.08), and Partial Factor Productivity (PFPN) (60.99).

### 2.3.11 Neem Products Effects on Yield of Crops

The application of 150% of the fertilizer's recommended dose, zinc sulphate @ 2 5 kg/ha, NC @ 2 00 kg/ha, combined with 2 kg/ha of azotobacter, produced the maximum grain yield of 6 20.48 kg/ha and overall output of 8951.91 kg/ha, according to Kamlakannan *et al.* (2019). The fertilizer addition that employed only half of the recommended dose had the least impact on N uptake, Stover yield, and grain production. By using the entire prescribed amount of nitrogen through urea coated with neem at 4 ml NL/100 g urea, economic yield and biological yields were significantly increased in contrast to all other treatments. 100% N through NCU reported the maximum economic yield of 42.40 q/ha, this was closely followed by 100% nitrogen using urea (37.37 q ha-1) and 80% nitrogen using neem coated urea (35.36 q/ha) above farmer practice, which recorded the lowest grain production (34.77 q/ha). This research assessed the impact of applying various nitrogen sources on wheat yield (Mangat 2004).

In order to maximize production and returns from their maize crop, farmers should apply NC (0.57 t/ha), urea (130.5 kg/ha), zinc (5 kg/ha), vermicompost (1.66 t/ha), and boron (0.5 kg/ha), according to Dwivedi *et al.* (2022). To achieve the highest yield of green gram, Kamal *et al.* (2021) noted applying NPK at a rate of 20: 40: 00 kg/ha along with NC at a rate of 1 t/ha produced maximum yields in maize. They attributed it to positive effects of the treatment's higher growth parameters, the abundance of stored photosynthetic energy that was transferred into different yield attributes, the slow release of nutrients over a long period, and the accessibility of nutrients by the plant in its later stages of growth. NC at a rate of 3 t/ha was suggested by Das *et al*. (2018) to be used on spice crops like ginger, turmeric and large cardamom in order to increase productivity. NC, applied at a rate of 150 kg/ha, has also been found to be beneficial in controlling soil-borne pests in common crops like rice and corn. NC was found to perform better than leaf extracts in preventing the autumn army worm (*Spodoptera frugiperda*) in a different study (Silva *et al.*, 2015). Datt *et al*. (2007) investigated the relative effectiveness of neem- and neem-coated urea for wheat and rice in terms of nitrogen mineralization. The results showed that rice and wheat crops both produced more grain and straw when treated with 100% neem coated urea (9.2% and 6.8% greater yield, respectively).

According to Narkhede *et al.* (2001), the best method for maximizing sesame productivity was to apply castor oil seed cake at a rate of one ton per hectare and 50 kilograms of nitrogen. Jaishankar and Wahab (2005), also reported rapid growth and highest yield components of sesame were obtained when NPK fertilizer and vermicompost were incorporated at a rate of 5 t/ha. Using NL and cake at 1.2 t/ha with composted chicken droppings at 3. 47 t/ha maximized the yield of grain (5236 kg/ha), while using absolute control resulted in noticeably reduced grain yield (2814 kg/ha) (Jothi *et al.*, 2021). Meena *et al.* (2019) found out, applying NCU at 12 5% RDN with a 50: 25: 25 different stages at the basal (B), tillering stage , and panicle initiation stages increased grain yield to 10.95% greater than the standard procedure. Crops have been reported to perform better when both organic and inorganic nutrients are used together than when they are used separately (Ayeni, 2008; Ayoola and Makinde, 2009). According to Krupnit *et al.* (2004), combining organic and inorganic fertilizer can lower crop fertilizer costs and requirements.

NC with urea was the most effective treatment, according to Salma and Hossain (2021), for increasing plant height, area, dry weight, and yield, all of which were closely related to N and P uptake. According to statistics, this treatment outperformed all others. Shardha and Sujathamma (2018), use of NPK + inorganic fertilizers considerably increased rice grain production In order to increase yields and maintain soil health, Jeyabala and Kuppuswamy (2001) suggested applying integrated nutrition, which includes N fertilizers, vermicompost and biofertilizers, to rice-leaf cropping systems. When it comes to managing nutrients in crops like maize, rice, buckwheat, mustard, rapeseed, soybean, ginger, and turmeric, NC is said to be the best substitute (Das *et al.*, 2020). NC at a supply rate of 200 g m-2 combined with arbuscular mychorrhiza fungus boosted the amount of phosphorus in the soil and helped the okra plants grow taller (Mohapatra *et al*., 2020). According to Ayito and Iren (2018), using 60 kg of NPK and 60 kg of Neem together boosted the yield of okra to 8.43 t/ha. It was also discovered that the maximum economic yield production of 620.48 kg/ha was considerably registered by the administration of 150% of the recommended fertilizer dose, zinc sulphate @ 25 kg/ha, NC @ 200 kg/ha, and azotobacter @ 2 kg/ha. Lowest grain yield, was observed in the fertilizer treatment combinations of 50 % recommended dose (Kamlakannan *et al.*, 2019).



### 2.3.12 Neem Products Effects on Dry Matter Accumulation

Arafa (2004) asserts that nitrogen fertilization produces an increase in the size of cell, lengthening, and its division, raising the height of plant, branch count, additional and parched foliage production, number of tubers produced per plant, weight of tuber, percentage of tubers, and chemical constituents of foliage and tubers. According to Raskar *et al.* (2012), a balanced supply of NPK and NC boosted plant height with subsequent increase in the number of grains in maize. When organic manure was treated with the stipulated amount of NPK, its yield increased in as compared with the sole chemical fertilization (Abdelsalam *et al.*, 2016). Plant shoot weight was positively impacted in comparison to control by applying neem kernel powder to increase the duration of nutrient availability. This finding backs up comparable studies on soyabean (Arafat *et al.*, 1999), rice (Rayar and Bello, 1985). (Murali *et al.*, 1999). By strengthening the physicochemical properties of the soil, organic manures like farmyard manure and vermicompost serve to maintain soil productivity and also help to increase the effectiveness of chemical fertilizers that are used. It allays the unwanted effects of chemical fertilization on soil beneficial microbes by lowering chemical toxicity and so create a conducive environment for their growth and activities within the soil (Abdelsalam *et al.*, 2016).

For maize, Dwivedi *et al.* (2022) found that applying NC at a rate of 0.57 tons per hectare along with vermicompost at a rate of 1.66 tons per hectare, urea at a rate of 130.5 kilograms per hectare, zinc at a rate of 5 kilograms in a hectare, and boron applied at 0.5 kilograms in a hectare with the resultant production of maximum plant height of 207.20cm. According to Gurja *et al*. (2022), interventions using NPK+ Zinc+ 100% NC and N120 P60 K60 Zn20 Kg/ha + NC were effective. Plant height increased as did the number of leaves per plant, dry weight (164.07g), and length of the cob (18 cm). The study's findings revealed that adding NC along with N, P, K, zinc, and NL considerably improved plant growth and maize yield.

The maximum fertilization of NPK, NC, and their mixtures at 100 kg/ha of NPK and 3 t/ha NC meaningfully increased the growth, peak yield, and yield components of sesame plants (Eifediy *et al.,* 2017). NC increased the leaf area index (0.154), plant's height (24 cm), and dry weight (1254 kg/ha) by 258%, 132%, and 450%, respectively, in comparison to the control and to urea, charcoal, and animal manure in spinach. In their study of green gram, Kamal *et al*. (2021) discovered that the addition of NPK at 20:40:00 kg/ha plus NC at 1 t/ha resulted in higher parameters of growth as well as yield parameters for the plant. The combination of N20P40 Kg/ha + NC 1 t/ha had the highest grain yield (12.55 q ha-1). Under this approach, the highest net return of Rs. 70918 per hectare and the benefit cost ratio of 3.35:1 was also noted. Using NL and cake at 1.2 t/ha and composted chicken manure at 3.47 t/ha increased the yield of straw to 8640 kg/ha, while using absolute control resulted in noticeably lower yields (5105 kg/ha) (Jothi *et al.,* 2021).

Improved neem leaf extract (woodash + neem leaf extracts treated at 1200 liters/ha), according to Moyin-Jesu, E. I. (2012), enhanced the height of maize plant and stem girth by 11.78% and 27.43%, respectively, as well as maize grain yield and cob weight by 65.63% and 57.58%. The greatest soil pH (H2O) values were likewise found in poultry manure and modified neem leaf extract. For instance, modified neem leaf extract boosted soil pH (H2O), K, Ca, Mg, Na, O.M, P and N by 12.4%, 32.8%, 25%, 23.7%, 19.32%, and 20% when compared to 300 kg/ha NPK 15-15-15 + neem leaf extract and control. In their study, Lalnunpuia *et al.* (2018) came to the conclusion that the application of NPK at the Recommended Dose of Fertilization + NC 100 kg/ha was noted to be more advantageous and considerably increased potato growth metrics and production. Additionally, a discovery was made that, using 25 kg of zinc sulphate, 200 kg of NC, and 2 kg of azotobacter at 150% of the recommended fertilizer dose produced the highest stover yield of 8951.91 kg/ha. The combination of fertilization treatments at half of the required dose resulted in the lowest stover production (Kamlakannan *et al.*, 2019).

# CHAPTER THREE

# 3.0 MATERIALS AND METHODS

## 3.1 Experimental Site

The experiment was done at two on-station sites at UDS farms, Nyankpala near Tamale, and Technical University of Tamale (TaTU) farms in Tamale, in the North of Ghana during the 2021 farming season. Both locations are in the Guinea savannah ecological zone. The region typically experiences mono-modal rainfall from early July to the beginning of November, with a yearly rainfall of between 900–1,000 mm. In the rainy and dry seasons, respectively, daily average temperatures are 22°C and 34°C. The highest relative humidity of 80% observed during the rainy season, drops to as low as 53% when it is the dry season in the region. The soil at Nyankpala is brownish in color, sandy-loam, free from concretion, relatively shallow, and has a hardpan beneath the top soil. It is referred to locally as the Nyankpala series (SARI, 2007). The maximum mean rainfall documented was 28.6 mm in June whilst 9 mm minimum was logged in July during the study. The study span from June to November. Maximum mean temperature recorded in November was 35 °C and 24 °C was noted as the minimum mean temperature for the rest of the months as shown in Table 1 below.

Table 1: Monthly weather data throughout the period of study at both locations, June-November.

| Months | Rainfall (mm) | Temperature (°C) | |
|---|---|---|---|
| | | Minimum | Maximum |
| June | 28.6 | 24 | 33 |
| July | 9.0 | 24 | 30 |
| August | 15.0 | 24 | 30 |
| September | 12.0 | 24 | 30 |
| October | 10.0 | 24 | 32 |
| November | | 24 | 35 |
| TOTAL | 74.6 | | |
| MEAN | 12.4 | | |

**Source:** *CSIR_SARI weather station. 2021 records, Tamale.*

## 3.2 Laboratory Analyses

### 3.2.1 Soil Analysis

Basal soil samples were picked from the sites of the experiment at a depth of 0–20 cm, and their physico-chemical characteristics were examined (Table 2). The chemical analysis was carried out at the CSIR-SARI, Nyankpala-Tamale soil chemistry laboratory.

Soil samples were examined for pH using a glass electrode pH meter and water and calcium chloride in a 1:2.5 soil to solution ratio. Using the hydrometer approach as outlined by Gee and Bauder (1986), soil textural class was assessed. While ammonium acetate was employed to extract the exchangeable base, K, total nitrogen was determined using the Kjeldahl method (Bremner, 1965) and the Bray 1 extractant method (Bray and Kurtz, 1945) was employed to assess soil phosphorus. Flame photometer was used to calculate the K concentration.

### 3.2.3 Plant Tissue Analysis

Nitric acid ($HNO_3$), sulphuric acid ($H2SO_4$), and hydrochloric acid ($HClO_4$) were used to decompose ground plant samples, and the amounts of N, P, and K were then calculated as previously mentioned.

Table 2: Basal physico-chemical properties of the experimental soils at 0 - 20 cm depth.

| **PHYSICAL PROPERTIES** | **NYANKPALA** | **TaTU** |
|---|---|---|
| Texture | | |
| % Sand | 67.6 | 86.4 |
| % Silt | 22 | 10 |
| % Clay | 10.4 | 3.6 |
| Class | Sandy Loam | Loamy Sand |
| CHEMICAL PROPERTIES | | |
| $P^H$ | 5.28 | 5.28 |
| %N | 0.24 | 0.126 |
| mg/kg P | 6.08 | 28.931 |
| mg/kg K | 58 | 124 |
| C.E.C (cmol/kg) | 15.32 | 12.21 |

## 3.3 Planting Materials

### 3.3.1 The Hybrid Maize (Lake 601)

In Ghana, maize production is predominantly done using open-pollinated varieties (OPVs) and landrace with an average yield of 2 metric tons on a hectare, and this is lower than attainable yields (Ifie *et al.*, 2022). Ghana needs high-yielding hybrids of maize to boost production, guarantee food security, and achieve self-sufficiency. Due to the enormous yield advantage hybrids offer over OPVs, promoting and adopting them is one way to achieve self-sufficiency and food security. Hybrid varieties planted by farmers include but not limited to, Lake 601, Pan 12, Pan 53 and Pioneer (Ifie *et al.*, 2022). The lake hybrid maize used was obtained from the Ministry of Agriculture (MoFA), Crop Science Unit, Tamale. The Variety Release Committee of the Ministry of Food and Agriculture (MoFA) tried, evaluated, and approved the Lake 601 hybrid maize seed for use in the 2021 planting season. The grain was imported from South Africa. The highest yield potential is guaranteed when planted, making it the greatest choice for commercial and small farming

### 3.4 Experimental Design

A 2 × 3 × 3 factorial experiments laid in a randomized complete block design (RCBD) with three replications at both locations. The factorial treatment comprised of NC (0, 200 and 400 kg/ha), NL (0, 10 and 20L $ha^{-1}$) and NPK fertilizer rate (0 and 250 kg/ha). The maize variety tested was a hybrid maize variety Lake 601. Each plot measured 4.5 × 5.0 $m^2$ with an alley of 1 m between plots and 2 m between replications at a spacing of 75 × 20 $m^2$ with single seed per hill at the two locations. The resultant plant population was 53,333 plants/ha. The NC and NL were obtained from the women processors with the Sagnarigu Global 2000 Project.

### 3.5 Cultural Practices

From planting to harvesting all recommended cultural practices were followed: fertilizer application, weeding, and insect- pest control. Ploughing and harrowing of the land were done after which lining and pegging was done. Inorganic NPK fertilizer (15-15-15) at the rate of 250 kg/ha was applied at 2 WAP and side dressing was done by the application of ammonium sulphate fertilizer at 125 kg/ha, at 6 WAP (Kombiok *et al.,* 2012). Neem (200 kg/ha and 400 kg/ha) was applied as nitrification inhibitor alongside the NPK application. These were applied at least 5cm deep and 5cm away from the plants. Hoeing was done 2 WAP and again when the plants were 6 weeks old. Insect pest (army worm) control was carried out using Dimethrin 25g 1l (Plan D) at a rate of 25ml per 15 litres of water. This control measure was applied two times at 2 weeks interval to ensure complete control of insect pests.

### 3.6 Data Collected

Data were collected on the following parameters on both fields.

#### a) Plant height

In each treatment, ten middle rows of maize plants were randomly chosen, tagged, and measured every two weeks from the soil line to the uppermost visible node. The growth rate was calculated using the arithmetic mean.

**Crop Growth Rate**:

The growth rate (GR) between times initial plant height (T1) and final plant height (T2) was assessed using the relation:

$$\text{Crop Growth rate (GR)} = \frac{\text{Average maize Height at time T2} - \text{Average Height at time T1}}{\text{Average Height at time T1}} \qquad eqn.1"$$

Growth rate was estimated in centimeters per week.

#### b) Chlorophyll content

Using a chlorophyll meter, the chlorophyll content of two leaves was determined for each leaf's location beneath, at, and above the ear (Model: Minolta SPAD, Japan). Each plot contained the ten data plants chosen at random.

#### c) Total leaf area and Leaf area index

Using a metre rule, the length and widest width of all the green leaves on the chosen plants were measured every two weeks. The area of each leaf was calculated by multiplying the sum of its length and width by 0.75. By adding leaf areas of the ten plants, the total leaf area was calculated. For each plot, the average leaf area of a plant was calculated. The relation: was used to calculate the leaf area index.:

$$\text{Leaf area index (LAI)} = \frac{\text{Total leaf area of plant}}{\text{Land area}} \qquad eqn.2$$

#### d) Days to 50% tasseling and silking

Throughout the tasseling stage, the plants were closely scrutinized every day, and the quantity of tasseled plants was noted. When half (50%) of the population inside the plot began to tassel, the number of days to 50% tasseling was noted. Tasseled plants were checked daily for evidence of silking. Every day, the number of silked plants was tallied, and the time required to reach 50% silking was calculated.

### e) Plant height at maturity

A measuring tape was used to take the height of the mature plants from the soil line to the base of the tassel.

### f) Maize grain yield (economic yield)

From the cob, grain was shelled, then dried in the sun. The grain weight of the plants in the sample was calculated as kilograms per hectare.

### g) Total stover biomass yield (Biological yield)

The sampled plants' above-ground Stover output was dried in the oven at 70 °C to a consistent weight. The total dry matter yield per hectare was calculated by averaging the corresponding grain weights.

### h) The harvest Index

Calculation of harvest index (HI) was done by the relation:

$$\mathrm{HI} = \frac{\text{Economic yield}}{\text{Biological yield}} \qquad eqn. 3$$

### i) Nutrient Uptake

The nutrient uptake was calculated using the relation:

$$\text{"Nutrient uptake (kg } ha^{-1}) = \frac{Nutrient\ content\ (\%) \times Yield\ (kg\ ha^{-1})}{100} \qquad eqn. 4\text{"}$$

**j) Nutrient Uptake Efficiency**

The Nutrient uptake efficiency (NUptE) (kg/kg) determination was done using the formula (Xu et al. 2020):

$$\text{NUptE}\left(\frac{\text{kg}}{\text{kg}}\right) = \frac{\text{Accumulation of Nutrients in plant}}{\text{Nutrient applied}} \qquad eqn.6$$

## k) Grain Yield Increase

The yield increase was calculated using the relation,

$$\text{Yield increase} = \frac{Yield\ from\ treated\ plot\ (kg\ ha^{-1})}{Yield\ from\ control\ plot\ (\text{kg}\ ha^{-1})}\ X\ 100 \qquad eqn.5$$

### 3.7 Statistical Analysis

The acquired data was arranged in Microsoft Excel and subjected to Analysis of Variance (ANOVA) using Genstat 12th edition statistical package. The factorial treatment combination of NC, NL and NPK fertilizer was analyzed using General Treatment Structure in Randomized Block to determine treatment effects on parameters measured. First data for the two locations were combined and analysed to determine location effect, before separate location for parameters where there was no location by treatment effect. The different treatment averages were compared using the Least Significant Difference (LSD) at the 5% probability. The affiliation between grain yield, nutrient uptake and uptake efficiency was examined using correlation analysis.

