ASSESSMENT OF N, P, K DEFICIENCY OF MAIZE (*Zea mays* L) THROUGH NUTRIENT OMISSION TRIAL IN OMO NADDA DISTRICT, SOUTHWESTERN ETHIOPIA

MSc. THESIS

BY

MUSTEFA EDAO CHAWICHA

June, 2024

Jimma, Ethiopia

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A Thesis Submitted to the Department of Horticulture and Plant sciences, college of Agriculture and Veterinary medicine, Jimma University, in Partial fulfillment of the Requirements for the Degree of Master of Science in Agronomy

Major Advisor: Dr. Amsalu Nebiyu (PhD)
Co-Advisor: Dr. Milkiyas Ahmed (PhD)

June, 2024

Jimma, Ethiopia

# DEDICATION

This thesis is dedicated to my beloved mother, **Medina Sero**, and all my family, as well as to the farmers in Biso Gombo and Doyo Yaya who dedicated their farmlands to this fieldwork.

## STATEMENTS OF THE AUTHOR

I, Mustefa Edao, hereby declare that the thesis allowed (Assessment of N, P, K Deficiency of Maize (*Zea Mays L*) Through Nutrient Omission Trial in Omo Nadda District, Southwest Ethiopia) is entirely my own work. In the preparation, data collection, analysis, and compilation of this thesis, I have adhered to the highest ethical and technical standards of scholarship. This thesis is submitted in partial fulfillment of the requirements for the degree of Master of Science (MSc) at Jimma University. I grant permission for this thesis to be deposited in the Jimma University library, making it accessible to borrowers in accordance with the library's established rules and regulations.

Name: Mustefa Edao Chawicha

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## BIOGRAPHICAL SKETCH

The author, **Mustefa Edao Chawicha**, was born in April 1997 to his father **Edao Chawicha** and mother **Medina Sero** at Hindhet Burkitu kebele in Gedab Assasa district, West Arsi zone of Oromia National Regional State, Ethiopia. He attended his primary education at Mamuda Tuse Elementary School from 2005 to 2013. After he completed his elementary education, he was enrolled in Gedab Assasa Senior Secondary School and completed secondary education (Grades 9 and 10) from 2013 to 2014. After completing secondary education, he joined Assasa Preparatory School (Grades 11 to 12) in 2015 to 2016 and took the Ethiopian University Entrance Examinations Certificate in 2016. After completing preparatory school, he joined Jimma University, College of Agriculture and Veterinary Medicine in the 2016/17 academic year and graduated with a Bachelor of Science degree in Plant Science in June 2019. Following his graduation, he was recruited by the Department of Horticulture and Plant Science to serve as a Graduate Assistant. After serving for two years, he joined the School of Graduate Studies of JUCAVM in the 2021/22 academic year to pursue his graduate studies leading to an MSc in Agronomy.

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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AE | Agronomic efficiency |
| ANOVA | Analysis of Variance |
| CEC | Cation Exchange Capacity |
| CV | Coefficient of Variance |
| DAE | Days after Emergence |
| EthioSIS | Ethiopian Soil information system |
| GLM | General Linear Model |
| JMO | Jimma Meteorological Office |
| LSD | Least Significance Difference |
| NSTC | National Soil Testing Centre |
| NOTs | Nutrient omission Trial |
| ONARD | Omo Nada Agricultural Rural Development |
| GYGA | Global Yield Gap Atlas |
| SOM | Soil Organic Matter |
| RE | Recovery efficiency |
| TSP | Triple Super Phosphate |

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## ABSTRACT

Maize (*Zea mays* L.) is a fundamental staple food crop in Ethiopia, with widespread cultivation and consumption across various regions. Despite continuous growth, maize yields in the study area have not reached their full potential due to persistent nutrient deficiencies and improper fertilizer application practices. To address this issue, a study was conducted in the Nitisols of Omo Nada District; Southwestern Ethiopia in 2023 to identify the key nutrients limiting yields and assess the impact of nutrient omission on maize production. The trail was laid-out on farmers' field in southwest Ethiopia. Various nutrient omission treatments were applied, including Control, PK (-N), NK (-P), NP (-K), NPK, and NPK+ Lime. Analyzed using SAS 9.3 software. The findings highlighted that the full dose fertilization of NPK significantly improved growth parameters, yield, and yield components. Significant enhancements were observed in growth parameters such as plant height (295.6 cm) and leaf area index (4.6), as well as yield components like grain yield per cob (630g) and thousand grain weights (248.7 g). The application of NPK resulted in significantly higher grain yield (9.7 ton/ha) and total biomass (11.66 ton/ha). The study revealed clear grain yield penalties of 5.76 ton/ha (59.38%) and 3.93 ton/ha (40.52%) due to N and P omissions, emphasizing the importance of nitrogen and phosphorus as the primary yield-limiting nutrients. Moreover, the inclusion of lime with the full dose of NPK led to a 10.93% increase in grain yield compared to NPK alone, indicating that soil acidity was negatively impacting yields in the study area. The order of grain yield reduction levels for different nutrient omissions was found to be (con (72.37)> PK (50.38) > NK (40.52) > NP (1.24) compared with NPK. Maximum agronomic efficiencies for N (68.39), P (178.42), and K (164.15) were achieved with the NPK+ Lime treatment.

Overall, the results underscored that nitrogen and phosphorus are the primary yield-limiting nutrients for maize cultivation on Nitisols in southwest Ethiopia. By implementing a comprehensive nutrient management strategy that addresses these deficiencies and soil acidity, farmers can optimize maize production and enhance agronomic efficiencies for sustainable crop yields in the region.

**Keywords:** Agronomic Efficiency, NPK, Nutrient Omission, Yield Reduction

# 1. INTRODUCTION

Maize (*Zea mays L.*) stands out as a crucial cereal crop on a global scale, primarily cultivated in Central America (Kumar et al., 2011). Its adaptability is unmatched, thriving across diverse elevations and latitudes, in varying temperatures and soil conditions, making it a staple in 125 developing countries, with 75 of them ranking it among the top three major crops (Boddupalli, 2011). With a vast cultivation area of approximately 100 million hectares worldwide, maize plays a pivotal role in the livelihoods of millions, notably smallholder farmers and lower middle-income countries contributing significantly to its production (Shiferaw *et al*., 2011).

In Ethiopia, maize has emerged as a cornerstone of food security, especially post the harrowing drought and famine of 1984 (Abate *et al*., 2015). Its popularity in the country stems from its dual role as a staple food crop and a valuable source of animal fodder and fuel for rural communities (Abate *et al*., 2015). With maize being a dietary staple for many Ethiopians, its significance is further underscored by its exceptional photosynthetic system, enabling high biological and grain yields (Aslam *et al*., 2015).

Recent data from FAOSTAT (2021) highlights maize's dominance in both production and productivity in Ethiopia, accounting for 2.53 million hectares and 10.7 million tons in 2021. Poor soil fertility is one of the main causes of low maize productivity in SSA, particularly in Ethiopia. Nitrogen and phosphorus are particularly deficient in major parts of the country, including the study area, as a consequence of low fertilizer input that is frequently exceeded by the removal of N, P, and K from fields through crop harvest (Debelle *et al*., 2002, Atnafu *et al*., 2021). Moreover, the mountainous topography and intensive farming practices that rely on cereal production for subsistence have increased the vulnerability of top soil losses and lower crop yields in Ethiopia (Atnafu *et al*., 2021). This consequently leads to quite low recovery fractions of applied nutrients because of nutrient losses and unbalanced nutrient application (Bhaduri and Gautam, 2012). Accordingly, proper crop management practices such as application of optimum NP fertilizers coupled with other best agronomic managements to the country’s maize belts could help achieve the potential yield of maize.

Despite its prominence, maize yield in Ethiopia faces challenges due to soil fertility issues, particularly nitrogen and phosphorus deficiencies (Kena and Yohaness, 1993). The national average yield of maize remains low at 4.00 ton/ha (FAOSTAT, 2022), significantly below the crop's water-limited yield potential of 12.5 ton/ha estimated by the Global Yield Gap Atlas (GYGA, 2019). This yield gap is largely attributed to inadequate fertilizer management practices, given maize's high nutrient requirements for optimal grain production (Asadu and Unagwu, 2012). In Ethiopia, poor soil fertility poses a significant barrier to achieving high maize productivity, with nitrogen and phosphorus deficiencies prevalent across various regions, including the study area (Debelle *et al*., 2002; Atnafu *et al*., 2021). In addition to these variations in soil fertility status, crop management methods and crop responses to nutrients could contribute to maize yield limitation.

Unbalanced fertilizer use, primarily NPK, during crop cultivation can deplete soil nutrients, leading to decreased crop productivity and soil degradation (Rawal *et al.*, 2018). To sustain agricultural productivity, it is essential to apply the correct type and amount of balanced fertilizers to preserve soil nutrients. Omission trials demonstrate the crop's response to nutrient availability in a visible sequence (Timkhum *et al.*, 2013). Limited nutrient omission studies have been conducted on maize production in southwest Ethiopia, including research by Atnafu *et al.* (2021), Kenea *et al.* (2021), and Amare *et al*. (2022), indicating that nitrogen (N) and phosphorus (P) are limiting nutrients for maize production. Despite increased yields with full NPK application, the yields still fall short of their potential. Various limiting factors such as soil acidity, poor nutrient availability, and soil nutrient retention capacity may contribute to this shortfall. There is a lack of research on nutrient omission trials and the application of lime to enhance maize yields in farmers' fields. Therefore, to enhance maize productivity, it is crucial to assess soil nutrient supply for macronutrients like nitrogen, phosphorus, and potassium (NPK), while also adjusting soil pH through liming.