# CHAPTER FOUR

# 4.0 RESULTS

## 4.1 COMBINED LOCATION ANALYSIS

The combined data analysis showed only location by NPK interaction effects on most of the parameters and presented herewith.

### 4.1.1 Plant Height

At 2 weeks after planting (WAP) ($P < 0.01$) and 4 WAP ($P < 0.001$), plant height was significantly affected by the interaction of location by NPK fertilizer application. Taller plants of maize were observed at Nyankpala (77.2 cm, 124.2 cm) than TaTU (13.2 cm, 21.6 cm) with 250 kg/ha NPK at both timings (Figure 1). Plant height at TaTU at 4 WAP did not statistically increase over the entry at 2 WAP by the NPK fertilizer.

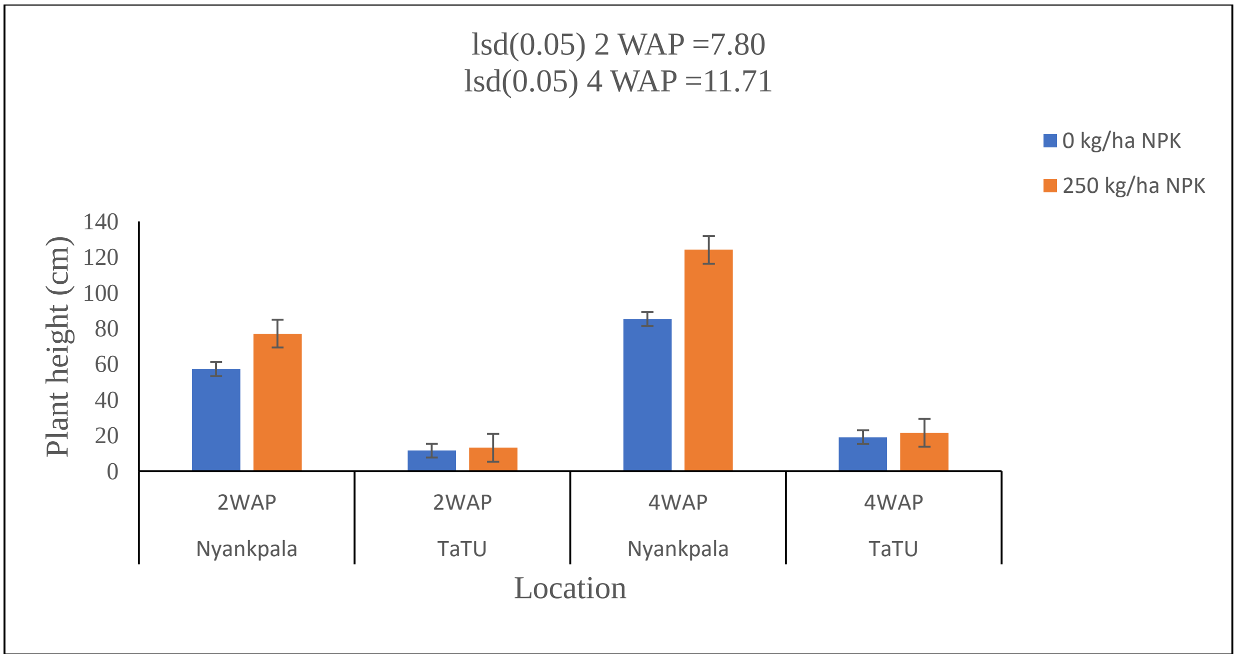


Figure 1: Interaction effects of location by NPK fertilizer application on plant height at 2 and 4 WAP. Bars represent SEM.

### 4.1.2 Growth Rate

The growth rate in height of a crop evaluates the proportion at which the crop rises in height for a period of time. There was first order interaction ($P < 0.05$) of location by NPK on growth rate (cm per week) at 4 WAP. Highest growth rate of 2.57 cm per week was attained at Nyankpala followed by TaTU entry (0.45 cm per week) due to 250 kg/ha NPK (Figure 2).

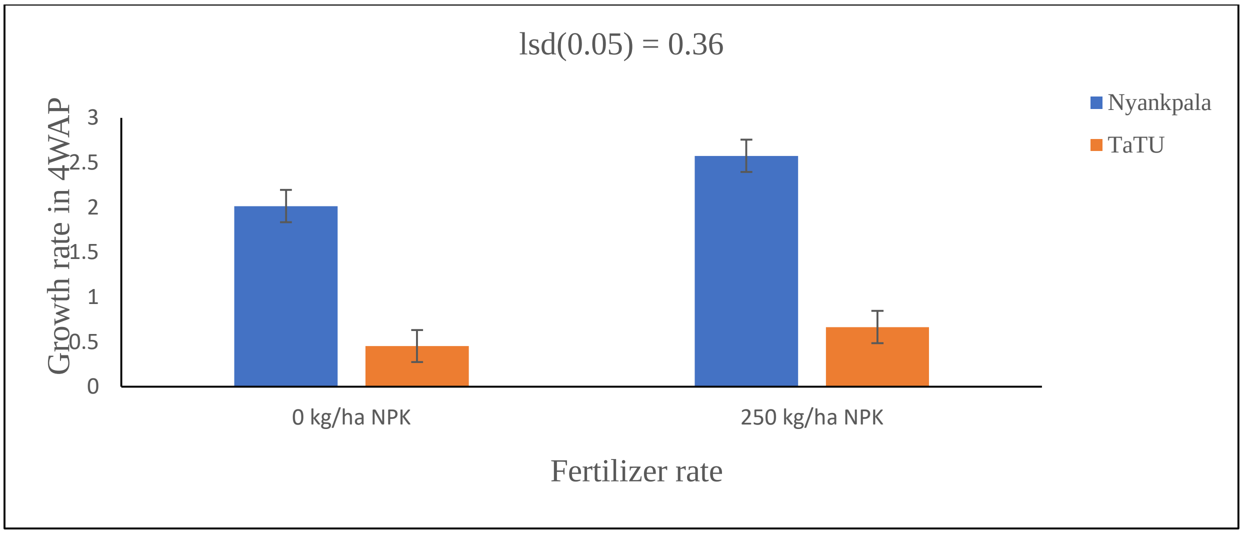


Figure 2: Interaction effects of location by NPK fertilizer on growth rate at between 4 WAP. Bars represent SEM.

### 4.1.3 Leaf Area Index (LAI)

The results of leaf area index at 2 WAP ($P < 0.05$) and 4 WAP ($P < 0.05$) were affected significantly by the interaction effects of location by NPK fertilizer. Application of 250 kg NPK/ha supported higher LAI at 2 WAP (4.25) and 4 WAP (5.58) at Nyankpala than at TaTU (Figure 3).

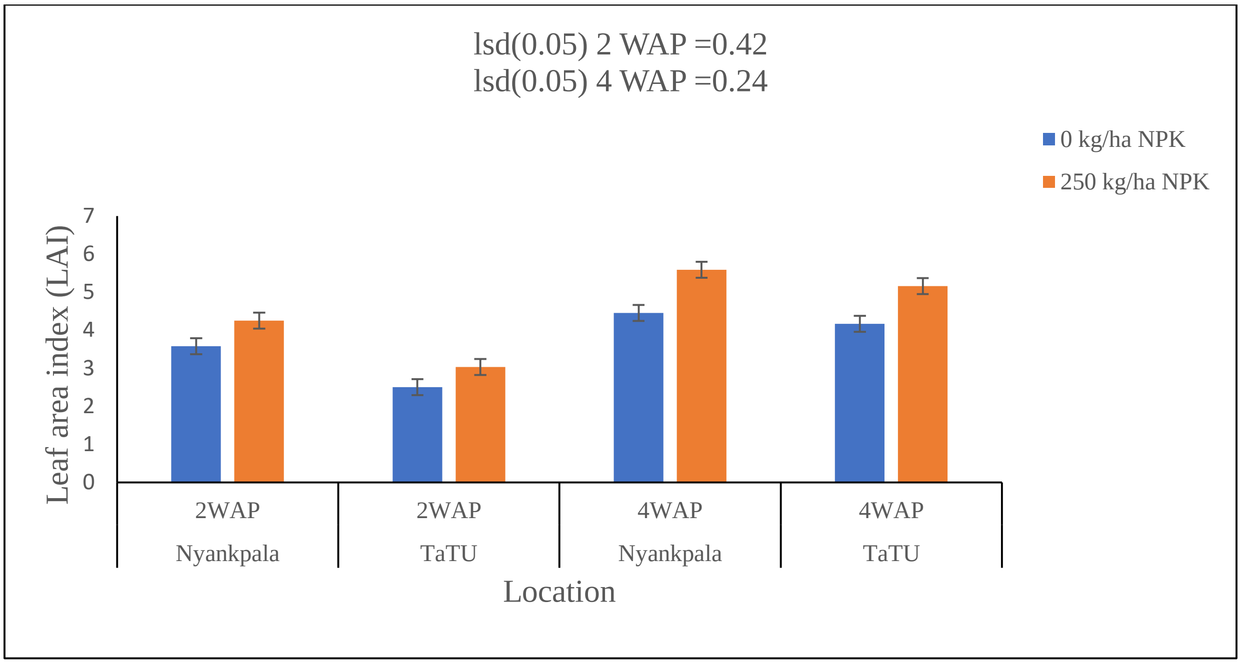


Figure 3: Interaction effects of location by NPK fertilizer on leaf area index at 2 and 4 WAP. Bars represent SEM.

### 4.1.4 Chlorophyll Content

Chlorophyll content statistically ($P < 0.001$) was affected by interaction effect of location by NPK fertilizer application. Nyankpala recorded higher chlorophyll content of 52.81 (spad) than TaTU (45.49 spad) with 250 kg/ha NPK (Figure 4).

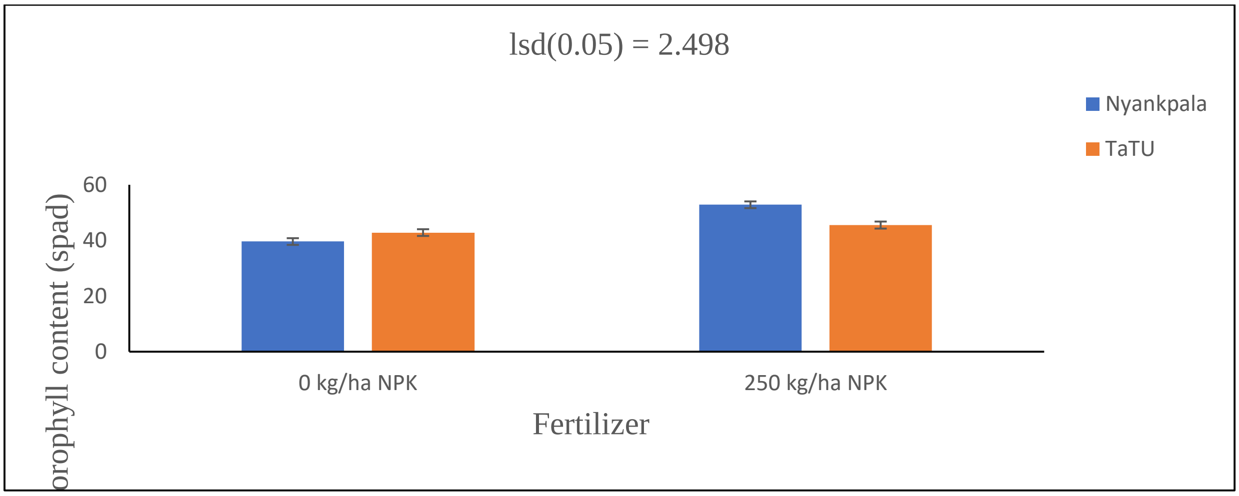


Figure 4: Interaction effects of location by NPK fertilizer application on chlorophyll content. Bars represent SEM.

### 4.1.5 Shoot Biomass

Shoot biomass of maize was statistically (P < 0.01) affected by NPK incorporation. Application of 250 kg NPK/ha gave the maximum shoot biomass of 18015 kg/ha at Nyankpala with a lower value of 11401 kg/ha at TaTU (Figure 5).

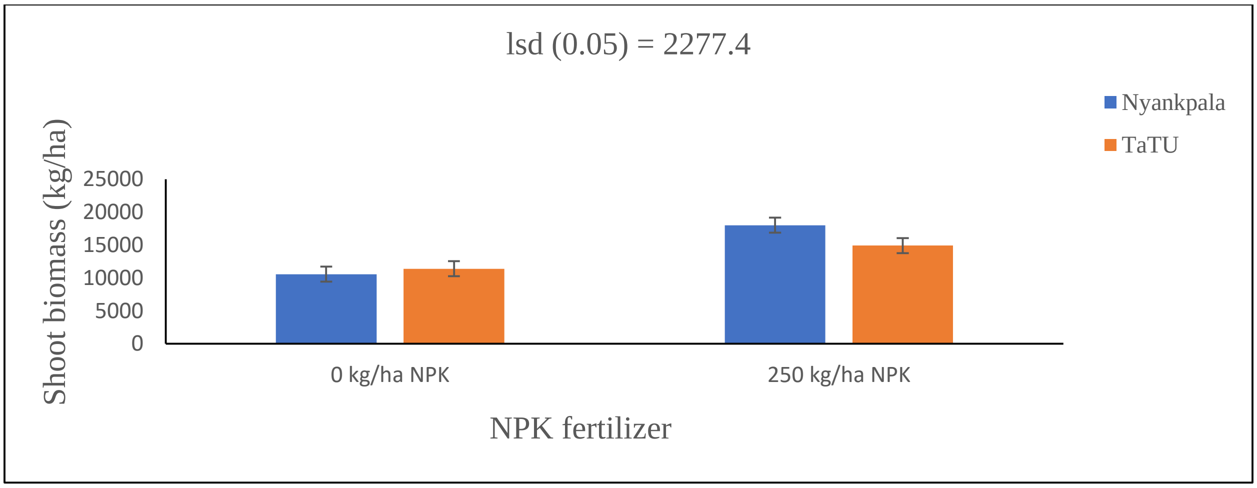


Figure 5: Interaction effects of location by NPK fertilizer on shoot dry weight. Bars represent SEM.

### 4.1.6 N uptake in Straw and Grain

There was significant difference (P < 0.001) in N-uptake in straw and grain of maize due to interaction of location and NPK fertilizer application. Higher N-uptake of 479.7 kg/ha) in straw was observed at Nyankpala with application of 250 kg/ha NPK, followed by 286.0 kg/ha at TaTU . Least uptake of 211.3 kg/ha was noted in TaTU by control (Figure 6a). Similar performance was observed for N-uptake in grain (Figure 6b). Application of fertilizer at Nyankpala outperformed with uptake of 167.4 kg/ha. than at TaTU with 115.8 kg/ha; Nyankpala supported with lowest uptake of 74 kg/ha.

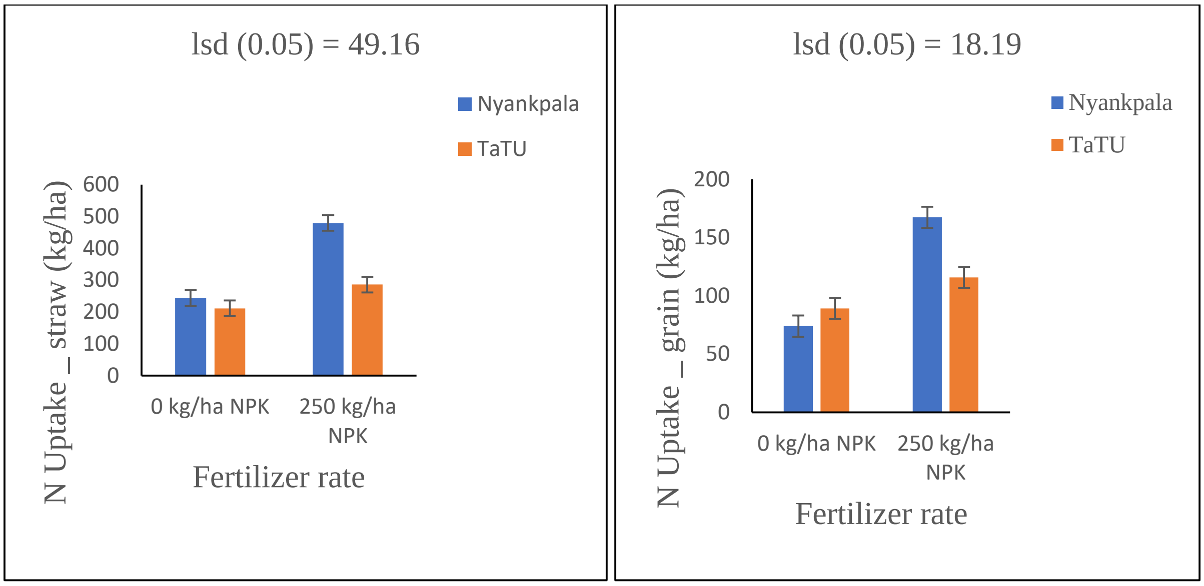


Figure 6: Interaction effects of location and NPK fertilization on N uptake in straw (a) and percentage N uptake in grain (b). Bars represent SEM.

### 4.1.7 Phosphorus Uptake in Straw and Grain

Location by NPK fertilizer application showed statistically significant ($P < 0.001$) effect on P uptake in maize as determined in straw and grain yield. Higher uptake of P was observed in straw at Nyankpala (94.9 kg/ha) than TaTU (38.1 kg/ha) due to the addition of 250 kg/ha NPK fertilization (Figure 7a). Similar observation was made for P-uptake in grain where NPK fertilizer recorded the higher uptake of 62.8 kg/ha at Nyankpala, than at TaTU with 27.9 kg/ha (Figure 7b).