## 1.1 Objectives

### 1.1.2 General objective

- To assess N, P, K deficiency on maize (*Zea mays* L) through nutrient omission trials in Omo Nadda District, Southwest Ethiopia

### 1.1.3 Specific objectives

- To evaluate the effects of nitrogen and phosphorus omission on maize growth and yield in in Omo Nadda southwest Ethiopia
- To determine the extent of yield reduction due to omission of N,P and K in maize production in in Omo Nadda southwest Ethiopia

# 2. LITERATURE REVIEW

## 2.1. Maize Origin and Distribution

Maize, originating in Central America, was introduced to West Africa by Portuguese traders in the early 1500s (Worku *et al*., 2002). Onasanya *et al*. (2009) emphasized that maize (*Zea mays* L.) is a crucial cereal crop, ranking third globally in terms of vegetative growth and grain development, following wheat and rice. The leading maize producers, as reported by Onasanya *et al*. (2009), include the United States, Brazil, France, India, and Italy. In Africa, maize cultivation predominantly serves as human sustenance, with an increasing trend towards animal feed utilization. The expansion of maize production beyond its Central American origins reached new territories, notably the United States and Canada, during the second millennium (Shiferaw *et al.*, 2011). By the 1930s, maize had become significant in smallholder agriculture in Africa, serving both as a subsistence and commercially valuable crop (Shiferaw *et al*., 2011). The introduction of maize into Ethiopia dates back to the 17th century (Huffnagel, 1961). Presently, maize stands as a major staple crop worldwide, boasting the highest average yield per hectare and ranking third in total production after wheat and rice (Worku *et al*., 2002).

## 2.2. Soil Fertility and Management in Maize

Despite its potential agricultural richness, Ethiopia faces food insecurity challenges within Sub-Saharan Africa. The nation struggles with low agricultural productivity due to recurrent food shortages and hunger, exacerbated by drought and soil fertility issues stemming from excessive degradation and nutrient depletion (Kirda, 1999). Primary plant nutrients such as nitrogen and phosphorus are commonly supplemented to the soil through urea fertilizers and diammonium phosphate, while soil acidity, often overlooked, poses a threat to crop yields. The cultivation of improved crop varieties without balanced nutrient management exacerbates nutrient deficiencies, particularly N and P, hindering optimal crop growth. This deficiency underscores the necessity for external supply of N and P fertilizers to enhance plant growth and yield, aligning with the low organic carbon, total nitrogen, and available phosphorus levels in the experimental soil (Wondesen and Sheleme, 2011). Scholars have highlighted soil infertility as a critical challenge to agricultural productivity in Sub-Saharan Africa, attributed to continuous land cultivation, population growth, and limited fertilizer usage (Bationo *et al*., 2018). The consequences of declining soil fertility manifest in reduced crop yields, vegetation cover loss, increased soil erosion, declining farm productivity, rising urban migration rates, and diminishing household and national food security levels (Wise, 2020).

## 2.3. Maize Response to Nutrient

Maize requires an adequate supply of nutrients, particularly nitrogen, phosphorus, and potassium, for growth and high yield. Nitrogen and phosphorus are essential for good vegetative growth and grain development in maize production. The quantity required for these nutrients, particularly nitrogen, depends on the removal of crop residue after harvesting, organic matter content, tillage method, and light intensity (Ayanlaja and Sanwo, 1991). Atnafu *et al*. (2021) reported that some of the major causes of low maize yield are declining soil fertility and insufficient use of fertilizers, resulting in severe nutrient depletion of soils. Nitrogen is an essential plant nutrient and a major yield determining factor required for maize production (Adediran and Banjoko, 1995). It is very essential for plant growth and makes up 1%–4% of dry matter of plants (Onasanya *et al*., 2009).

Nitrogen is a component of protein and nucleic acids, and when nitrogen is suboptimal, growth is reduced (Haque *et al*., 2001). Its availability in sufficient quantity throughout the growing season is essential for optimum maize growth. It is also a characteristic constituent element of proteins and an integral component of many other compounds essential for plant growth processes, including chlorophyll and many enzymes. It also mediates the use of phosphorus, potassium, and other elements in plants (Rao *et al*., 1999). The optimal amounts of these elements in the soil cannot be utilized efficiently if nitrogen is deficient in plants. Therefore, nitrogen deficiency or excess can reduce maize yields.

Maize is a high-yielding crop that absorbs a significant amount of nutrients from the soil throughout its growth stages, making it an exhaustive crop with immense potential compared to other cereals. Among these essential nutrients, phosphorus stands out as one of the key elements crucial for achieving high yields Chen *et al.,* (1994) and plays a vital role in controlling the reproductive growth of plants (Wojnowska *et al*., 1995). Phosphorus is the second most limiting nutrient for crops in most soils, following nitrogen in terms of fertilizer use. Its application influences plant growth behavior and is essential for various processes such as growth, sugar and starch utilization, photosynthesis, nucleus formation, cell division, and the formation of fats and proteins. Energy from photosynthesis and metabolism of carbohydrates is stored in phosphate compounds for later use in growth production (Ayub *et al*., 2002). It is simply trans located within plants, moving from older to younger tissues as the plant forms cells and develops roots, stems, and leaves (Ali *et al*., 2002).

Adequate P results in rapid growth and earlier maturity and improves the quality of vegetative growth. Phosphorus deficiency is responsible for crooked and missing rows as kernel twists and produce small ears nubbins in maize. Phosphorus deficiency will slow overall plant growth(Ahmad *et al*., 2013) . Ali *et al*., (2002) reported a significant effect of P application on grain yield, whereas Ayub e*t al*., (2002) observed a significant effect of P application on dry matter yield and individual plant characteristics such as plant height, number of leaves, and leaf area.

The response of maize plants to the application of nitrogen and phosphorus fertilizers varies from variety to variety and location to location and depends on the availability of the nutrients(Onasanya *et al*., 2009). Many studies have shown that various maize cultivars differ markedly in grain yield response to nitrogen fertilization (Matusso and Materusse, 2016). The application rate of 120kgN/ha +40kgP/ha significantly (P =0.05) enhanced grain yield in Southern Nigeria (Onasanya *et al*., 2009). The aim of determined that the increase in maize grain yield later the study search out judge the effect of various nitrogen implantation is mostly on account of an increase in the rates of nitrogen and phosphorus fertilizers on the progress number of ears per plant, increase in total dry matter and yield of maize (*Zea mays* L.) in Akure, Ondo State in delivered to the seed and increase in average attention burden (Onasanya *et al*., 2009).

Okalebo *et al*., (2009) reported that soil acidity, the prevalence of H+ and Al3+ cations within the soil solution, as reflected in soil pH levels generally below 5, is far reaching within the profoundly weathered and filtered soils within the tropics (basically the acrisols, feralsols and nitisols).Most of south west Ethiopian soils are acidic; therefore, it reduces the growth and yield of maize. Negese and Oromia, (2019) reported that soil acidity is one of the major factor that limits and hinders sustainable and profitable agricultural productivity in many parts of the world. Similarly, Alemu *et al.*, (2022)Reported that Soil acidity is the main soil chemical constraint that limits agricultural productivity in the high-rainfall Ethiopian highlands. Abebe( 2007) reported that about 41% of Ethiopia's arable lands are affected by soil acidityAl3+ toxicity.

According toTamene *et al*., (2017), soil acidity is increasing in Ethiopia in terms of level and intensity, considerably limiting agricultural production.

## 2.4. Effect of Nutrient Application on Plant Bio -volume

Studies have shown that the application of optimal fertilizer accelerates plant growth, resulting in taller and greener plants (Zhang *et al*., 2010). According to Fashina *et al.* (2002), the availability of sufficient growth nutrients from inorganic fertilizers leads to improved cell activities, enhanced cell multiplication, enlargement, luxuriant growth, and eventually high yields. This was observed in NPK, NPK+ manure, NPK+ lime, and NP treatments. Muthaura et al. (2017) found that PK and NK achieved low biomass volumes across the season. This report aligns with the findings of Adediran and Banjoko (2003), who indicated that the absence of N and P nutrients resulted in stunted growth and depressed yields. Nitrogen is typically the most limiting nutrient in maize production (Sawyer *et al*., 2006). This observation was confirmed by the poor performance of PK treatments in both seasons. Ahmad *et al.* (2009) and Ahmad *et al.* (2013) indicated that the availability of adequate phosphorus improves plant growth and hastens maturity. This was evident in the NPK, NPK+ manure, NPK+ lime, and NP treatments, which achieved improved biomass volume. This observation was further affirmed by Ayub *et al*. (2002), who indicated that growth and yield increased with an increase in the rate of phosphorus application.

## 2.5. Effect of Nutrient Application on Grain and Stover yields

Adediran and Banjoko, (2003) reported that a high yield of maize is obtained with balanced fertilizer treatments. This can be attributed to the optimum utilization of solar light, higher assimilate production, and its conservation to starches, which resulted in a higher grain number (Derby *et al.*, 2004). Sangoi *et al*., (2007) reported that a lack of N before or at sowing results in reduced grain yield in maize. Studies conducted bySamira *et al*., (1998) and Torbert *et al*., (2001) found that N application increased the yield and yield components of maize. Studies by Ransom (2004) indicated that plants suffering from N deficiency mature earlier; thus, the vegetative growth stage is shortened, leading to low grain yields. Furthermore, (Malhi *et al*., 2001). Kogbe and Adediran, (2003) reported that the application of insufficient P depressed maize yield. Another study by Grant (2018) found that plants require adequate P from the very early stages of growth for optimum crop production. Further studies that confirm the observations made in this study were conducted by Vu *et al*., (2008) and Bünemann *et al*., (2004), who reported depressed maize yields when P supply was inadequate over the entire maize growth period. Enhanced early season P nutrition in maize increased dry matter partitioning to the grain later in the development stage (Gavito and Miller, 1998). There exists low biomass production of maize under P deficiency in field conditions because the aboveground biomass accumulation was severely reduced (60% ) during the early stage of maize growth(Plénet *et al*., 2000). The spectacular effect of P deprivation on early reduction in shoot growth is explained by a slight but rapid stimulation of root growth (Mollier and Pellerin, 1999). Phosphorus deficiency results in plants that grow slowly with a poorly developed root system and small leaves of grayish-green color (Plénet *et al*., 2000).Adequate supply of nitrogen leads to significant increases in grain yields and its components.