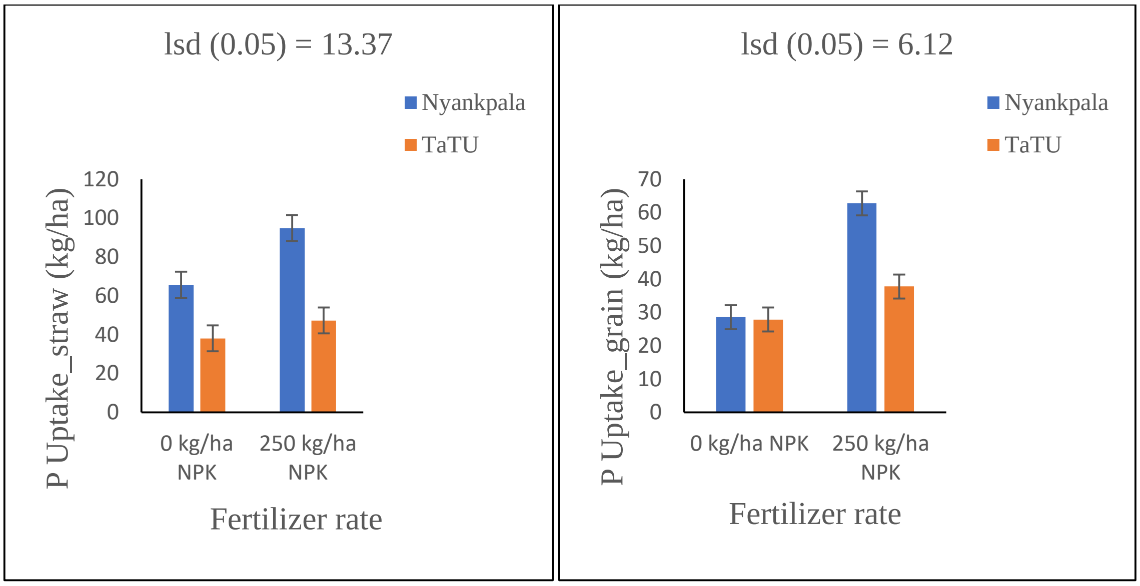


Figure 7: Interaction effects of location by NPK fertilization on P uptake in straw (a) and P uptake grain (b). Bars represent SEM.

### 4.1.8 Potassium Uptake in Straw and Grain

K uptake in straw was significantly ($P < 0.05$) influenced by the interaction of location by NPK fertilization. 250 kg NPK/ha gave higher potassium uptake in straw (176.3 kg/ha) at TaTU than at Nyankpala (55 kg/ha) (Figure 8a).

Grain potassium uptake was significantly ($P < 0.001$) affected by the interaction effects of location and NPK fertilization. Application of 250 kg/ha NPK gave the maximum K uptake in grain (116.6 kg/ha) at Nyankpala with a lower value at the control (Figure 8b).

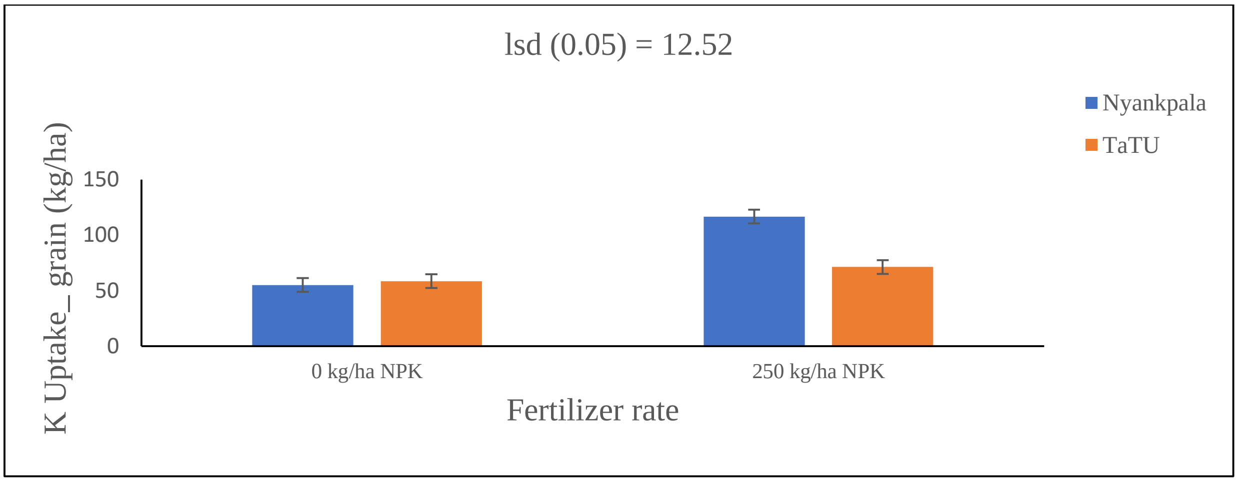


Figure 8: Effect of different location x NPK fertilization on K uptake in straw (a) and K uptake in grain (b). Bars represent SEM.

#### 4.1.9 N uptake Efficiency

Location by NPK fertilizer application by NC by NL demonstrated significance ($P < 0.01$) on efficiency of N uptake in maize. Higher N uptake efficiency of 0.05 was recorded at Nyankpala compared to 0.02 at TaTU (Table 3).

Table 3: Interaction effects of location by NPK fertilization by neem oil (NL) by neem cake (NC) on N uptake efficiency of maize.

| Nyankpala | | | | | TaTU | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **N, P, K (kg/ha)** | **NC (kg/ha)** | **NL (l/ha)** | | | **N, P, K (kg/ha)** | **NC (kg/ha)** | **NL (l/ha)** | | |
| | | **0** | **10** | **20** | | | **0** | **10** | **20** |
| **0** | **0** | 0.023 | 0.031 | 0.036 | **0** | **0** | 0.020 | 0.027 | 0.033 |
| | **200** | 0.034 | 0.033 | 0.035 | | **200** | 0.030 | 0.027 | 0.032 |
| | **400** | 0.034 | 0.035 | 0.029 | | **400** | 0.029 | 0.030 | 0.026 |
| **250** | **0** | 0.038 | 0.034 | 0.034 | **250** | **0** | 0.031 | 0.029 | 0.028 |
| | **200** | 0.038 | 0.036 | 0.029 | | **200** | 0.032 | 0.028 | 0.024 |
| | **400** | 0.036 | 0.042 | 0.032 | | **400** | 0.030 | 0.035 | 0.029 |
| **Grand mean** | | 0.03396 | | | | | | | |
| **Lsd (0.05)** | | 0.003 | | | | | | | |
| **CV** (%) | | 6.7 | | | | | | | |

### 4.1.10 P uptake Efficiency

Location by NPK fertilizer application by NC by NL statistically presented significance ($P < 0.001$) on efficiency of P uptake in the crop. 250 kg NPK /ha application + 400 kg/ha NC + 10 l/ha NL produced higher uptake efficiency of P at 0.08 than TaTU at 0.03 (Table 4).

Table 4: Interaction effects of location by NPK fertilizer by neem oil (NL) by neem cake (NC) on P uptake efficiency of maize.

| Nyankpala | | | | | TaTU | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **N, P, K (kg/ha)** | **NC (kg/ha)** | **NL (l/ha)** | | | **N, P, K (kg/ha)** | **NC (kg/ha)** | **NL (l/ha)** | | |
| | | **0** | **10** | **20** | | | **0** | **10** | **20** |
| **0** | **0** | 0.056 | 0.042 | 0.043 | **0** | **0** | 0.043 | 0.031 | 0.033 |
| | **200** | 0.056 | 0.043 | 0.046 | | **200** | 0.041 | 0.034 | 0.050 |
| | **400** | 0.041 | 0.039 | 0.046 | | **400** | 0.032 | 0.030 | 0.024 |
| **250** | **0** | 0.045 | 0.062 | 0.045 | **250** | **0** | 0.037 | 0.048 | 0.034 |
| | **200** | 0.055 | 0.042 | 0.041 | | **200** | 0.043 | 0.032 | 0.042 |
| | **400** | 0.056 | 0.057 | 0.043 | | **400** | 0.041 | 0.034 | 0.033 |
| **Grand mean** | | 0.05 | | | | | | | |
| **Lsd (0.05)** | | 0.005 | | | | | | | |
| **CV** (%) | | 5.4 | | | | | | | |

### 4.1.11 K uptake Efficiency

Location by NPK fertilizer application with NC and NL statistically showed significance ($P < 0.001$) on K uptake efficiency in maize. Higher K uptake efficiency of 0.07 was attained with fertilizer addition of 250 kg NPK/ha by 400 kg/ha NC by 10 l/ha NL at Nyankpala while TaTU recorded low uptake of 0.03 (5th Table).

Table 5: Interaction effects of location by NPK fertilizer by neem oil (NL) by neem cake (NC) on K uptake efficiency of maize.

| **Nyankpala** | | | | | **TaTU** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **N, P, K (kg/ha)** | **NC (kg/ha)** | **NL (l/ha)** | | | **N, P, K (kg/ha)** | **NC (kg/ha)** | **NL (l/ha)** | | |
| | | **0** | **10** | **20** | | | **0** | **10** | **20** |
| **0** | **0** | *0.033* | *0.047* | *0.051* | **0** | **0** | 0.026 | 0.037 | 0.042 |
| | **200** | *0.052* | *0.045* | *0.050* | | **200** | 0.041 | 0.038 | 0.042 |
| | **400** | *0.050* | *0.050* | *0.040* | | **400** | 0.039 | 0.040 | 0.036 |
| **250** | **0** | *0.055* | *0.047* | 0.042 | **250** | **0** | 0.043 | 0.037 | 0.036 |
| | **200** | *0.051* | *0.052* | *0.041* | | **200** | 0.041 | 0.041 | 0.028 |
| | **400** | *0.048* | *0.051* | *0.046* | | **400** | 0.038 | 0.035 | 0.033 |
| **Grand mean** | | *0.05* | | | | | | | |
| **Lsd (0.05)** | | *0.003* | | | | | | | |
| **CV** (%) | | *7.5* | | | | | | | |

### 4.1.12 Biological Yield

Biological yield statistically showed significance ($P < 0.01$) with effect from the interaction between location and NPK fertilizer application. 250 kg/ha NPK fertilization gave maximum biological yield of 24313 kg/ha at Nyankpala followed by TaTU (20958 kg/ha) while the control at Nyankpala had the lowest biological yield of 13783 kg/ha (Figure 9).

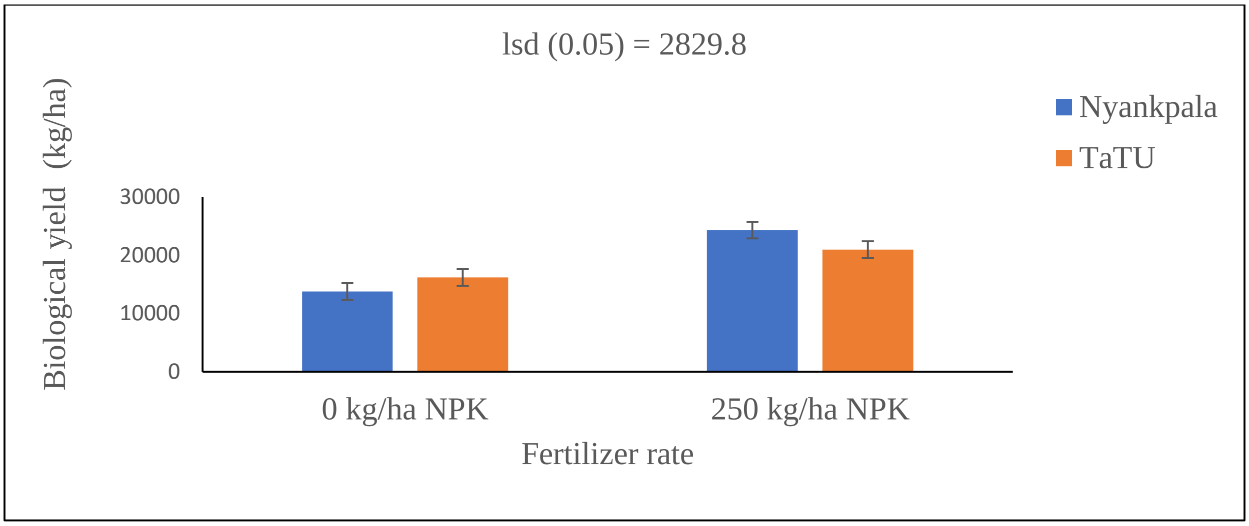


Figure 9: Interaction effects of location by NPK fertilizer on biological yield. Bars represent SEM.

### 4.1.13 Economic Yield

Data presented, statistically demonstrated significance ($P < 0.01$) on grain output by the interaction between location and NPK fertilizer application. 250 kg/ha NPK fertilizer application at Nyankpala recorded the highest economic yield of 6298.0 kg/ha followed by at TaTU with 6024 kg/ha whereas the control at Nyankpala had the least economic yield of 3195 kg/ha (Figure 10).

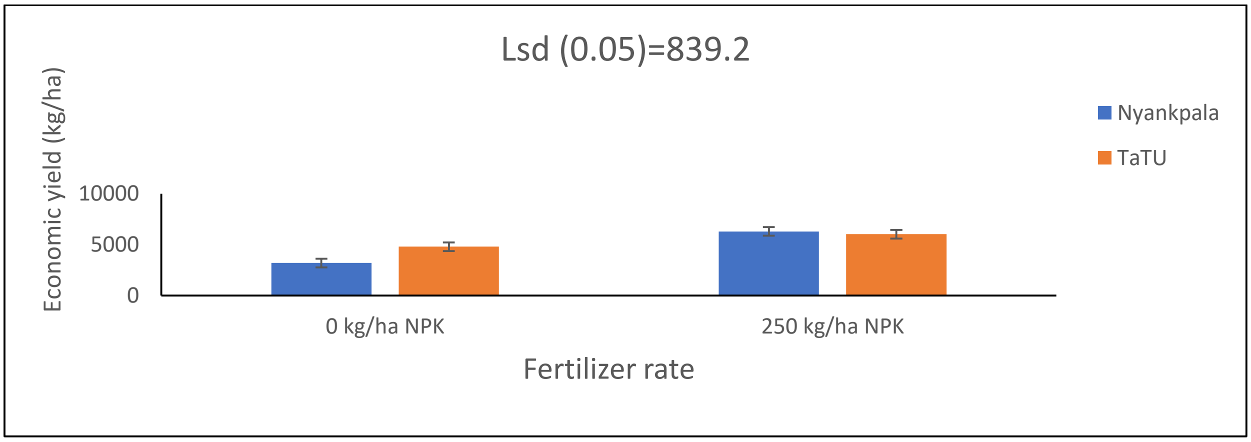


Figure 10: Interaction effects of location by NPK fertilizer on economic yield. Bars represent SEM.

## 4.2.0 RESULTS OF POOLED DATA

### 4.2.1 Plant Height

At 4, 6, 8 WAP and at maturity, the height of plant was significantly affected ($P < 0.001$) by NPK rate. All other main effects and interactions showed no statistical ($P > 0.05$) effect on plant height. 250 kg NPK/ha recorded the maximum plant height at all the timings, while the control supported lower values (Figure 12). With regards to the two levels of NPK application, plant height recorded were: 6WAP (97.2, 124.4), 8 WAP (137.5, 166.7) and at maturity (149.2, 174.4).

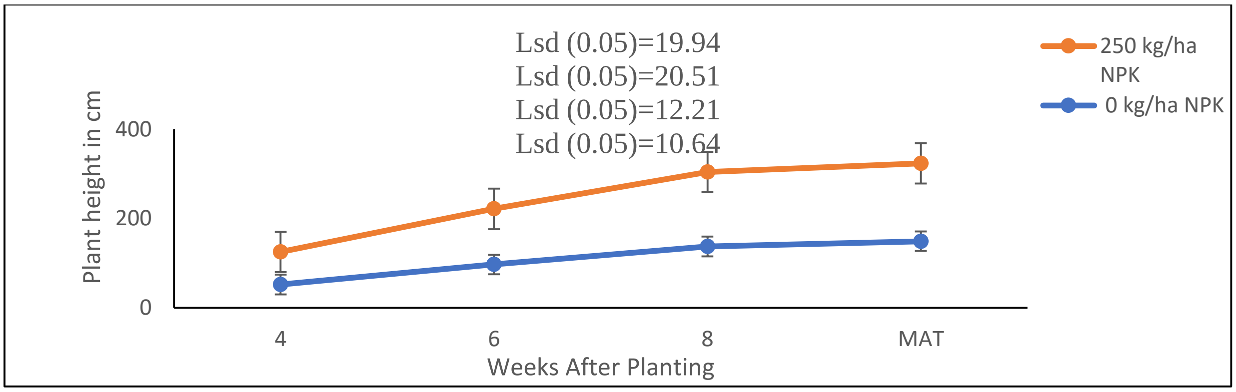


Figure 11: Effect of NPK rate on plant height at 4, 6, 8 WAP and at maize maturity. Bars represent SEM.

### 4.2.2 Crop Growth Rate

At 6 – 8 WAP, growth rate was significantly affected (P < 0.05) by NPK fertilizer application. All other main effects and interactions showed no statistical (P > 0.05) effect on growth rate. 250 kg/ha NPK supported maximum growth rate of 0.111, while the control had minimum growth rate of 0.081 (Figure 13).

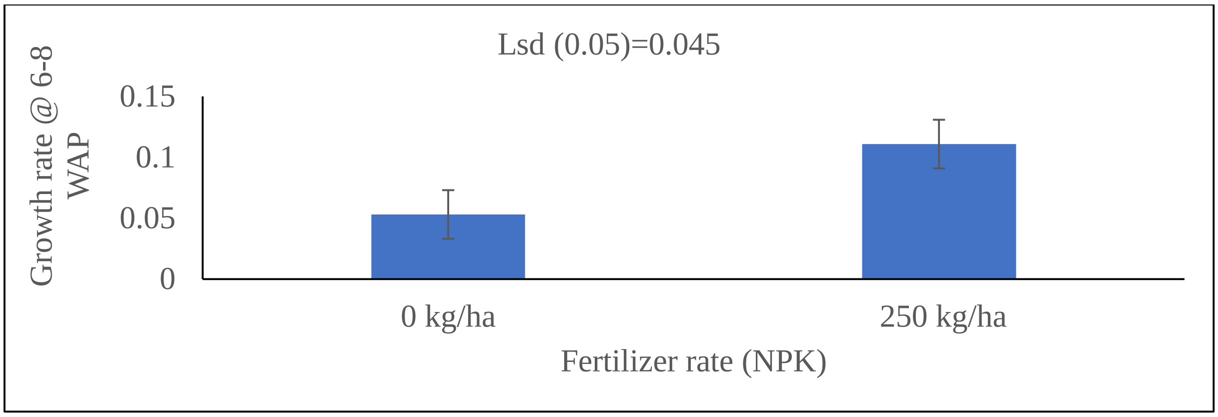


Figure 12: Effect of different NPK on rate of growth at 6 WAP of maize. Bars represent SEM.