## 2.6. Soil Fertility Variability in maize Farms

Spatial variability of soil properties within or among agricultural fields is inherent in nature due to geologic and pedologic factors Deckers(2001), but variability in soils of similar texture is induced by diverse management practices unique to farmers. Normally, fields closest to the homestead receive comparatively larger nutrient resources, leading to the establishment of gradients of decreasing soil fertility from the homestead to distant filedCarter and Murwira, (1995); Tittonell *et al*., (2006); (Zingore *et al.*, 2007). This is a result of labor constraints considerations that obviously lead farmers to concentrate nutrient resources on fields closest to their homesteads. In some places, the opposite has been evident, where by nutrient gradients of increasing fertility away from the homestead are evident, such as in the enteral highland of Ethiopia (Haileslassie *et al*., 2007). The link between socioeconomic status and soil fertility has been demonstrated to influence soil fertility across farms. Studies have consistently shown that when farmers ranked their fields in terms of fertility, the higher resource groups had higher fertility than the poorer farmers for the same category (Mtambanengwe and Mapfumo, 2005, Tittonell *et al*., 2010). Richer farmers have access to manure as a result of livestock ownership and use more mineral fertilizers than their poor counterparts, thus building up on their farms.

## 2.7. Limiting Nutrients in Smallholder Maize Fields

Soil fertility decline in SSA has contributed to the loss of nitrogen, phosphorus, and potassium (Amede, 2003).According to Roy *et al.*, (2003), negative nutrient balances for nitrogen and phosphorus have been found in smallholder farming systems in SSA. Henao and Baanante, (2006) computed per hectare nitrogen, phosphorus and potassium nutrient balances for the whole of Africa for 2002–2004. They found that the average annual depletion rate of all Sub-Saharan Africa countries was 54 NPKha$^{-1}$ ranging from 23ha$^{-1}$yr$^{-1}$ in South Africa to as much as 88kgha$^{-1}$yr$^{-1}$ for Somalia. Shepherd *et al*., (1997) observed that nitrogen and phosphorus are the main limiting nutrients in food crop production in western Kenya. Hartemink *et al.*, (2000) reported that nitrogen fertilizer input was required to sustain high crop yields in an intensive crop production system.

Furthermore, nitrogen deficiency can be improved through the application of inorganic and organic fertilizers and biological nitrogen fixation. According to Lungu and Dynoodt, (2008),one of the ways of addressing the impact of soil mining is the use of inorganic fertilizers. However, the use of these inputs among smallholder farmers is currently low. Nitrogen is a key nutrient for crop production. It is the most mobile, volatile, and the most exhausted nutrient due to its ability to exist in different forms and its easy leach ability (Palm *et al*., 1997). Snapp *et al*., (1998) observed that maize removes about 40 kgha$^{-1}$ to produce 2 to 2.5 ton of grain yield per hectare in the tropics. According to Kwabiah *et al.,* (2003), phosphorus is a limiting nutrient in maize production due to low native soil P and high P fixation. In addition, Fairhust(1999) observed that phosphorus, unlike nitrogen, cannot be replenished through biological fixation. For many cropping systems in the tropics, the application of P from organic and inorganic sources is essential to sustain high crop yield. Kwabiah *et al*., (2003) concluded that phosphorus deficiency is a factor limiting crop production in tropical and subtropical soils. Correcting P deficiency with the application of phosphoric fertilizers is a challenge for most poor smallholder farmers in SSA due to the high cost of mineral fertilizers and the availability of fertilizers for the farmers.

## 2.8. Importance of Nitrogen in Maize Production

Nitrogen (N) stands as a cornerstone of plant nutrition, wielding unparalleled influence over crop productivity. Over the past four decades, the remarkable doubling of global agricultural food production has been intrinsically linked to a staggering seven-fold surge in the utilization of nitrogen fertilizers. This underscores the undeniable importance of nitrogen in meeting the world's food demands. Nitrogen plays a critical role as a fundamental structural element in plants. As highlighted by Brady *et al.* (2008), nitrogen is instrumental in the biosynthesis of chlorophyll, the pigment responsible for capturing light energy during photosynthesis. Consequently, nitrogen is a driving force behind robust vegetative growth, laying the foundation for high crop yields. Ransom (2004) elucidates the diverse forms of nitrogen present in soil, categorized as organic and inorganic. Organic nitrogen, originating from living organisms, constitutes a part of the complex organic compounds that persist after their death and subsequent decomposition. In contrast, inorganic nitrogen encompasses all forms of nitrogen liberated from organic compounds through mineralization or introduced into the soil through chemical fertilizers (Zhu and Chen, 2002).Crucially; plants primarily absorb nitrogen in the forms of nitrate and ammonium, as reported by Shafreen *et al.* (2021). However, the uptake of these essential nitrogen forms is not a simple process. Mengel and Kirkby (1982) astutely observed that the absorption of nitrate and ammonium by plants is intricately influenced by a complex interplay of factors, including soil water availability, the dynamic activities of soil microorganisms, and the prevailing chemical reactions within the soil environment.

Nitrate uptake is encouraged when the soil pH is low and depressed when the soil pH is high. This is due to the competitive effect of OH ions, which suppress the $NO_3^-$ uptake and transport. Furthermore, plant uptake of ammonium proceeds best at neutral pH values and is depressed by acidity due to competition between hydrogen ($H^+$) and ammonium on plant roots.

Nitrogen plays a vital role in the nutritional and physiological status of maize and promotes changes in the mineral composition of the crop (Zhu and Chen, 2002). Lu *et al*., (2010) reported that increasing nitrogen levels up to 120kgNha$^{-1}$leads to a significant increase in grain yield and its components. However, most plants only utilize less than one-half of the fertilizer N applied, and the loss of fertilizer N is high (Zhu and Chen, 2002). According to Getinet *et al*., (2022), the highest grain yield response was obtained from the application of 120 kg/ ha N, indicating that N is the most yield-limiting essential nutrient in maize production, thus requiring special attention. Balemi *et al.*, (2019)reported that the average grain yield for N-missed plots was 7.9 ton ha$^{-1}$ compared with an average grain yield of 8.3 ton/ ha for the NPK-treated plots. Nitrogen management in agro-ecosystems has been extensively studied due to its importance in improving crop yield and quality (Dambreville *et al*., 2008). Nitrogen is a vital plant nutrient and a major yield determining factor for maize production (Adediran and Banjoko, 1995, Adhikari *et al*., 2021).

It is essential for plant growth and makes up 1%–4% of dry matter of plants (Onasanya *et al*., 2009). Nitrogen is a component of proteins and nucleic acids, and when nitrogen is suboptimal, growth is reduced (Roy *et al*., 2019). Its availability in sufficient quantity throughout the growing season is essential for optimum maize growth. It is also a characteristic constituent element of proteins and an integral component of many other compounds essential for plant growth processes, including chlorophyll and many enzymes. It also mediates the use of phosphorus, potassium, and other elements in plants (Brady, 1984). The optimal amounts of these elements in the soil cannot be utilized efficiently if nitrogen is deficient in plants. Therefore, nitrogen shortage or excess can reduce maize yields.

## 2.9. Importance of Phosphorus in Maize Production

Phosphorus is by far the most important mineral nutrient for crop production, after nitrogen compared to other major nutrients, P is the least available to plants due to its high fixation in most soil conditions and slow diffusion(Datta *et al*., 2015) . Therefore, P can be a major limiting nutrient for plant growth and development in many soils across the world. Agricultural productivity will be lower for P, and consequently less food will be produced per unit area of land, especially in developed and developing countries where access to P fertilizers is restricted due to the rising costs of P fertilizer (Richardson *et al*., 2011). Therefore, P is essential for the intensive agricultural production system and thus contributes significantly to the present and future global food production and security. `

Balemi and Negisho, (2012), reported that phosphorus is the second most widely limiting nutrient in soil after nitrogen and critical macronutrient for plant growth. In tropical agro ecosystem soil, P deficiency is a major limitation to crop production(Mustonen *et al*., 2012). Phosphorus is the precursor for flowering and plays a significant role in shortening the maturity period(Pokharel *et al*., 2016) . Research report indicates that < 1%of soil P is available for plant uptake Fosu-Mensah and Mensah (2016) because of the strong adsorption of phosphate by iron and aluminum oxides (Xavier *et al.*, 2023). According to Fosu-Mensah and Mensah ( 2016), phosphorus plays a role in sustaining and building up soil fertility, especially under an intensive system of agriculture. Thus, its deficiency is an important chemical factor restricting plant growth in soils. While N is the most limiting nutrient generally in soil Delve *et al*., (2009) showed that deficiency of soil P reduces the efficiency of N use by crops. Ransom (2004) described phosphorus as a naturally occurring element that can be found in the earth's crust, water, and all living organisms.

Plants absorb phosphorus largely as primary and secondary orthophosphate ions ( $H_2PO_4$ and $HPO_4^-$) present in the soil solution (Ransom, 2004). The phosphorus compounds adenosine di-phosphate and adenosine triphosphate act as energy currency within plants (Lal, 2000).Good supply of phosphorus increases root development. It is also associated with early maturity and strength of crop tissue, improving the quality of final yields (Waldron *et al*., 2003). Grant *et al.*, (2009) found that plants require adequate P from the very early stage of growth for optimum crop production. However, this nutrient is frequently limited in most African soils. According to Vu *et al*., (2008), the dynamics of soil P are characterized by interactions between physicochemical (absorption and desorption) and biological (immobilization and mineralization) processes. The rate and direction of these reactions are influenced by chemical conditions and biophysical dynamics as well as by the agricultural crops adopted (Bünemann *et al.*, 2004). Soil P undergoes biological Eger *et al.*, (2018) transformations, which are short and term transformations, respectively. In highly P-fertilized soils, the P concentration in the soil solution is high, and the depletion zone is readily replenished. The replenishment is low when soil solution P is low, especially for the soil solid phase with a low buffer capacity (Kpongor, 2007). The quantity of P ion solution at any given time generally represents less than 1% of P annually taken up by crops. Approximately 99% of P taken up by plants is bound to soil constituents before uptake (Morel *et al.*, 2021). The importance of adequate tissue P concentration during early season growth has been reported in different crop species (Grant *et al*., 2001).

## 2.10. Importance of Potassium in Maize Production

Next to N and P, the third most essential element that plants require in the largest amounts is potassium (Marschner, 1995). It is involved in photosynthesis, sugar transport, movement of water and nutrients, protein synthesis, and starch formation (Logah, 2009). Soils with a greater proportion of clay minerals are high in K; thus, the greater the potential K availability in soils (Mouhamad *et al*., 2016). Soil K mostly occurs in a mineral form and the daily K needs of plants are little affected by organic-associated K, except for exchangeable K adsorbed on SOM. Jobbagy and Jackson (2001) reported that nutrients strongly cycled by plants, such as K, were more concentrated in the surface soil than nutrients usually less limiting for growth of plants. Potassium is another macronutrient required for crop growth. In soil, K exists in exchangeable and non-exchangeable forms, which are in dynamic equilibrium with each other (Cox *et al*., 1999). Singh *et al*., (2018) observed that potassium in solution and exchangeable potassium are replenished by non-exchangeable potassium when these forms of K are depleted by plant removal or leaching.