### 4.2.3 Leaf Area Index (LAI)

At 2, 4 and 6 WAP, LAI was significantly (P < 0.05) (P < 0.01) and (P < 0.01) affected by the application of NPK fertilizer. All other main effects and interactions showed no statistical (P > 0.05) effect on LAI. 250 kg NPK/ha fertilization recorded higher LAI at all the timings (Figure 14).

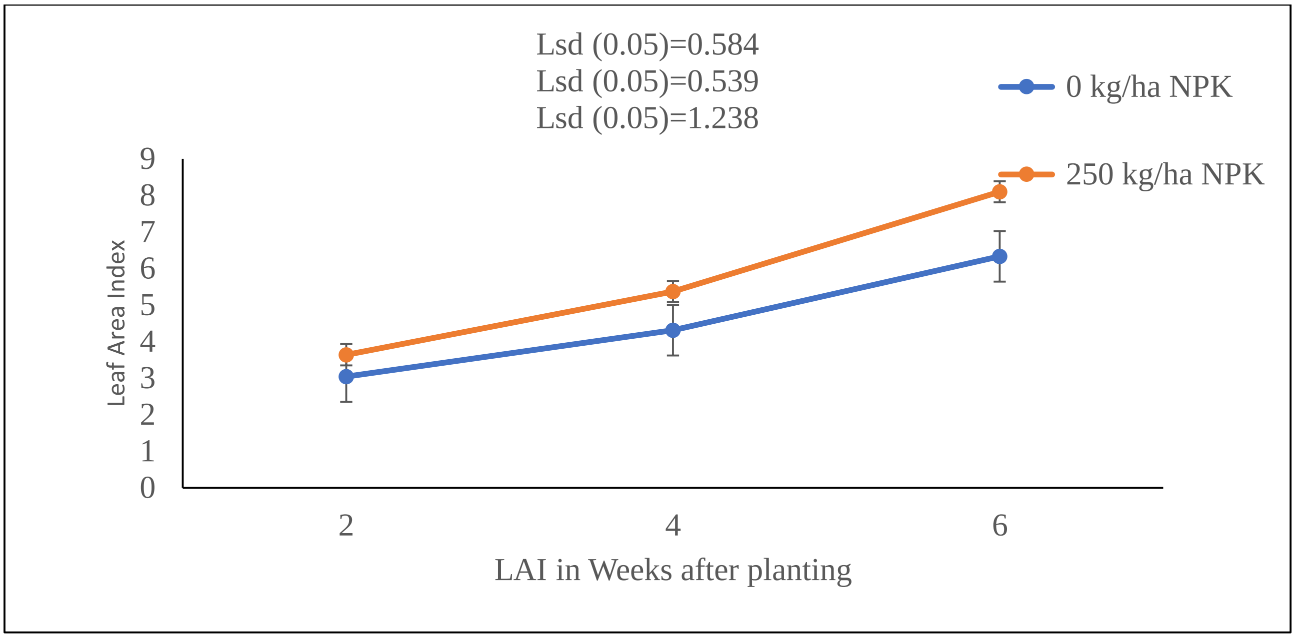


Figure 13: Effect of different NPK rate on LAI at 2, 4 and 6 WAP of maize. Bars represent SEM.

### 4.2.4 Shoot Biomass

Shoot dry weight was significantly affected ($P < 0.05$) by NPK application. All other interactions and main effects showed no statistical ($P > 0.05$) effect on shoot biomass. Application of 250 kg NPK/ha yielded maximum dry weight of 16474 kg/ha, while the least shoot biomass of 10994 kg/ha was obtained from the control (Figure 15).

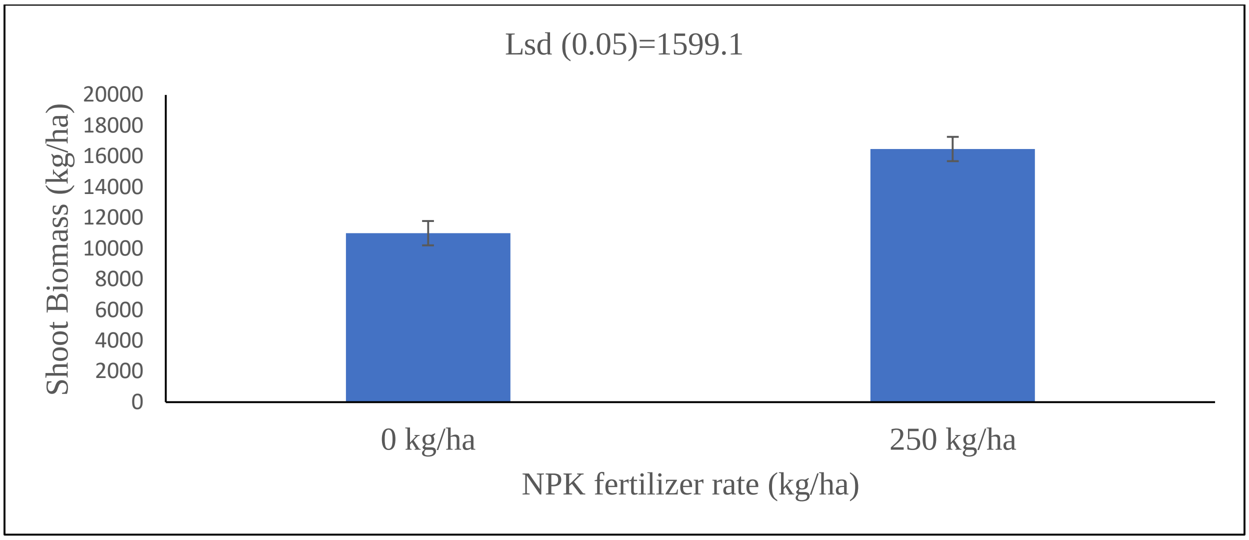


Figure 14: Effect of different NPK on maize shoot biomass. Bars represent SEM.

### 4.2.5 Chlorophyll Content

Chlorophyll content was influenced significantly ($P < 0.001$) by NPK fertilizer application in maize. All other main effects and interactions showed no statistical ($P > 0.05$) effect on chlorophyll content. The highest spad reading of 49 was observed with the incorporation of NPK, which is significantly different from all the other treatments (Figure 16).

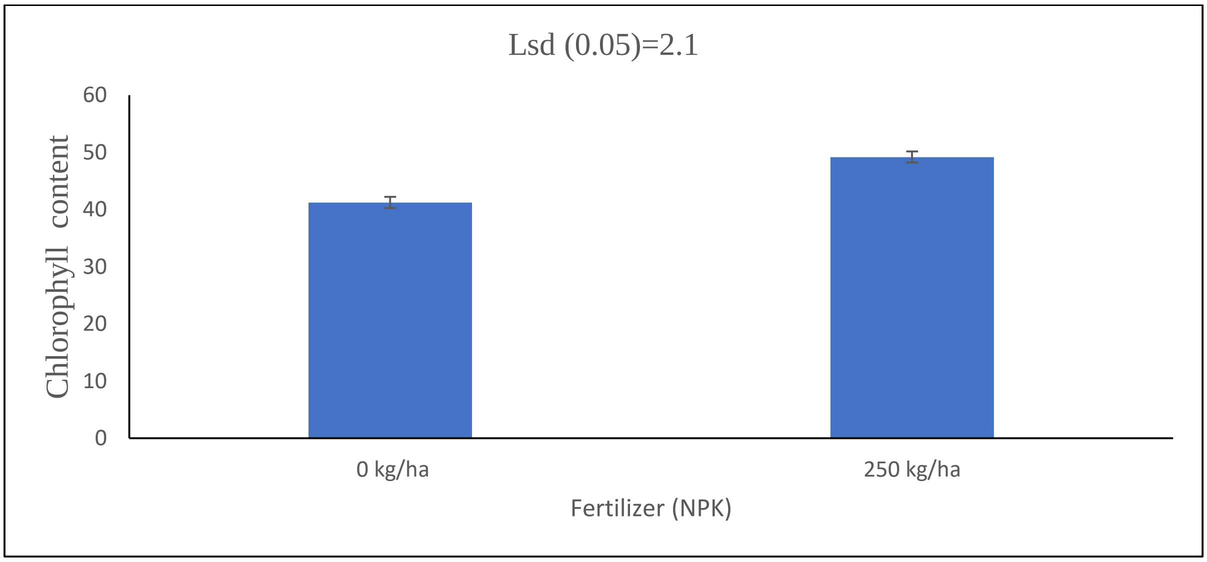


Figure 15: Effect of different NPK on chlorophyll content of maize. Bars represent SEM.

### 4.2.6 Grain N uptake

Grain N -uptake showed significant effects (P < 0.05) by the interaction between NL and NPK fertilizer application. All other interactions and main effects showed no statistical (P >0.05) effect on N uptake .

The highest N -uptake of 161 kg/ha in grain was noted with 10 l/ha NL by 250 kg NPK/ha while the least N -uptake of 74.1 kg/ha in grain was noted in control (Table 8).

Table 6: Effects of interaction of NPK fertilization by NL on N -uptake in straw of maize.

| N uptake in grain | | | |
|---|---|---|---|
| **NPK (kg/ha)** | **NL (l/ha)** | | |
| | **0** | **10** | **20** |
| **0** | 74.1 | 83.9 | 86.8 |
| **250** | 150.4 | 161 | 113.5 |
| **Grand mean** | 111.6 | | |
| **Lsd (0.05)** | 26.24 | | |
| **CV** (%) | 3.9 | | |

### 4.2.7 Grain P uptake

Data on P-uptake in grain showed significant influence by the interaction of NPK fertilizer rate by NC application (P < 0.01) and NPK fertilizer by NL (P < 0.01). All other interactions and main effects showed no statistical (P > 0.05) effect on P uptake in grain. 250 kg NPK/ha with 400 kg/ha NC supported the uppermost P-uptake of 61.1 kg/ha in grain while control noted least P-uptake of 24 kg/ha (Table 7). Interaction of NPK fertilizer and NC also determined P-uptake as observed in the maize grain. 10 l/ha NL with 250 kg NPK/ha gave maximum N-uptake of 58.2 kg/ha, while the 10 l/ha NL supported the minimum N-uptake of 26.0 (Table 7).

Table 7: Effects of interaction of NPK fertilizer application by NL and NC by NL application on maize grain P-uptake

| Grain P uptake (kg/ha) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **N, P, K (kg/ha)** | **NC (kg/ha)** | | | **NPK (kg/ha)** | **NL (l/ha)** | | |
| | **0** | **200** | **400** | | **0** | **10** | **20** |
| **0** | 24 | 30.9 | 29.9 | **0** | 28.7 | 26.0 | 30.1 |
| **250** | 47.7 | 42.1 | 61.1 | **250** | 54.5 | 58.2 | 38.2 |
| **Grand mean** | 39.3 | | | **Grand mean** | 39.3 | | |
| **Lsd(0.05)** | 11.02 | | | **Lsd(0.05)** | 11.02 | | |
| **CV** (%) | 4.9 | | | **CV** (%) | 4.9 | | |

### 4.2.8 Nitrogen (N) Uptake Efficiency in Grain

Data on N uptake efficiency in grain presented a significant influenced by the incorporation of NPK fertilizer ($P < 0.01$). All other interactions and main effects showed no statistical ($P > 0.05$) effect on N uptake efficiency in grain. 250 kg NPK/ha fertilization supported the highest N uptake efficiency of 0.035 in grain while control recorded least N-uptake efficiency of 0.032 (Figure 17).

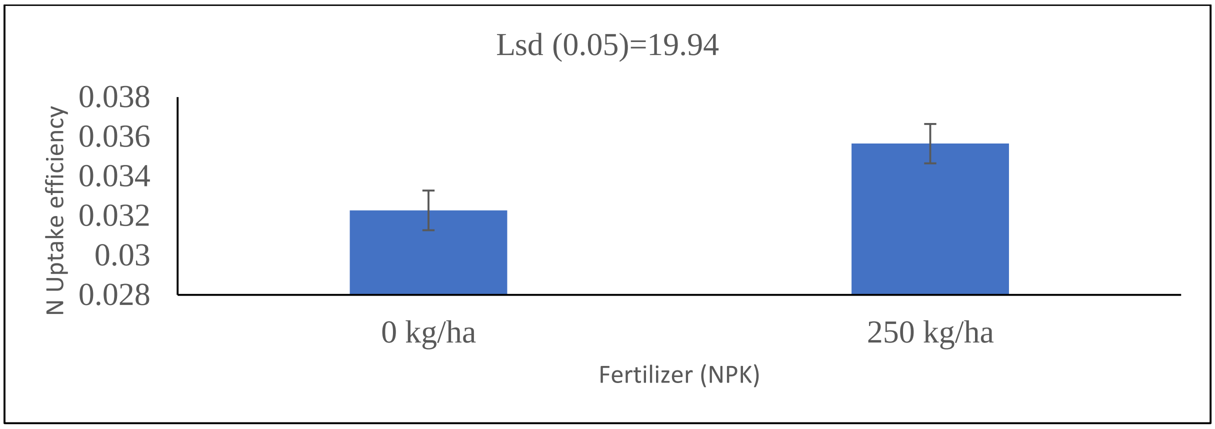


Figure 16: Effect of different NPK on N uptake efficiency of maize. Bars represent SEM.

### 4.2.9 Potassium Uptake efficiency in Grain

K uptake efficiency in grain was significantly (P < 0.05) affected by the secondary interaction of NPK, NL and cake. All other interactions and main effects showed no statistical (P > 0.05) effect on K uptake efficiency in grain. 250 kg/ha NPK by 400 kg/ha NC by 10 l/ha NL recorded the highest K uptake efficiency of 0.0521 while the control supported the minimum K uptake efficiency of 0.0326 (Table 8).

Table 8: Effect of neem cake (NC) by NPK fertilization on K -uptake in grain of maize.

| **K uptake efficiency** | | | | |
|---|---|---|---|---|
| **N, P, K (kg/ha)** | **NC (kg/ha)** | **NL (l/ha)** | | |
| | | **0** | **10** | **20** |
| **0** | **0** | 0.0326 | 0.0467 | 0.0509 |
| | **200** | 0.0516 | 0.0446 | 0.0506 |
| | **400** | 0.0505 | 0.0500 | 0.0396 |
| **250** | **0** | 0.0467 | 0.0473 | 0.0423 |
| | **200** | 0.0514 | 0.0512 | 0.0415 |
| | **400** | 0.0483 | 0.0521 | 0.0460 |
| **Grand mean** | | 0.0473 | | |
| **Lsd (0.05)** | | 0.01266 | | |
| ***CV*** *(%)* | | 6.4 | | |

### 4.2.10 Biological Yield

Biological yield demonstrated significance (P < 0.05) on the application of NPK fertilizer and also NC rate application. All other interactions and main effects showed no statistical (P > 0.05) effect on biological yield. Application of 250 kg NPK/ha gave the uppermost biological yield of 22,635 kg/ha, while the control had the least biological yield of 14,995 kg/ha (Figure 18a). NC application at 400 kg/ha gave the uppermost biological yield of 21,048 kg/ha, while the control had the least biological yield of 17,299 kg/ha (Figure 18b).

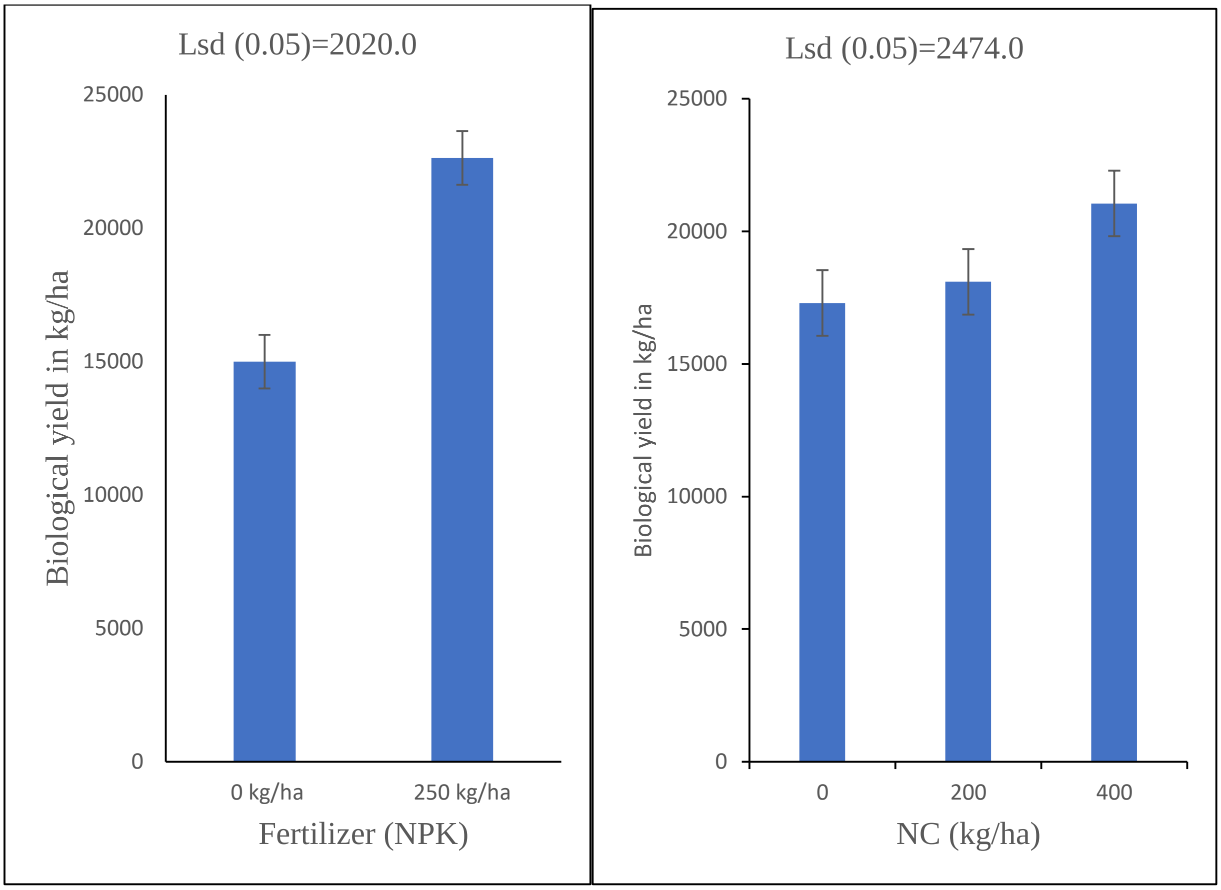


Figure 18: Effect of (a) NPK and (b) NC rate on biological yield of maize. Bars represent SEM.