Plants can only absorb potassium as the potassium ion $K^+$ (Dong *et al*., 2010). The author observed that potassium plays a particularly critical role in plant growth and metabolism. It contributes greatly to the survival of plants that are under various biotic and abiotic stresses. According to Shabala and Pottosin (2010), the concentration of $K^+$ in the cytoplasm has consistently been found to be between 100 and 200mm. Apo plastic $K^+$ concentration may vary between 10 and 200 or even reach up to 500mm(White *et al*., 2010) .

Potassium plays a vital role as a macronutrient in plant growth and sustainable crop production (Bukhsh *et al*., 2012). It maintains the turgor pressure of the cell, which is essential for cell expansion. It helps in osmoregulation of plant cells and assists in opening and closing of stomata (Mengel and Kirkby, 1987). It plays a key role in the activation of more than 60 enzymes

(Tisdale *et al.*, 1993). Its application has a nascent effect on growth and development (Srivastava and Malhotra, 2017) and grain yield in maize (Ahmad *et al.*, 2009). It not only affects the transport of assimilates but also regulates the rate of photosynthesis in maize. It is known for its antagonistic and synergetic interactions with essential macro and micronutrients (Dibb and Thompson Jr, 1985).

Potassium is very important for efficient N utilization and has a consistent effect on lowering tissue concentrations of Ca and Mg (Ahmad *et al.*, 2012). According to Lal (2000), K deficiency typically results in stunted plants with weak stalks that lodge easily. When the deficiency is very acute, the leaves show yellow spots followed by necrosis on the tips and edges. K deficiency is common in sandy soils with low exchange capacities and in soils with high potassium fixing capacity.

## 2.11. Effect of Nutrients on Growth Parameters

A nutrient has different effects on growth parameters; for instance, if the nutrients applied to the crop are below the optimum and above the optimum, it has an impact on different growth parameters that is reported by many authors. Atnafu *et al.*, (2021) reported that maize plant height was significantly affected ($p$<0.05) by nutrients treatments. Notably, the tallest plant (296.5 cm) was obtained when applying the NPK+ and NPK treatments (285.5 cm) compared with all other treatments, while the shortest plant (228.4 cm) was recorded in the control treatment, followed by the N omitted (245.5 cm) and the P-ignored treatment (266 cm). Atnafu *et al.*, (2021) reported that the degree of plant height reduction due to nutrient deficiency is in the order: N deficiency > P deficiency > K deficiency.

According to Onasanya *et al.*, (2009), the shortest plant height (167.06 cm) was recorded in the omission of the NPK plot, and the tallest plant(192.5 cm)was obtained from(120kgN/ha + 0kgP/ha) application of nutrients.Ahmad *et al.*, (2013)reported that application of P significantly (p < 0.05) increased the maize plant height.

The authors found that the minimum plant height (180.6 cm) was recorded in control plots, whereas the maximum plant height (219.6cm) was recorded from the application of P at the rate of 135 kg $ha^{-1}$. Even if the application of P increased the height of maize, if the application of P was above the optimum, it was not effective, indicating that plants had attained the potential height. Similarly, Zakirullah and Khalil (2010)reported that fast plant growth and development with the highest rate of P application. According to Atnafu *et al*., (2021)Phosphorus is important for shoot and root development where metabolism is high and cell division is fast, while K is required for stomatal regulation and hence entry of raw materials for photosynthesis and water regulation. Cox *et al*., (1993) reported that application of a high nitrogen rate stimulates leaf area throughout vegetative development and also supports maintenance of functional leaf area. Atnafu *et al*., (2021) reported that the maximum leaf area index (3.92) is recorded with the application of well-adjusted NPK and NPK+ (3.69), both of which are at statically the same .

The minimum leaf area indices (2.15) and (2.48) were obtained from the control and N-missed plots, respectively. According to Onasanya *et al.*, (2009), the maximum leaf area is obtained with application of (120kgN/ha + 20kgP/ha), whereas the minimum leaf area is obtained from the control plot. Similarly, Getinet *et al*., (2022) reported that leaf area index values were obtained with the applications of (NPKSZn), whereas the lowest leaf area index was recorded from the control plots. Onasanya *et al*., (2009) reported that the number of leaves was significantly affected by different fertilization rates. The application of (120kgN/ha + 0kgP/ha) gave a maximum number of leaves that was significantly different from all other treatments, whereas the minimum number of leaves per plant was obtained from the control. Generally, nutrients have a significant impact on the growth parameters of maize, especially nitrogen and phosphorus, which are the main limiting factors for maize growth parameters. Optimum application of nitrogen and phosphorus is good for improving crop growth, so it is important to conduct research on nutrient omission trials to identify and quantify which nutrient is the main limiting factor for growth and yield parameters in smallholder farmers.