### 4.2.11 Economic Yield

Economic yield was significantly ($P < 0.01$) effected by the application of NPK fertilizer and also NC rate application. All other interactions and main effects showed no statistically ($P > 0.05$) effect on biological yield. Application of 250 kg/ha NPK gave the highest economic yield of 1,232 kg/ha, while the control had the least economic yield of 800 kg/ha (Figure 19a). NC application at 400 kg/ha gave the highest biological yield of 1,172 kg/ha, while the control had the least economic yield of 912 kg/ha (Figure 19b).

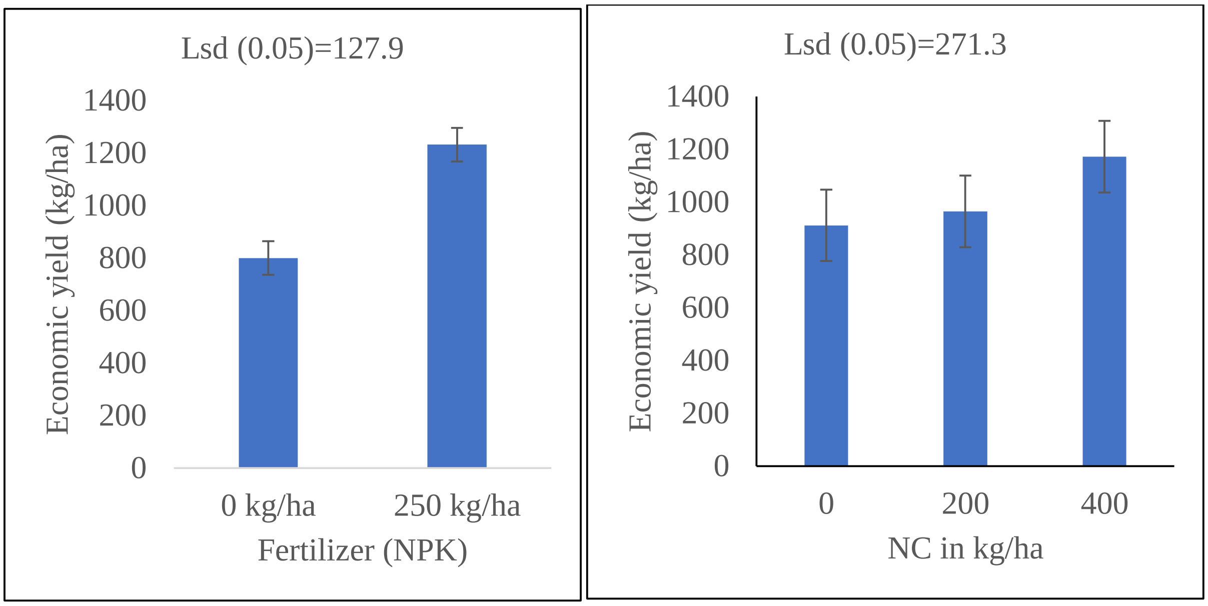


Figure 19: Effect of (a) NPK and (b) NC on economic yield of maize. Bars represent SEM.

## 4.3 Correlation Analysis

Grain yield positively correlated with N uptake, P uptake, K uptake, N uptake efficiency, but P and K uptake efficiency didn't show significant correlation (r= 0.91**, 0.82**, 0.85**, 0.20*, 0.01, 0.03), respectively (Table 9).

Table 9: Spearman's correlation coefficients ® for parameters measured.

| Column1 | HTM | CHL | DMY | LAIM | NUP | PUP | KUP | NUPE | PUPE | KUPE | BIOY | GY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HTM | 1.000 | | | | | | | | | | | |
| CHL | 0.636** | 1.000 | | | | | | | | | | |
| DM | 0.619** | 0.703** | 1.000 | | | | | | | | | |
| LAI | 0.735** | 0.661** | 0.644** | 1.000 | | | | | | | | |
| NUP | 0.604** | 0.694** | 0.781** | 0.591** | 1.000 | | | | | | | |
| PUP | 0.625** | 0.695** | 0.736** | 0.623** | 0.902** | 1.000 | | | | | | |
| KUP | 0.645** | 0.683** | 0.754** | 0.611** | 0.963** | 0.886** | 1.000 | | | | | |
| NUPE | 0.626** | 0.381* | 0.36* | 0.431* | 0.527** | 0.497* | 0.564* | 1.000 | | | | |
| PUPE | 0.485** | 0.292* | 0.193* | 0.303* | 0.233* | 0.501* | 0.287* | 0.588* | 1.000 | | | |
| KUPE | 0.588** | 0.236* | 0.226* | 0.37* | 0.342* | 0.345* | 0.472* | 0.896** | 0.581* | 1.000 | | |
| BIOY | 0.588** | 0.711** | 0.979** | 0.628** | 0.858** | 0.793** | 0.819** | 0.324* | 0.143* | 0.172* | 1.000 | |
| GY | 0.417* | 0.604** | 0.755** | 0.482* | 0.913** | 0.817** | 0.853** | 0.201* | 0.012 | 0.033 | 0.865** | 1.000 |

**Where: ***Significant at $p \leq 0.05$**, ****highly significant at $p \leq 0.05$. HTM= Height at maturity, CHL= Chlorophyll content. DMY= Dry matter in kg/ha LAIM = Leaf Area Index, NUP= N uptake, PUT= P uptake grain, KUP= K uptake , NUPE= N uptake efficiency, PUPE= P uptake efficiency, KUPE= K uptake efficiency, BIO= Biological yield, GY= Grain yield.

# CHAPTER FIVE

## 5.0 DISCUSSION

### 5.1 Effect of Location by NPK Fertilizer on Maize

Plant height increased, as predictable, when 250 kg NPK/ha was applied, with taller plants observed at Nyankpala than TaTU location at both 2 and 4 WAP (Figure 1). The height of the plant responded more to 250 kg NPK/ha fertilizer application at Nyankpala than TaTU due to probably differences in soil texture, as Nyankpala site has sandy loam texture at compared with loamy sand at TaTU. In addition, the basal percent Nitrogen content at Nyanpala was greater than at TaTU (Table 2), and that could have supported the increased in the height of the plant at Nyankapla more than TaTU. Khan *et al.* (2014) reported similar findings, finding a substantial increase in maize plant height when NPK was combined and administered at 30 DAE or 60 DAE. Ntiamoah *et al.* (2022) in addition, observed a considerable rise in the height of maize following an addition of NPK fertilization at the early stages of growth, and the reaction to NPK at Nyankpala was supported by their findings. Afrida and Tampubolon (2022), also noted significant outcome of NPK fertilization at maturity on height of maize. Speaking in deductive terms, a higher NPK concentration in the soil might have been the cause of the height increase associated with an increased NPK rate. According to Ibrahim *et al.* (2021), higher fertilization rates may be better able to give the nutrients necessary for maize growth, leading to more robust growth of vegetative parts and overall development in maize plants, as observed by the rapid growth of the plants that benefitted from higher fertilization rates. Agyin-Birikorang *et al.* (2022) demonstrated in a similar vein that proper fertilization boosts the height of plants and yield by boosting the amount of nutrient in tissues of plants. Based on a study by Chi *et al*. (2022), chemical fertilizer treatment significantly increased the growth of maize, physiological parameters, and yield component. Zhang et al. (2022) also noted that applying NPK fertilizer at the appropriate rate increased crop growth and output, provided adequate NPK, and improved soil health.

The incorporation of NPK at 250 kg/ha supported higher LAI at 2 WAP (4.25) and 4 WAP (5.58) at Nyankpala than at TaTU (Figure 3). The differences in LAI at 2 and 4 WAP could be due to different soil characteristics in Nyankapla and TaTU as described earlier. This is consistent with Berdjour *et al.* (2020), who noted comparable effects on maize LAI in the early stages of maize development. This might be because mineral NPK fertilizer can supply enough readily available plant nutrients during the first stages of plant growth. According to research by Szabó *et al.* (2022), LAI was dramatically raised when sufficient amounts of plant-available nutrients were provided. According to Guo *et al.* (2022) and Li *et al.* (2022), increasing NPK fertilizer level often resulted in an increase in LAI. According to Szabó *et al.* (2022), nitrogen is important for the growth and development of maize crops as well as the development of leaves and solar interception.

Addition of NPK fertilization showed a significant effect on chlorophyll content similar to plant height and LAI (Figure 4). This outcome was similar to the research by Kutasy *et al.* (2021) who noted the significant effect of mineral N fertilization levels on chlorophyll content. Higher rate of NPK fertilizer added at both locations were noted with higher chlorophyll content compared the control. According to Hou *et al.* (2020), a rise in N fertilization levels considerably enhanced chlorophyll content, which is consistent with the increase in chlorophyll content observed with increasing NPK fertilization. Increased NPK fertilization may have enhanced and improved leaf N content and, as a result, amplified the chlorophyll content {Mahil and Kumar, 2019; Ghafoor *et al.,* 2021). According to studies by Niewiadomska *et al.* (2010), Kutasy *et al.* (2021), and Lotfi *et al.* (2022), nitrogen fertilizer has been shown to activate enzymes involved in chlorophyll production.

Results presented in (Figure 5) showed significant effect on shoot dry weight as affected by interaction between location and NPK fertilizer application. The results indicated adding 250 kg NPK/ha fertilization enhanced total dry matter accumulation at Nyankpala more than TaTU, similar to plant height, LAI and chlorophyll content. Studies revealed nitrogen fertilization supported a multiplication in the number leaves per plant (Kandil *et al.,* 2011; Amana *et al.,* 2022). Studies by Arafa (2004), Small and Degenhardt (2018), Guan *et al.* (2021) noted fertilizer incorporation produced an increased cell size, elongation and enhancement of cell division, which increased plant height, number of branches, fresh and dry foliage, number of tubers per plant, tuber weight and tuber percentage and chemical composition of foliage and potato tubers.

Results (Figure 6) showed harvest index (HI) was significantly affected by location by NPK fertilizer interaction. 250 kg/ha NPK fertilizer resulted in maximum harvest index at Nyankpala. Harvest index is the physiological efficiency of agricultural plants in converting photosynthetic products into grain production (Luo *et al.,* 2022; Lopez *et al.,* 2022). It is possible that the increased

HI with higher amount of NPK is related to more efficient portioning of assimilates into the yield components. These observations are similar to those of Khan *et al.*, (2021) and Yang *et al.* (2022) who confirmed that increased NPK fertilization outputted higher HI.

Observed N, P and K-uptake in straw and grain as affected by location and NPK showed significance of NPK fertilizer at both locations. 250 kg/ha NPK fertilization at Nyankpala had the most N, P,K uptake than TaTU (Figure 7 and 8). This finding could be due to a good textured soil in Nyankpala, which supplied higher amount of N, P and K nutrient for uptake by the tested crop as earlier reported by Walter and Rao, (2015). Generally N, P and K uptake in straw and grain improved by increasing NPK fertilizer rate from 0 to 250 kg/ha and this established the conclusions of Nigussie *et al.* (2021), that as fertilizer rate increased, plant N content steadily increase.

Location by NPK by cake by NL, all produced a considerable effect on the efficiency of N, P and K uptake at both sites. At Nyankpala, as opposed to TaTU, 250 kg NPK/ha by 400 kg/ha NC by 10 l/ha NL maximized the efficiency of N, P and K uptake (Tables 3. 4 and 5). With rising nutrient availability levels, N, P, K absorption efficiency rises (Walter and Rao, 2015). This was in agreement with Nigussie *et al.* (2021), which showed that plant N content increased continuously as N rates rose. Neem and fertilizer applications were found to increase N, P, and K uptake efficiency, according to Datt *et al*. (2007) study on nitrogen mineralization and the relative efficacy of neem and neem coated urea (NCU) for wheat and rice. According to Meena et al. (2019), the addition of urea coated with neem and 125% of the approved dose of nitrogen (RDN) with 50:25:25 NPK increased the efficiency of P and K uptake. The results also supported those of a study on maize by Dwivedi *et al*. (2022).

Biological yield was influenced by the interaction between location and NPK fertilizer application (Figure 9), such that 250 kg NPK/ha fertilization produced higher biological yield at Nyankpala more than TaTU. This observation implies the soil condition at Nyankpala might have enhanced better response to NPK at 250 kg/ha than TaTU. This could be attributable to the good soil texture at Nyankpala. This is in concordance with Singh *et al.* (2013), who reported significant effect on Stover yield by NPK fertilization. The above ground biomass stover yield and economic yield were impacted by NPK fertilizer treatment, according to Agyin-Birikorang *et al.* (2022). Novak *et al.* (2021) noticed a similar trend in maize crops, claiming that NPK fertilizer had a substantial impact on stover output. These conclusions were also consonant with those of Ekero *et al.* (2020), that discovered that blended fertilizers increased maize crop straw weight more than control.

Maximum economic yield was obtained at Nyankpala with 250 kg/ha NPK fertilization (Figure 10). Such increase in maize grain could have been associated to an overall improvement in soil chemical and biological qualities as a result of the fertilizer application. Crop growth, development, maturity, and yield are highly dependent on quantity of nutrient it is able to uptake and utilize without such nutrients been lost wastefully (Carranca *et al.*, 2018). Increased N rate increased soil nutrient content, which probably favored the composition, profile and texture of the soil for improved nutrient absorption (Hossain *et al.*, 2020). Heightening NPK supply within limitations is correlated to increased leaf area, leaf weight, and chlorophyll content, which influence the photosynthetic activity of the leaf, dry matter production and nutrient distribution among plant organs (Moe *et al.*, 2019; Verma *et al.*, 2022). Similar report was given by Koile (2018) and Hamad (2021) which noted application rate of NPK fertilizer-treated plants produced considerably more grains and 100-seed weight than untreated plants.



## 5.2 POOLED DATA DISCUSSION

With the incorporation of 250 kg NPK/ha, height of plant increased as anticipated (Figure 12). With 250 kg NPK/ha fertilization applied, plant height increased significantly, most likely as a result of more nutrients being available in the soil for plants to utilize. Khan *et al.* (2014) observed similar results, showing a substantial surge in maize plant height following the addition of NPK. Ntiamoah et al. (2022), reported a considerable surge in the height of maize plant as a consequence of the incorporation of NPK fertilization during the young growing stages, and this response of plant height to NPK supported their findings. Significant impact of NPK fertilization on the height of maize at maturity were also found by Afrida and Tampubolon (2022). In general, a rise in height with higher NPK rate could be associated to an upsurge in soil NPK level. Higher fertilization rates, according to Ibrahim *et al.* (2021), may have had a larger ability to deliver the nutrition required for the growth of maize, resulting in a surge in vegetative growth of maize plant and its general development, which produced taller maize plants. Similarly, Agyin-Birikorang *et al.* (2022) demonstrated proper fertilization boosts crop growth and output by raising nutrient content in the tissue of the plant. Based on a study (Chi *et al.*, 2022), noted chemical fertilizer amendment significantly increased maize growth, physiological parameters, and yield parameters.

At 2, 4 and 6 WAP, 250 kg NPK/ha fertilization showed a significant increase on LAI (Figure 14). Higher LAI was observed with 250 kg NPK/ha fertilization. This was perhaps the effect of greater accessibility of NPK in the soil for absorption by the maize plant. This is confirmed by Zhang *et al*. (2022) that using endorsed proportion of NPK fertilization boosted crop LAI. NPK fertilization were positively correlated with LAI in comparison with the control (Ghulam *et al.*, 2016).

NPK at 250 kg/ha gave the highest shoot biomass weight (Figure 15). This reaffirmed the importance of NPK fertilizer, which supplies and augments nutrients required for all plant growth in the soil for absorption, hence increasing plant dry matter output (Roshan and Verma, 2015). According to Szabó *et al*. (2022), appropriate provision of plant accessible nutrients enhanced dry matter output substantially. In general, increasing NPK fertilization levels occasioned an increase in dry matter (Guo *et al.*, 2022; Li *et al.*, 2022). According to Szabó et al. (2022), nitrogen plays an important role in leaf development, solar interception, and maize crop growth and development.

Addition of NPK fertilization showed a momentous effect on chlorophyll content similar to plant height and LAI (Figure 16). This observation was in agreement with the that of Kutasy *et al.* (2021), who noted that mineral N fertilizer levels had a substantial influence on chlorophyll content. In comparison to the control, a higher rate of NPK fertilizer addition was seen with increased chlorophyll content. The rise in chlorophyll content with increasing NPK fertilizer levels is in consonant with the conclusions of Hou *et al*. (2020), which related, adding more N fertilization levels considerably boosted chlorophyll content. According to Mahil and Kumar (2019) and Ghafoor *et al*. (2021), increasing NPK fertilizer supply may have been responsible for the higher leaf N and, as a result, increased chlorophyll content. Nitrogen fertilization has been shown to activate enzymes involved in chlorophyll production, resulting in greater chlorophyll concentrations (Niewiadomska *et al.*, 2020; Kutasy *et al.*, 2021; Lotfi *et al.*, 2022).

NPK uptake and uptake efficiency were significantly influence by NC. NPK with NC, NC with NL on N uptake and NPK with NL and NC with NL on P uptake (Table 6,7,.8 and Figure 17). This studies revealed that application of NL at 10 l/ha with 400 kg NC/ha with 250 kg NPK/ha fertilization enhanced N, P and K uptake and uptake efficiency. This could be due to neem effect on reducing the escape of nitrogen in the soil thereby retaining such indispensable nutrient and enhancing N, P and K uptake. According to Hindersah *et al*. (2020), NC has a function of adding organic amendment to the soil as well as minimizing nitrogen leak in the soil, giving the necessary nutrient and acting as a biofertilizer for the plant's efficient growth and development and improving NPK uptake efficiency. Similar conclusions were made by Sarma *et al. (*2017). Ramachandrappa *et al.* (2019) reported the uptake of NPK by maize improved by the addition of 75% of the prescribed fertilization dose combined with 2.7 t/ha vermicompost. Research by Piya *et al.* (2018) noted organic materials like FYM and Vermicompost help to maintain soil productivity by improving the physicochemical qualities of the soil, and as well aid to improve the efficacy of applied chemical fertilizers. According to Singh *et al*. (2018), using manure from organic sources increase the quantity of nitrogen (N) accessible to the crop while also enhancing the soil's nutritional value. Sharma *et al*. (2019) discovered that neem treatments combined with chemical fertilizers had higher N uptake and uptake efficiency levels than the control. Merging inorganic and organic fertilizers had the effect of increasing NPK uptake and efficiency in maize, according to Geng *et al*. (2019). It was also discovered that at the 10 liters/ha threshold, N uptake in grain decreased. This conclusion is consistent with Devakumar and Goswami's (1992) discovery of NL's dose-dependent nitrification inhibitory activity.

Incorporation of 400 kg NC/ha and NPK fertilization meaningfully amplified biological yield as compared to control (Figure 18). The addition of NC to soil could have reduced nitrogen loss, which resulted in increased absorption, cell growth, elongation, and cell division, resulting in increased biological yield. Dwivedi *et al*. (2022) showed in maize that application of NC with 130.5 kg/ha recorded maximum plant height, plant dry weight, crop growth rate, number of cobs per plant, length of cob, diameter of cob, number of grains per cob, grain yield and straw yield as related to other treatments. Gurja *et al.*, (2022) reported increased biomass, cob length, number of grains per cob and Grain yield in treatment of N: P: K, with 100% NC as compared to control. Salma and Hossain (2021) reported highest plant dry weight with 5 t/ha NC and inorganic fertilizer in spinach production.

The maximum economic yield was noted at 250 kg NPK/ha and 400 kg/ha NC (Figure 19). This finding might be due to enhanced accessibility to nutrients and its subsequent absorption, that could have occasioned a balanced C/N ratio of the plant and increased plant metabolism. Amending the soil with neem seed cake has the ability to decrease nitrification, enhance nutrient content of soil, and ultimately increase crop production, culminating in a greater economic output. According to "Dwivedi *et al.* (2022)", the use of neem has been demonstrated to be more productive and may be employed by farmers to maximize productivity and financial earnings from their maize output. Kamal *et al*. (2021) achieved the highest yield of green gram with 20:40:00 kg NPK/ha m and 1 t/ha NC. They attributed this improved yield to the treatment's higher growth parameters; the large amount of stored photosynthetic energy that was transferred into different yield attributes; the ongoing mineralization process, and the availability of nutrients at later stages of plant growth. Khan *et al*. (2018) found that applying half the recommended dose of NPK fertilizer and 10 t/ha NC as a biofertilization had a substantial influence on yield. Greater amount of neem seed cake and inorganic fertilization resulted in the highest seed yield per plant (Eifediyi *et al*., 2017).

# CHAPTER SIX

# CONCLUSION AND RECOMMENDATION

## 6.1 Conclusion

On the basis of the results of the study conducted to ascertain neem extracts and NPK fertilizer effects on uptake and uptake efficiency of nitrogen, phosphorus and potassium on growth, yield components and grain yield of maize, the following conclusions were drawn:

The grain yield, biological yield and harvest index of maize increased with increasing NC from 200 kg/ha to 400 kg/ha combined with 250 kg NPK/ha fertilizer.

On the other hand, economic yield, biological yield and harvest index of maize decreased with increasing NL rate from 10 liters per hectare to 20 liter per hectare combined with 250 kg NPK/ha fertilizer; as such the NL was observed to have best performance at the threshold of 10 l/ha beyond which its effectiveness decreased.

Optimum uptake of N, P and K uptake and uptake efficiencies were noted with 400 kg NC/ha combined with 250 kg NPK/ha, as well as 10 l/ha NL with same rate of NPK. 7.3 % N, 6.8% P and 28% P

The optimum grain yield was obtained at 250 kg/ha NPK rate with either 10 l/ha NL or 400 kg/ha NC. Optimum uptake of N, P and K and their uptake efficiencies were noted with 400 kg NC/ha combined with 250 kg NPK/ha, as well as 10 l/ha NL with same rate of NPK.

Grain yield positively and significantly correlated with N uptake, P uptake, K uptake, N uptake efficiency, but P and K uptake efficiency didn't show significant correlation (r= 0.91**, 0.82**, 0.85**, 0.20*, 0.01, 0.03). Higher nutrient uptake therefore means higher yield

### 6.2 Recommendation

It is therefore recommended that:

1) At both locations, 250 kg NPK/ha fertilizer application with 400 kg/ha NC could be adopted for maximum harvest.
2) At both locations, 250 kg NPK/ha fertilizer application with 10 l/ha NL is equally a good combination for higher yield.
3) On-farm adaptive trials are required to validate these findings in order to arrive at conclusive recommendations of neem extracts for maize production within the guinea savannah agro-ecological zone of Ghana.
4) Further work should be carried out on neem extracts effects on other cereals like millet, sorghum and rice in the Guinea savanna ecological zone.
5) Studies could also be conducted on nutrient uptake enhancement of other cheaply available botanicals, like shea cake in the ecological zone.

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# APPENDICES

## APPENDIX ON COMBINED ANALYSIS ANOVA

APPENDIX 1: Height at two weeks after planting.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 587.6 | 293.8 | 1.41 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 80918.5 | 80918.5 | 388.53 | <.001 |
| NPK | 1 | 3133.6 | 3133.6 | 15.05 | <.001 |
| NO | 2 | 161.9 | 81.0 | 0.39 | 0.679 |
| NC | 2 | 50.9 | 25.4 | 0.12 | 0.885 |
| Location.NPK | 1 | 2275.6 | 2275.6 | 10.93 | 0.001 |
| Location.NO | 2 | 86.7 | 43.4 | 0.21 | 0.813 |
| NPK.NO | 2 | 610.3 | 305.2 | 1.47 | 0.238 |
| Location.NC | 2 | 16.1 | 8.1 | 0.04 | 0.962 |
| NPK.NC | 2 | 447.6 | 223.8 | 1.07 | 0.347 |
| NO.NC | 4 | 114.2 | 28.5 | 0.14 | 0.968 |
| Location.NPK.NO | 2 | 909.0 | 454.5 | 2.18 | 0.120 |
| Location.NPK.NC | 2 | 345.6 | 172.8 | 0.83 | 0.440 |
| Location.NO.NC | 4 | 124.3 | 31.1 | 0.15 | 0.963 |
| NPK.NO.NC | 4 | 518.3 | 129.6 | 0.62 | 0.648 |
| Location.NPK.NO.NC | 4 | 622.3 | 155.6 | 0.75 | 0.563 |
| Residual | 70 | 14578.9 | 208.3 | | |
| Total | 107 | 105501.4 | | | |

APPENDIX 2: Height at four weeks after planting.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | . | | | | |
| Reps/stratum | 2 | 1102.2 | 551.1 | 1.18 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 192481.5 | 192481.5 | 413.86 | <.001 |
| NPK | 1 | 11503.1 | 11503.1 | 24.73 | <.001 |
| NO | 2 | 131.3 | 65.7 | 0.14 | 0.869 |
| NC | 2 | 922.9 | 461.4 | 0.99 | 0.376 |
| Location.NPK | 1 | 8936.2 | 8936.2 | 19.21 | <.001 |
| Location.NO | 2 | 368.5 | 184.3 | 0.40 | 0.674 |
| NPK.NO | 2 | 1784.4 | 892.2 | 1.92 | 0.154 |
| Location.NC | 2 | 560.1 | 280.0 | 0.60 | 0.550 |
| NPK.NC | 2 | 285.2 | 142.6 | 0.31 | 0.737 |

| | | | | | |
|---|---|---|---|---|---|
| NO.NC | 4 | 2263.5 | 565.9 | 1.22 | 0.312 |
| Location.NPK.NO | 2 | 1843.1 | 921.5 | 1.98 | 0.146 |
| Location.NPK.NC | 2 | 189.6 | 94.8 | 0.20 | 0.816 |
| Location.NO.NC | 4 | 1587.6 | 396.9 | 0.85 | 0.496 |
| NPK.NO.NC | 4 | 845.6 | 211.4 | 0.45 | 0.769 |
| Location.NPK.NO.NC | 4 | 764.8 | 191.2 | 0.41 | 0.800 |
| Residual | 70 | 32556.5 | 465.1 | | |
| Total | 107 | 258126.3 | | | |

APPENDIX 3: Height at maturity.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 1261.4 | 630.7 | 1.24 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 29774.0 | 29774.0 | 58.51 | <.001 |
| NPK | 1 | 17146.2 | 17146.2 | 33.70 | <.001 |
| NO | 2 | 816.5 | 408.2 | 0.80 | 0.452 |
| NC | 2 | 1434.5 | 717.2 | 1.41 | 0.251 |
| Location.NPK | 1 | 21.8 | 21.8 | 0.04 | 0.837 |
| Location.NO | 2 | 762.9 | 381.4 | 0.75 | 0.476 |
| NPK.NO | 2 | 291.3 | 145.6 | 0.29 | 0.752 |
| Location.NC | 2 | 30.3 | 15.1 | 0.03 | 0.971 |
| NPK.NC | 2 | 1338.0 | 669.0 | 1.31 | 0.275 |
| NO.NC | 4 | 526.8 | 131.7 | 0.26 | 0.903 |
| Location.NPK.NO | 2 | 593.6 | 296.8 | 0.58 | 0.561 |
| Location.NPK.NC | 2 | 21.4 | 10.7 | 0.02 | 0.979 |
| Location.NO.NC | 4 | 511.5 | 127.9 | 0.25 | 0.908 |
| NPK.NO.NC | 4 | 1404.0 | 351.0 | 0.69 | 0.601 |
| Location.NPK.NO.NC | 4 | 753.3 | 188.3 | 0.37 | 0.829 |
| Residual | 70 | 35618.2 | 508.8 | | |
| Total | 107 | 92305.5 | | | |

APPENDIX 4: Growth rate at two WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 0.1071 | 0.0535 | 0.12 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 81.4236 | 81.4236 | 187.31 | <.001 |
| NPK | 1 | 0.8196 | 0.8196 | 1.89 | 0.174 |

| | | | | | |
|---|---|---|---|---|---|
| NO | 2 | 0.0711 | 0.0355 | 0.08 | 0.922 |
| NC | 2 | 1.2547 | 0.6274 | 1.44 | 0.243 |
| Location.NPK | 1 | 4.0240 | 4.0240 | 9.26 | 0.003 |
| Location.NO | 2 | 0.1724 | 0.0862 | 0.20 | 0.821 |
| NPK.NO | 2 | 1.7115 | 0.8557 | 1.97 | 0.147 |
| Location.NC | 2 | 1.5034 | 0.7517 | 1.73 | 0.185 |
| NPK.NC | 2 | 0.4821 | 0.2411 | 0.55 | 0.577 |
| NO.NC | 4 | 4.9430 | 1.2358 | 2.84 | 0.030 |
| Location.NPK.NO | 2 | 0.5577 | 0.2788 | 0.64 | 0.530 |
| Location.NPK.NC | 2 | 0.7587 | 0.3793 | 0.87 | 0.422 |
| Location.NO.NC | 4 | 2.0983 | 0.5246 | 1.21 | 0.316 |
| NPK.NO.NC | 4 | 1.9895 | 0.4974 | 1.14 | 0.343 |
| Location.NPK.NO.NC | 4 | 1.1243 | 0.2811 | 0.65 | 0.631 |
| Residual | 70 | 30.4286 | 0.4347 | | |
| Total | 107 | 133.4695 | | | |

APPENDIX 5: Leaf area Index at 2 WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources . | | | | | |
| Reps/stratum | 2 | 7.600 | 3.800 | 2.32 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 35.565 | 35.565 | 21.76 | <.001 |
| NPK | 1 | 9.850 | 9.850 | 6.03 | 0.007 |
| NO | 2 | 2.155 | 1.077 | 0.66 | 0.520 |
| NC | 2 | 2.093 | 1.047 | 0.64 | 0.530 |
| Location.NPK | 1 | 0.153 | 0.153 | 0.09 | 0.004 |
| Location.NO | 2 | 4.085 | 2.042 | 1.25 | 0.293 |
| NPK.NO | 2 | 0.588 | 0.294 | 0.18 | 0.836 |
| Location.NC | 2 | 0.488 | 0.244 | 0.15 | 0.861 |
| NPK.NC | 2 | 5.078 | 2.539 | 1.55 | 0.219 |
| NO.NC | 4 | 4.100 | 1.025 | 0.63 | 0.645 |
| Location.NPK.NO | 2 | 2.158 | 1.079 | 0.66 | 0.520 |
| Location.NPK.NC | 2 | 0.142 | 0.071 | 0.04 | 0.957 |
| Location.NO.NC | 4 | 6.336 | 1.584 | 0.97 | 0.430 |
| NPK.NO.NC | 4 | 6.765 | 1.691 | 1.03 | 0.396 |
| Location.NPK.NO.NC | 4 | 8.607 | 2.152 | 1.32 | 0.272 |
| Residual | 70 | 114.420 | 1.635 | | |
| Total | 107 | 210.183 | | | |

APPENDIX 6: Leaf area Index at 4 WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 9.700 | 4.850 | 1.97 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 3.419 | 3.419 | 1.39 | 0.003 |
| NPK | 1 | 30.567 | 30.567 | 12.39 | <.001 |
| NO | 2 | 7.921 | 3.960 | 1.61 | 0.208 |
| NC | 2 | 3.849 | 1.925 | 0.78 | 0.462 |
| Location.NPK | 1 | 0.120 | 0.120 | 0.05 | 0.006 |
| Location.NO | 2 | 4.069 | 2.034 | 0.82 | 0.443 |
| NPK.NO | 2 | 3.192 | 1.596 | 0.65 | 0.527 |
| Location.NC | 2 | 5.334 | 2.667 | 1.08 | 0.345 |
| NPK.NC | 2 | 2.000 | 1.000 | 0.41 | 0.668 |
| NO.NC | 4 | 9.178 | 2.294 | 0.93 | 0.452 |
| Location.NPK.NO | 2 | 2.633 | 1.316 | 0.53 | 0.589 |
| Location.NPK.NC | 2 | 3.701 | 1.851 | 0.75 | 0.476 |
| Location.NO.NC | 4 | 4.409 | 1.102 | 0.45 | 0.774 |
| NPK.NO.NC | 4 | 6.955 | 1.739 | 0.70 | 0.591 |
| Location.NPK.NO.NC | 4 | 8.349 | 2.087 | 0.85 | 0.501 |
| Residual | 70 | 172.673 | 2.467 | | |
| Total | 107 | 278.069 | | | |

APPENDIX 7: Chlorophyl content.

| Variation sources | | | | | |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 16.14 | 8.07 | 0.38 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 113.97 | 113.97 | 5.38 | 0.023 |
| NPK | 1 | 1702.44 | 1702.44 | 80.41 | <.001 |
| NO | 2 | 106.01 | 53.00 | 2.50 | 0.089 |
| NC | 2 | 20.10 | 10.05 | 0.47 | 0.624 |
| Location.NPK | 1 | 748.96 | 748.96 | 35.38 | <.001 |
| Location.NO | 2 | 60.11 | 30.06 | 1.42 | 0.249 |
| NPK.NO | 2 | 52.04 | 26.02 | 1.23 | 0.299 |
| Location.NC | 2 | 40.40 | 20.20 | 0.95 | 0.390 |
| NPK.NC | 2 | 27.06 | 13.53 | 0.64 | 0.531 |
| NO.NC | 4 | 242.97 | 60.74 | 2.87 | 0.029 |
| Location.NPK.NO | 2 | 49.28 | 24.64 | 1.16 | 0.318 |

| | | | | | |
|---|---|---|---|---|---|
| Location.NPK.NC | 2 | 57.66 | 28.83 | 1.36 | 0.263 |
| Location.NO.NC | 4 | 53.71 | 13.43 | 0.63 | 0.640 |
| NPK.NO.NC | 4 | 69.72 | 17.43 | 0.82 | 0.515 |
| Location.NPK.NO.NC | 4 | 48.63 | 12.16 | 0.57 | 0.682 |
| Residual | 70 | 1481.98 | 21.17 | | |
| Total | 107 | 4891.17 | | | |

APPENDIX 8: Dry matter yield.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 8.092E+07 | 4.046E+07 | 2.30 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 3.473E+07 | 3.473E+07 | 1.97 | 0.165 |
| NPK | 1 | 8.108E+08 | 8.108E+08 | 46.06 | <.001 |
| NO | 2 | 2.533E+07 | 1.266E+07 | 0.72 | 0.491 |
| NC | 2 | 1.192E+08 | 5.960E+07 | 3.39 | 0.039 |
| Location.NPK | 1 | 1.024E+08 | 1.024E+08 | 5.82 | 0.019 |
| Location.NO | 2 | 1.803E+07 | 9.015E+06 | 0.51 | 0.601 |
| NPK.NO | 2 | 2.829E+07 | 1.414E+07 | 0.80 | 0.452 |
| Location.NC | 2 | 1.509E+07 | 7.545E+06 | 0.43 | 0.653 |
| NPK.NC | 2 | 5.204E+06 | 2.602E+06 | 0.15 | 0.863 |
| NO.NC | 4 | 7.119E+07 | 1.780E+07 | 1.01 | 0.408 |
| Location.NPK.NO | 2 | 2.324E+07 | 1.162E+07 | 0.66 | 0.520 |
| Location.NPK.NC | 2 | 1.773E+07 | 8.867E+06 | 0.50 | 0.606 |
| Location.NO.NC | 4 | 5.808E+07 | 1.452E+07 | 0.82 | 0.514 |
| NPK.NO.NC | 4 | 5.574E+07 | 1.393E+07 | 0.79 | 0.535 |
| Location.NPK.NO.NC | 4 | 3.696E+07 | 9.240E+06 | 0.52 | 0.718 |
| Residual | 70 | 1.232E+09 | 1.760E+07 | | |
| Total | 107 | 2.735E+09 | | | |

APPENDIX 9: N-uptake grain.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 1373. | 686. | 0.61 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 8963. | 8963. | 7.98 | 0.006 |
| NPK | 1 | 97246. | 97246. | 86.61 | <.001 |
| NO | 2 | 8962. | 4481. | 3.99 | 0.023 |

| | | | | | |
|---|---|---|---|---|---|
| NC | 2 | 22929. | 11464. | 10.21 | <.001 |
| Location.NPK | 1 | 30070. | 30070. | 26.78 | <.001 |
| Location.NO | 2 | 651. | 326. | 0.29 | 0.749 |
| NPK.NO | 2 | 14955. | 7477. | 6.66 | 0.002 |
| Location.NC | 2 | 927. | 463. | 0.41 | 0.663 |
| NPK.NC | 2 | 6657. | 3328. | 2.96 | 0.058 |
| NO.NC | 4 | 15658. | 3914. | 3.49 | 0.012 |
| Location.NPK.NO | 2 | 906. | 453. | 0.40 | 0.669 |
| Location.NPK.NC | 2 | 4244. | 2122. | 1.89 | 0.159 |
| Location.NO.NC | 4 | 8096. | 2024. | 1.80 | 0.138 |
| NPK.NO.NC | 4 | 6946. | 1736. | 1.55 | 0.198 |
| Location.NPK.NO.NC | 4 | 5665. | 1416. | 1.26 | 0.293 |
| Residual | 70 | 78596. | 1123. | | |
| Total | 107 | 312843. | | | |

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APPENDIX 10: N-uptake straw

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 26898. | 13449. | 1.64 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 345709. | 345709. | 42.15 | <.001 |
| NPK | 1 | 650524. | 650524. | 79.31 | <.001 |
| NO | 2 | 59439. | 29719. | 3.62 | 0.032 |
| NC | 2 | 111062. | 55531. | 6.77 | 0.002 |
| Location.NPK | 1 | 175270. | 175270. | 21.37 | <.001 |
| Location.NO | 2 | 7835. | 3918. | 0.48 | 0.622 |
| NPK.NO | 2 | 71791. | 35895. | 4.38 | 0.016 |
| Location.NC | 2 | 19618. | 9809. | 1.20 | 0.309 |
| NPK.NC | 2 | 18620. | 9310. | 1.14 | 0.327 |
| NO.NC | 4 | 123826. | 30957. | 3.77 | 0.008 |
| Location.NPK.NO | 2 | 19397. | 9698. | 1.18 | 0.313 |
| Location.NPK.NC | 2 | 7826. | 3913. | 0.48 | 0.623 |
| Location.NO.NC | 4 | 45052. | 11263. | 1.37 | 0.252 |
| NPK.NO.NC | 4 | 30951. | 7738. | 0.94 | 0.444 |
| Location.NPK.NO.NC | 4 | 36115. | 9029. | 1.10 | 0.363 |
| Residual | 70 | 574139. | 8202. | | |
| Total | 107 | 2324071 | | | |

APPENDIX 11: P-uptake gran.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | . | | | | |
| Reps/stratum | 2 | 264.6 | 132.3 | 0.85 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 4489.2 | 4489.2 | 28.74 | <.001 |
| NPK | 1 | 13071.9 | 13071.9 | 83.70 | <.001 |
| NO | 2 | 1416.6 | 708.3 | 4.54 | 0.014 |
| NC | 2 | 2096.7 | 1048.3 | 6.71 | 0.002 |
| Location.NPK | 1 | 3991.9 | 3991.9 | 25.56 | <.001 |
| Location.NO | 2 | 99.2 | 49.6 | 0.32 | 0.729 |
| NPK.NO | 2 | 2813.1 | 1406.6 | 9.01 | <.001 |
| Location.NC | 2 | 1132.2 | 566.1 | 3.62 | 0.032 |
| NPK.NC | 2 | 1825.2 | 912.6 | 5.84 | 0.004 |
| NO.NC | 4 | 1552.3 | 388.1 | 2.48 | 0.051 |
| Location.NPK.NO | 2 | 337.6 | 168.8 | 1.08 | 0.345 |
| Location.NPK.NC | 2 | 293.7 | 146.9 | 0.94 | 0.395 |
| Location.NO.NC | 4 | 1749.3 | 437.3 | 2.80 | 0.032 |
| NPK.NO.NC | 4 | 993.3 | 248.3 | 1.59 | 0.187 |
| Location.NPK.NO.NC | 4 | 1325.6 | 331.4 | 2.12 | 0.087 |
| Residual | 70 | 10932.2 | 156.2 | | |
| Total | 107 | 48384.6 | | | |

APPENDIX 12: P-uptake straw.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 2822.5 | 1411.2 | 2.33 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 173779.1 | 173779.1 | 286.47 | <.001 |
| NPK | 1 | 5775.2 | 5775.2 | 9.52 | 0.003 |
| NO | 2 | 1534.8 | 767.4 | 1.27 | 0.289 |
| NC | 2 | 1.3 | 0.7 | 0.00 | 0.999 |
| Location.NPK | 1 | 5714.6 | 5714.6 | 9.42 | 0.003 |
| Location.NO | 2 | 1529.0 | 764.5 | 1.26 | 0.290 |
| NPK.NO | 2 | 539.6 | 269.8 | 0.44 | 0.643 |
| Location.NC | 2 | 1.2 | 0.6 | 0.00 | 0.999 |
| NPK.NC | 2 | 1217.9 | 608.9 | 1.00 | 0.372 |
| NO.NC | 4 | 1445.8 | 361.5 | 0.60 | 0.667 |
| Location.NPK.NO | 2 | 533.2 | 266.6 | 0.44 | 0.646 |
| Location.NPK.NC | 2 | 1215.3 | 607.6 | 1.00 | 0.372 |

| | | | | | |
|---|---|---|---|---|---|
| Location.NO.NC | 4 | 1451.2 | 362.8 | 0.60 | 0.665 |
| NPK.NO.NC | 4 | 2864.5 | 716.1 | 1.18 | 0.327 |
| Location.NPK.NO.NC | 4 | 2861.6 | 715.4 | 1.18 | 0.327 |
| Residual | 70 | 42463.1 | 606.6 | | |
| Total | 107 | 245749.8 | | | |

*APPENDIX 13: K -uptake grain.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | . | | | | |
| Reps/stratum | 2 | 513.6 | 256.8 | 0.48 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 11821.9 | 11821.9 | 22.21 | <.001 |
| NPK | 1 | 37251.5 | 37251.5 | 69.99 | <.001 |
| NO | 2 | 3456.8 | 1728.4 | 3.25 | 0.045 |
| NC | 2 | 7790.4 | 3895.2 | 7.32 | 0.001 |
| Location.NPK | 1 | 16098.0 | 16098.0 | 30.24 | <.001 |
| Location.NO | 2 | 229.3 | 114.6 | 0.22 | 0.807 |
| NPK.NO | 2 | 6095.8 | 3047.9 | 5.73 | 0.005 |
| Location.NC | 2 | 1281.3 | 640.6 | 1.20 | 0.306 |
| NPK.NC | 2 | 1218.2 | 609.1 | 1.14 | 0.324 |
| NO.NC | 4 | 5426.1 | 1356.5 | 2.55 | 0.047 |
| Location.NPK.NO | 2 | 717.7 | 358.9 | 0.67 | 0.513 |
| Location.NPK.NC | 2 | 2748.1 | 1374.0 | 2.58 | 0.083 |
| Location.NO.NC | 4 | 2468.5 | 617.1 | 1.16 | 0.336 |
| NPK.NO.NC | 4 | 4873.1 | 1218.3 | 2.29 | 0.068 |
| Location.NPK.NO.NC | 4 | 860.5 | 215.1 | 0.40 | 0.805 |
| Residual | 70 | 37259.4 | 532.3 | | |
| Total | 107 | 140110.3 | | | |

*.APPENDIX 14: K-uptake straw*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 3820. | 1910. | 0.81 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 136980. | 136980. | 57.85 | <.001 |
| NPK | 1 | 67739. | 67739. | 28.61 | <.001 |
| NO | 2 | 10069. | 5035. | 2.13 | 0.127 |
| NC | 2 | 10931. | 5466. | 2.31 | 0.107 |
| Location.NPK | 1 | 3554. | 3554. | 1.50 | 0.025 |
| Location.NO | 2 | 2732. | 1366. | 0.58 | 0.564 |

| | | | | | |
|---|---|---|---|---|---|
| NPK.NO | 2 | 11443. | 5721. | 2.42 | 0.097 |
| Location.NC | 2 | 985. | 492. | 0.21 | 0.813 |
| NPK.NC | 2 | 2648. | 1324. | 0.56 | 0.574 |
| NO.NC | 4 | 10856. | 2714. | 1.15 | 0.342 |
| Location.NPK.NO | 2 | 3213. | 1607. | 0.68 | 0.511 |
| Location.NPK.NC | 2 | 6087. | 3044. | 1.29 | 0.283 |
| Location.NO.NC | 4 | 933. | 233. | 0.10 | 0.983 |
| NPK.NO.NC | 4 | 14954. | 3739. | 1.58 | 0.190 |
| Location.NPK.NO.NC | 4 | 3697. | 924. | 0.39 | 0.815 |
| Residual | 70 | 165756. | 2368. | | |
| Total | 107 | 456398 | | | |

APPENDIX 15: N uptake efficiency.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 0.000E+00 | 0.000E+00 | 0.00 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 2.369E-03 | 2.369E-03 | 826.85 | <.001 |
| NC | 2 | 7.468E-05 | 3.734E-05 | 13.03 | <.001 |
| NO | 2 | 1.345E-04 | 6.727E-05 | 23.48 | <.001 |
| NPK | 1 | 3.067E-04 | 3.067E-04 | 107.04 | <.001 |
| Location.NC | 2 | 1.993E-05 | 9.963E-06 | 3.48 | 0.036 |
| Location.NO | 2 | 1.074E-04 | 5.370E-05 | 18.74 | <.001 |
| NC.NO | 4 | 4.561E-04 | 1.140E-04 | 39.80 | <.001 |
| Location.NPK | 1 | 1.435E-04 | 1.435E-04 | 50.08 | <.001 |
| NC.NPK | 2 | 1.235E-04 | 6.177E-05 | 21.56 | <.001 |
| NO.NPK | 2 | 2.936E-04 | 1.468E-04 | 51.23 | <.001 |
| Location.NC.NO | 4 | 2.490E-05 | 6.226E-06 | 2.17 | 0.081 |
| Location.NC.NPK | 2 | 6.284E-06 | 3.142E-06 | 1.10 | 0.340 |
| Location.NO.NPK | 2 | 3.290E-06 | 1.645E-06 | 0.57 | 0.566 |
| NC.NO.NPK | 4 | 2.896E-04 | 7.241E-05 | 25.27 | <.001 |
| Location.NC.NO.NPK | 4 | 5.356E-05 | 1.339E-05 | 4.67 | 0.002 |
| Residual | 70 | 2.006E-04 | 2.865E-06 | | |
| Total | 107 | 4.607E-03 | | | |

APPENDIX 16: P uptake efficiency.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 0.000E+00 | 0.000E+00 | 0.00 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 1.171E-02 | 1.171E-02 | 1499.33 | <.001 |
| NC | 2 | 6.593E-05 | 3.296E-05 | 4.22 | 0.019 |
| NO | 2 | 1.016E-03 | 5.078E-04 | 65.02 | <.001 |
| NPK | 1 | 3.898E-04 | 3.898E-04 | 49.92 | <.001 |
| Location.NC | 2 | 1.117E-03 | 5.585E-04 | 71.52 | <.001 |
| Location.NO | 2 | 4.830E-04 | 2.415E-04 | 30.93 | <.001 |

| | | | | | |
|---|---|---|---|---|---|
| NC.NO | 4 | 7.988E-04 | 1.997E-04 | 25.57 | <.001 |
| Location.NPK | 1 | 2.315E-05 | 2.315E-05 | 2.96 | 0.090 |
| NC.NPK | 2 | 7.143E-04 | 3.572E-04 | 45.74 | <.001 |
| NO.NPK | 2 | 9.874E-04 | 4.937E-04 | 63.22 | <.001 |
| Location.NC.NO | 4 | 1.505E-03 | 3.762E-04 | 48.17 | <.001 |
| Location.NC.NPK | 2 | 5.266E-05 | 2.633E-05 | 3.37 | 0.040 |
| Location.NO.NPK | 2 | 3.324E-04 | 1.662E-04 | 21.28 | <.001 |
| NC.NO.NPK | 4 | 1.226E-03 | 3.065E-04 | 39.25 | <.001 |
| Location.NC.NO.NPK | 4 | 7.634E-04 | 1.909E-04 | 24.44 | <.001 |
| Residual | 70 | 5.466E-04 | 7.809E-06 | | |
| Total | 107 | 2.173E-02 | | | |

APPENDIX 17: K uptake efficiency

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
| Reps/stratum | 2 | 0.000E+00 | 0.000E+00 | 0.00 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 9.673E-03 | 9.673E-03 | 3760.37 | <.001 |
| NC | 2 | 1.531E-04 | 7.655E-05 | 29.76 | <.001 |
| NO | 2 | 2.635E-04 | 1.318E-04 | 51.22 | <.001 |
| NPK | 1 | 1.025E-04 | 1.025E-04 | 39.85 | <.001 |
| Location.NC | 2 | 7.855E-05 | 3.927E-05 | 15.27 | <.001 |
| Location.NO | 2 | 5.198E-05 | 2.599E-05 | 10.10 | <.001 |
| NC.NO | 4 | 4.225E-04 | 1.056E-04 | 41.06 | <.001 |
| Location.NPK | 1 | 2.262E-04 | 2.262E-04 | 87.92 | <.001 |
| NC.NPK | 2 | 1.256E-04 | 6.281E-05 | 24.42 | <.001 |
| NO.NPK | 2 | 4.973E-04 | 2.487E-04 | 96.67 | <.001 |
| Location.NC.NO | 4 | 1.563E-04 | 3.907E-05 | 15.19 | <.001 |
| Location.NC.NPK | 2 | 5.408E-05 | 2.704E-05 | 10.51 | <.001 |
| Location.NO.NPK | 2 | 2.672E-05 | 1.336E-05 | 5.19 | 0.008 |
| NC.NO.NPK | 4 | 1.507E-03 | 3.769E-04 | 146.51 | <.001 |
| Location.NC.NO.NPK | 4 | 2.621E-04 | 6.552E-05 | 25.47 | <.001 |
| Residual | 70 | 1.801E-04 | 2.572E-06 | | |
| Total | 107 | 1.378E-02 | | | |

APPENDIX 18: Biological_yield.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 8.534E+07 | 4.267E+07 | 1.57 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 5.859E+06 | 5.859E+06 | 0.22 | 0.644 |
| NPK | 1 | 1.576E+09 | 1.576E+09 | 58.00 | <.001 |
| NO | 2 | 5.661E+07 | 2.830E+07 | 1.04 | 0.358 |
| NC | 2 | 2.807E+08 | 1.403E+08 | 5.16 | 0.008 |
| Location.NPK | 1 | 2.255E+08 | 2.255E+08 | 8.30 | 0.005 |

| | | | | | |
|---|---|---|---|---|---|
| Location.NO | 2 | 4.221E+07 | 2.111E+07 | 0.78 | 0.464 |
| NPK.NO | 2 | 7.228E+07 | 3.614E+07 | 1.33 | 0.271 |
| Location.NC | 2 | 2.064E+07 | 1.032E+07 | 0.38 | 0.685 |
| NPK.NC | 2 | 2.552E+07 | 1.276E+07 | 0.47 | 0.627 |
| NO.NC | 4 | 1.478E+08 | 3.695E+07 | 1.36 | 0.257 |
| Location.NPK.NO | 2 | 3.216E+07 | 1.608E+07 | 0.59 | 0.556 |
| Location.NPK.NC | 2 | 4.748E+07 | 2.374E+07 | 0.87 | 0.422 |
| Location.NO.NC | 4 | 1.029E+08 | 2.573E+07 | 0.95 | 0.442 |
| NPK.NO.NC | 4 | 9.875E+07 | 2.469E+07 | 0.91 | 0.464 |
| Location.NPK.NO.NC | 4 | 7.571E+07 | 1.893E+07 | 0.70 | 0.597 |
| Residual | 70 | 1.902E+09 | 2.718E+07 | | |
| Total | 107 | 4.798E+09 | | | |

*APPENDIX 19: Economic yield.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | | | | | |
| Reps/stratum | 2 | 4694625. | 2347313. | 0.98 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 12059926. | 12059926. | 5.06 | 0.028 |
| NPK | 1 | 126057615. | 126057615. | 52.86 | <.001 |
| NO | 2 | 6213988. | 3106994. | 1.30 | 0.278 |
| NC | 2 | 34051645. | 17025822. | 7.14 | 0.002 |
| Location.NPK | 1 | 23982698. | 23982698. | 10.06 | 0.002 |
| Location.NO | 2 | 5256731. | 2628365. | 1.10 | 0.338 |
| NPK.NO | 2 | 11421310. | 5710655. | 2.39 | 0.099 |
| Location.NC | 2 | 772436. | 386218. | 0.16 | 0.851 |
| NPK.NC | 2 | 8007969. | 4003984. | 1.68 | 0.194 |
| NO.NC | 4 | 14826848. | 3706712. | 1.55 | 0.196 |
| Location.NPK.NO | 2 | 2400071. | 1200036. | 0.50 | 0.607 |
| Location.NPK.NC | 2 | 13503701. | 6751851. | 2.83 | 0.066 |
| Location.NO.NC | 4 | 9375225. | 2343806. | 0.98 | 0.423 |
| NPK.NO.NC | 4 | 9064813. | 2266203. | 0.95 | 0.440 |
| Location.NPK.NO.NC | 4 | 11763444. | 2940861. | 1.23 | 0.305 |
| Residual | 70 | 166917604. | 2384537. | | |
| Total | 107 | 460370649. | | | |

APPENDIX 20: Harvest index.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Variation sources | . | | | | |
| Reps/stratum | 2 | 0.027966 | 0.013983 | 2.82 | |
| Reps, Units, stratum | | | | | |
| Location | 1 | 0.106842 | 0.106842 | 21.54 | <.001 |

| | | | | | |
|---|---|---|---|---|---|
| NPK | 1 | 0.011078 | 0.011078 | 2.23 | 0.140 |
| NO | 2 | 0.000703 | 0.000352 | 0.07 | 0.932 |
| NC | 2 | 0.016707 | 0.008354 | 1.68 | 0.193 |
| Location.NPK | 1 | 0.023575 | 0.023575 | 4.75 | 0.033 |
| Location.NO | 2 | 0.008019 | 0.004009 | 0.81 | 0.450 |
| NPK.NO | 2 | 0.008568 | 0.004284 | 0.86 | 0.426 |
| Location.NC | 2 | 0.001142 | 0.000571 | 0.12 | 0.891 |
| NPK.NC | 2 | 0.003588 | 0.001794 | 0.36 | 0.698 |
| NO.NC | 4 | 0.001794 | 0.000449 | 0.09 | 0.985 |
| Location.NPK.NO | 2 | 0.002305 | 0.001153 | 0.23 | 0.793 |
| Location.NPK.NC | 2 | 0.020200 | 0.010100 | 2.04 | 0.138 |
| Location.NO.NC | 4 | 0.014579 | 0.003645 | 0.73 | 0.571 |
| NPK.NO.NC | 4 | 0.009802 | 0.002450 | 0.49 | 0.740 |
| Location.NPK.NO.NC | 4 | 0.024552 | 0.006138 | 1.24 | 0.303 |
| Residual | 70 | 0.347150 | 0.004959 | | |
| Total | 107 | 0.628570 | | | |

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APPENDIX 21: Height at 2 WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 588. | 294. | 0.26 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 51. | 25. | 0.02 | 0.978 |
| NO | 2 | 162. | 81. | 0.07 | 0.931 |
| NPK | 1 | 3134. | 3134. | 2.76 | 0.100 |
| NC.NO | 4 | 114. | 29. | 0.03 | 0.999 |
| NC.NPK | 2 | 448. | 224. | 0.20 | 0.821 |
| NO.NPK | 2 | 610. | 305. | 0.27 | 0.765 |
| NC.NO.NPK | 4 | 518. | 130. | 0.11 | 0.977 |
| Residual | 88 | 99877. | 1135. | | |
| Total | 107 | 105501 | | | |

APPENDIX 22: Height at 4 WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 1102. | 551. | 0.20 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 923. | 461. | 0.17 | 0.844 |
| NO | 2 | 131. | 66. | 0.02 | 0.976 |
| NPK | 1 | 11503. | 11503. | 4.23 | 0.043 |
| NC.NO | 4 | 2263. | 566. | 0.21 | 0.933 |
| NC.NPK | 2 | 285. | 143. | 0.05 | 0.949 |
| NO.NPK | 2 | 1784. | 892. | 0.33 | 0.721 |
| NC.NO.NPK | 4 | 846. | 211. | 0.08 | 0.989 |
| Residual | 88 | 239288. | 2719. | | |
| Total | 107 | 258126 | | | |

APPENDIX 23: Height at 6 WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 1548. | 774. | 0.27 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 2147. | 1073. | 0.37 | 0.690 |
| NO | 2 | 105. | 53. | 0.02 | 0.982 |
| NPK | 1 | 19873. | 19873. | 6.91 | 0.010 |
| NC.NO | 4 | 2070. | 517. | 0.18 | 0.948 |
| NC.NPK | 2 | 937. | 469. | 0.16 | 0.850 |
| NO.NPK | 2 | 1017. | 509. | 0.18 | 0.838 |
| NC.NO.NPK | 4 | 977. | 244. | 0.08 | 0.987 |
| Residual | 88 | 253038. | 2875. | | |
| Total | 107 | 258126 | | | |

*APPENDIX 24: Height at 8 WAP.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 2952. | 1476. | 1.47 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 1909. | 954. | 0.95 | 0.390 |
| NO | 2 | 348. | 174. | 0.17 | 0.841 |
| NPK | 1 | 22954. | 22954. | 22.88 | <.001 |
| NC.NO | 4 | 964. | 241. | 0.24 | 0.915 |
| NC.NPK | 2 | 810. | 405. | 0.40 | 0.669 |
| NO.NPK | 2 | 171. | 86. | 0.09 | 0.918 |
| NC.NO.NPK | 4 | 1610. | 403. | 0.40 | 0.807 |
| Residual | 88 | 88294. | 1003. | | |
| Total | 107 | 120013 | | | |

APPENDIX 25: Height at maturity.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 1261.4 | 630.7 | 0.82 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 1434.5 | 717.2 | 0.93 | 0.400 |
| NO | 2 | 816.5 | 408.2 | 0.53 | 0.592 |
| NPK | 1 | 17146.2 | 17146.2 | 22.16 | <.001 |
| NC.NO | 4 | 526.8 | 131.7 | 0.17 | 0.953 |
| NC.NPK | 2 | 1338.0 | 669.0 | 0.86 | 0.425 |
| NO.NPK | 2 | 291.3 | 145.6 | 0.19 | 0.829 |
| NC.NO.NPK | 4 | 1404.0 | 351.0 | 0.45 | 0.769 |
| Residual | 88 | 68086.9 | 773.7 | | |
| Total | 107 | 92305.5 | | | |

APPENDIX 26: Growth rate_2 WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 0.5236 | 0.2618 | 0.52 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 1.4610 | 0.7305 | 1.45 | 0.239 |
| NO | 2 | 0.8207 | 0.4104 | 0.82 | 0.445 |
| NPK | 1 | 0.0014 | 0.0014 | 0.00 | 0.958 |
| NC.NO | 4 | 1.0999 | 0.2750 | 0.55 | 0.702 |
| NC.NPK | 2 | 0.2401 | 0.1200 | 0.24 | 0.788 |
| NO.NPK | 2 | 1.0989 | 0.5495 | 1.09 | 0.340 |
| NC.NO.NPK | 4 | 0.2686 | 0.0672 | 0.13 | 0.970 |
| Residual | 88 | 44.2360 | 0.5027 | | |
| Total | 107 | 49.7502 | | | |
| Total | 107 | 49.7502 | | | |

APPENDIX 27: Growth rate_4 WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 0.107 | 0.054 | 0.04 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 1.255 | 0.627 | 0.45 | 0.638 |
| NO | 2 | 0.071 | 0.036 | 0.03 | 0.975 |
| NPK | 1 | 0.820 | 0.820 | 0.59 | 0.444 |
| NC.NO | 4 | 4.943 | 1.236 | 0.89 | 0.473 |
| NC.NPK | 2 | 0.482 | 0.241 | 0.17 | 0.841 |
| NO.NPK | 2 | 1.711 | 0.856 | 0.62 | 0.542 |
| NC.NO.NPK | 4 | 1.990 | 0.497 | 0.36 | 0.837 |
| Residual | 88 | 122.091 | 1.387 | | |
| Total | 107 | 133.469 | | | |

APPENDIX 28: Growth rate 6 WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 0.2778 | 0.1389 | 0.26 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 0.3885 | 0.1942 | 0.37 | 0.692 |
| NO | 2 | 0.2994 | 0.1497 | 0.29 | 0.753 |
| NPK | 1 | 0.2928 | 0.2928 | 0.56 | 0.457 |
| NC.NO | 4 | 0.7577 | 0.1894 | 0.36 | 0.836 |
| NC.NPK | 2 | 0.5590 | 0.2795 | 0.53 | 0.589 |
| NO.NPK | 2 | 0.2228 | 0.1114 | 0.21 | 0.809 |
| NC.NO.NPK | 4 | 0.9346 | 0.2337 | 0.44 | 0.776 |
| Residual | 88 | 46.2075 | 0.5251 | | |
| Total | 107 | 49.9402 | | | |

*APPENDIX 29: Growth rate 8 WAP..*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 0.12852 | 0.06426 | 4.59 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 0.00470 | 0.00235 | 0.17 | 0.846 |
| NO | 2 | 0.00108 | 0.00054 | 0.04 | 0.962 |
| NPK | 1 | 0.09165 | 0.09165 | 6.54 | 0.012 |
| NC.NO | 4 | 0.04133 | 0.01033 | 0.74 | 0.569 |
| NC.NPK | 2 | 0.00580 | 0.00290 | 0.21 | 0.814 |
| NO.NPK | 2 | 0.00090 | 0.00045 | 0.03 | 0.968 |
| NC.NO.NPK | 4 | 0.02094 | 0.00523 | 0.37 | 0.827 |
| Residual | 88 | 1.23274 | 0.01401 | | |
| Total | 107 | 1.52766 | | | |

*.APPENDIX 30: Leaf area index at 2WAP.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 4.821 | 2.411 | 1.21 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 2.093 | 1.047 | 0.53 | 0.592 |
| NO | 2 | 2.155 | 1.077 | 0.54 | 0.583 |
| NPK | 1 | 9.850 | 9.850 | 4.96 | 0.028 |
| NC.NO | 4 | 4.100 | 1.025 | 0.52 | 0.724 |
| NC.NPK | 2 | 5.078 | 2.539 | 1.28 | 0.283 |
| NO.NPK | 2 | 0.588 | 0.294 | 0.15 | 0.863 |
| NC.NO.NPK | 4 | 6.765 | 1.691 | 0.85 | 0.496 |
| Residual | 88 | 174.733 | 1.986 | | |
| Total | 107 | 210.183 | | | |
| Total | 107 | 210.183 | | | |

APPENDIX 31: Leaf area index 4 WAP.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 9.004 | 4.502 | 1.93 | |
| \Reps, Units, stratum | | | | | |
| NC | 2 | 3.849 | 1.925 | 0.82 | 0.442 |
| NO | 2 | 7.921 | 3.960 | 1.70 | 0.189 |
| NPK | 1 | 30.567 | 30.567 | 13.10 | <.001 |
| NC.NO | 4 | 9.178 | 2.294 | 0.98 | 0.421 |
| NC.NPK | 2 | 2.000 | 1.000 | 0.43 | 0.653 |
| NO.NPK | 2 | 3.192 | 1.596 | 0.68 | 0.507 |
| NC.NO.NPK | 4 | 6.955 | 1.739 | 0.74 | 0.564 |
| Residual | 88 | 205.403 | 2.334 | | |
| Total | 107 | 278.069 | | | |
| Total | 107 | 278.069 | | | |

*APPENDIX 32: Leaf area index 6WAP.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 16.71 | 8.35 | 0.80 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 4.05 | 2.02 | 0.19 | 0.825 |
| NO | 2 | 0.45 | 0.23 | 0.02 | 0.979 |
| NPK | 1 | 84.72 | 84.72 | 8.09 | 0.006 |
| NC.NO | 4 | 7.67 | 1.92 | 0.18 | 0.947 |
| NC.NPK | 2 | 8.53 | 4.27 | 0.41 | 0.667 |
| NO.NPK | 2 | 2.60 | 1.30 | 0.12 | 0.884 |
| NC.NO.NPK | 4 | 13.51 | 3.38 | 0.32 | 0.862 |
| Residual | 88 | 922.14 | 10.48 | | |
| Total | 107 | 1060.38 | | | |

*APPENDIX 33: Leaf area index 8WAP.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 2.565 | 1.282 | 0.69 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 6.966 | 3.483 | 1.88 | 0.158 |
| NO | 2 | 7.221 | 3.611 | 1.95 | 0.148 |
| NPK | 1 | 14.740 | 14.740 | 7.97 | 0.126 |
| NC.NO | 4 | 3.248 | 0.812 | 0.44 | 0.780 |
| NC.NPK | 2 | 3.191 | 1.596 | 0.86 | 0.425 |
| NO.NPK | 2 | 4.176 | 2.088 | 1.13 | 0.328 |
| NC.NO.NPK | 4 | 2.519 | 0.630 | 0.34 | 0.850 |
| Residual | 88 | 162.680 | 1.849 | | |
| Total | 107 | 207.307 | | | |
| Total | 107 | 207.307 | | | |

*APPENDIX 34: Dry matter yield.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 8.092E+07 | 4.046E+07 | 2.31 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 1.192E+08 | 5.960E+07 | 3.41 | 0.037 |
| NO | 2 | 2.533E+07 | 1.266E+07 | 0.72 | 0.488 |
| NPK | 1 | 8.108E+08 | 8.108E+08 | 46.38 | <.001 |
| NC.NO | 4 | 7.119E+07 | 1.780E+07 | 1.02 | 0.403 |
| NC.NPK | 2 | 5.204E+06 | 2.602E+06 | 0.15 | 0.862 |
| NO.NPK | 2 | 2.829E+07 | 1.414E+07 | 0.81 | 0.449 |
| NC.NO.NPK | 4 | 5.574E+07 | 1.393E+07 | 0.80 | 0.530 |
| Residual | 88 | 1.538E+09 | 1.748E+07 | | |
| Total | 107 | 2.735E+09 | | | |

APPENDIX 35: Chlorophyll content.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 16.14 | 8.07 | 0.27 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 20.10 | 10.05 | 0.33 | 0.718 |
| NO | 2 | 106.01 | 53.00 | 1.76 | 0.179 |
| NPK | 1 | 1702.44 | 1702.44 | 56.43 | <.001 |
| NC.NO | 4 | 242.97 | 60.74 | 2.01 | 0.099 |
| NC.NPK | 2 | 27.06 | 13.53 | 0.45 | 0.640 |
| NO.NPK | 2 | 52.04 | 26.02 | 0.86 | 0.426 |
| NC.NO.NPK | 4 | 69.72 | 17.43 | 0.58 | 0.680 |
| Residual | 88 | 2654.70 | 30.17 | | |
| Total | 107 | 4891.17 | | | |

APPENDIX 36: N-uptake grain.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 1373. | 686. | 0.44 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 22929. | 11464. | 7.30 | 0.001 |
| NO | 2 | 8962. | 4481. | 2.85 | 0.063 |
| NPK | 1 | 97246. | 97246. | 61.96 | <.001 |
| NC.NO | 4 | 15658. | 3914. | 2.49 | 0.049 |
| NC.NPK | 2 | 6657. | 3328. | 2.12 | 0.126 |
| NO.NPK | 2 | 14955. | 7477. | 4.76 | 0.011 |
| NC.NO.NPK | 4 | 6946. | 1736. | 1.11 | 0.359 |
| Residual | 88 | 138118. | 1570. | | |
| Total | 107 | 312843 | | | |

*APPENDIX 37: P-uptake grain.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 264.6 | 132.3 | 0.48 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 2096.7 | 1048.3 | 3.79 | 0.026 |
| NO | 2 | 1416.6 | 708.3 | 2.56 | 0.083 |
| NPK | 1 | 13071.9 | 13071.9 | 47.24 | <.001 |
| NC.NO | 4 | 1552.3 | 388.1 | 1.40 | 0.240 |
| NC.NPK | 2 | 1825.2 | 912.6 | 3.30 | 0.042 |
| NO.NPK | 2 | 2813.1 | 1406.6 | 5.08 | 0.008 |
| NC.NO.NPK | 4 | 993.3 | 248.3 | 0.90 | 0.469 |
| Residual | 88 | 24350.8 | 276.7 | | |
| Total | 107 | 48384.6 | | | |

APPENDIX 38: K-uptake grain.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 513.6 | 256.8 | 0.31 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 7790.4 | 3895.2 | 4.66 | 0.012 |
| NO | 2 | 3456.8 | 1728.4 | 2.07 | 0.132 |
| NPK | 1 | 37251.5 | 37251.5 | 44.61 | <.001 |
| NC.NO | 4 | 5426.1 | 1356.5 | 1.62 | 0.175 |
| NC.NPK | 2 | 1218.2 | 609.1 | 0.73 | 0.485 |
| NO.NPK | 2 | 6095.8 | 3047.9 | 3.65 | 0.030 |
| NC.NO.NPK | 4 | 4873.1 | 1218.3 | 1.46 | 0.222 |
| Residual | 88 | 73484.7 | 835.1 | | |
| Total | 107 | 140110.3 | | | |

APPENDIX 39: N-uptake efficiency.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 0.00000000 | 0.00000000 | 0.00 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 0.00007468 | 0.00003734 | 1.12 | 0.330 |
| NO | 2 | 0.00013454 | 0.00006727 | 2.02 | 0.139 |
| NPK | 1 | 0.00030669 | 0.00030669 | 9.22 | 0.003 |
| NC.NO | 4 | 0.00045613 | 0.00011403 | 3.43 | 0.012 |
| NC.NPK | 2 | 0.00012354 | 0.00006177 | 1.86 | 0.162 |
| NO.NPK | 2 | 0.00029360 | 0.00014680 | 4.41 | 0.015 |
| NC.NO.NPK | 4 | 0.00028963 | 0.00007241 | 2.18 | 0.078 |
| Residual | 88 | 0.00292864 | 0.00003328 | | |
| Total | 107 | 0.00460746 | | | |

APPENDIX 40: P-uptake efficiency.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 0.0000000 | 0.0000000 | 0.00 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 0.0000659 | 0.0000330 | 0.18 | 0.839 |
| NO | 2 | 0.0010156 | 0.0005078 | 2.70 | 0.073 |
| NPK | 1 | 0.0003898 | 0.0003898 | 2.08 | 0.153 |
| NC.NO | 4 | 0.0007988 | 0.0001997 | 1.06 | 0.380 |
| NC.NPK | 2 | 0.0007143 | 0.0003572 | 1.90 | 0.155 |
| NO.NPK | 2 | 0.0009874 | 0.0004937 | 2.63 | 0.078 |
| NC.NO.NPK | 4 | 0.0012261 | 0.0003065 | 1.63 | 0.173 |
| Residual | 88 | 0.0165314 | 0.0001879 | | |
| Total | 107 | 0.0217293 | | | |
| Total | 107 | 0.0217293 | | | |

*APPENDIX 41: K-uptake efficiency.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 0.0000000 | 0.0000000 | 0.00 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 0.0001531 | 0.0000765 | 0.63 | 0.535 |
| NO | 2 | 0.0002635 | 0.0001318 | 1.08 | 0.343 |
| NPK | 1 | 0.0001025 | 0.0001025 | 0.84 | 0.361 |
| NC.NO | 4 | 0.0004225 | 0.0001056 | 0.87 | 0.487 |
| NC.NPK | 2 | 0.0001256 | 0.0000628 | 0.52 | 0.599 |
| NO.NPK | 2 | 0.0004973 | 0.0002487 | 2.04 | 0.136 |
| NC.NO.NPK | 4 | 0.0015075 | 0.0003769 | 3.10 | 0.020 |
| Residual | 88 | 0.0107092 | 0.0001217 | | |
| Total | 107 | 0.0137812 | | | |

*APPENDIX 42: Biological_yield.*

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 8.534E+07 | 4.267E+07 | 1.53 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 2.807E+08 | 1.403E+08 | 5.03 | 0.009 |
| NO | 2 | 5.661E+07 | 2.830E+07 | 1.01 | 0.367 |
| NPK | 1 | 1.576E+09 | 1.576E+09 | 56.50 | <.001 |
| NC.NO | 4 | 1.478E+08 | 3.695E+07 | 1.32 | 0.267 |
| NC.NPK | 2 | 2.552E+07 | 1.276E+07 | 0.46 | 0.634 |
| NO.NPK | 2 | 7.228E+07 | 3.614E+07 | 1.30 | 0.279 |
| NC.NO.NPK | 4 | 9.875E+07 | 2.469E+07 | 0.88 | 0.476 |
| Residual | 88 | 2.455E+09 | 2.790E+07 | | |
| Total | 107 | 4.798E+09 | | | |
| Total | 107 | 4.798E+09 | | | |

APPENDIX 43: Economic yield.

| Variation sources | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Reps/stratum | 2 | 187785. | 93893. | 0.84 | |
| Reps, Units, stratum | | | | | |
| NC | 2 | 1362066. | 681033. | 6.09 | 0.003 |
| NO | 2 | 248560. | 124280. | 1.11 | 0.334 |
| NPK | 1 | 5042305. | 5042305. | 45.09 | <.001 |
| NC.NO | 4 | 593074. | 148268. | 1.33 | 0.267 |
| NC.NPK | 2 | 320319. | 160159. | 1.43 | 0.244 |
| NO.NPK | 2 | 456852. | 228426. | 2.04 | 0.136 |
| NC.NO.NPK | 4 | 362593. | 90648. | 0.81 | 0.522 |
| Residual | 88 | 9841273. | 111833. | | |
| Total | 107 | 18414826. | | | |