## 2.12. Effect of Nutrients on Maize Grain Yield

The key to achieving high maize yield is to ensure that the crops have adequate supplies of all essential nutrients. This can be done through soil testing and optimum nutrient application because if we apply excess nutrients, it harms crops. For example, excess nitrogen can lead to excessive vegetative growth, which can reduce the number of ears produced and the grain yield. Deficiency of these nutrients can lead to many symptoms, including stunted growth, reduced leaf size, and poor flowering. These factors lead to reduced yield of maize, so optimum nutrient applications are essential for the growth and yield of the crops. Atnafu *et al.*, (2021) reported that maximum average grain yield of 9,185.1 kg $ha^{-1}$ and biomass yield of 10,307.8 kg $ha^{-1}$ of maize were recorded under balanced NPK fertilization, while the lowest was recorded in the treatment control and missing nitrogen, showing that nitrogen was the most limiting yield nutrient for corn production than any other nutrient in the study area. Atnafu *et al*., (2021) also reported that the yield response to K fertilizers is also not zero, although it is lower than for N or P fertilizers. Rurinda *et al*., (2020) indicated that nitrogen is the most limiting factor for maize growth, followed by phosphorus in each of Nigeria, Ethiopia, and Tanzania. Similarly, Kenea *et al.*, (2021)confirmed that nitrogen and phosphorus are the main nutrients limiting maize production in Ethiopia.

Getinet *et al.*, (2022) found that soil nitrogen availability is very low and strongly limits grain yield of maize, followed by P in the Omo Nadda District, South-western Ethiopia. Onasanya *et al*., (2009) found that application of 120 kg N/ha 40 kg P/ha) + 40 kg P/ha significantly (P=0.05) enhanced grain yield. The number of cobs per plot was also significantly affected by phosphorus application, and the maximum number was produced when supplied with 180 kg P $ha^{-1}$, followed by 135 kg P $ha^{-1}$. The minimum number of cobs in the control and lower applied phosphorus levels may be the result of some plant failure to produce cobs due to a short supply of phosphorus. On the whole, many studies have been conducted by different researchers in different areas on nutrient omission trials based on the fact that nitrogen and phosphorus are the main yield-limiting factors of maize production. To increase the yield of maize to feed the increasing populations of the country, we should apply the optimum nutrients to the crop otherwise the reduction of maize is increasing from time to time due to declining soil fertility especially in smallholder farmers in Omo Nadda District, southwest of Ethiopia

## 2.13. Total Nutrient Uptake

According to Getinet *et al*., (2022) the maximum total nutrient uptake, agronomic efficiency, and clear nutrient recovery were obtained from plots treated with fertilizer containing NPKS Zn. Balemi *et al*., (2019) reported that the total N uptake varied significantly between high-rainfall and water-stressed areas for each of the same treatments (except control and PK), as well as between treatments at the same location. The authors also reported that the response to fertilization in terms of grain yield, nutrient uptake, agronomic efficiency, and N and P recovery was clearly higher in high-rainfall areas than in low-rainfall areas. Low because rainfall during the growing season is the determining factor in variation.

## 2.14. Importance of Lime application in Maize Production

Dinkecha and Tsegaye (2017) reported that soil acidity and liming factors directly affect plant nutrition. According to Dinkecha and Tsegaye (2017)liming is an effective and popular method to improve agricultural production on acidic soils by increasing soil pH and the availability of P and other nutrients while reducing exchange acidity. The authors also reported that NPS Zn B (+Ve control) with lime improves soil fertility and brings maximum yield to maize and soybean plants under acidic soil conditions. Ayalew (2011)Reported that while liming alone did not affect maize yields in Areka, higher maize yields were achieved when lime was applied along with fertilizer. The author also reported that soil pH, available phosphorus, cation exchange capacity, and calcium increased in all cropping seasons with increasing application of lime. Similarly, Dereje *et al*., (2019) reported that lime increases soil pH and reduces exchange acidity, leading to high sorghum yields. According to Okalebo *et al*.,( 2009)Soil acidity can be improved in Western Kenya and related areas through the use of agricultural lime (available and affordable) combined with modest P and N additions of 26 kg P $ha^{-1}$ and improve soil quality and agricultural production 341 kg N $ha^{-1}$. Different studies have been conducted in different areas. These studies found that application of lime with nutrients increases crop production yield by improving the availability of phosphorus for the crop, which is the most yield-limiting macronutrient next to nitrogen, and by increasing soil PH and reducing exchange acidity. It is important to apply lime with a combination of nutrients in the southwest of Ethiopia because of the high soil acidity in this area to increase the yield of maize production.

## 2.15. Nitrogen Use Efficiency in Maize

Nutrient use efficiency is a direct measure of the rationality and advancement of fertilization (Hirel *et al*., 2011). Nutrient use efficiency can be expressed as agronomic efficiency and crop recovery efficiency (Dobermann, 2007). Using AE and RE to evaluate the effect of nutrient omission on nutrient utilization, where AE refers to the crop yield increase per unit nutrient applied and RE refers to the increase in plant nutrient uptake per unit nutrient applied. Agronomic efficiency or apparent recovery efficiency are appropriate performance indicators, especially in the selection of more efficient genotypes for nutrient uptake or to assess nutrient transfer among soil pools. However, both of these measures require a nil fertilizer application treatment to estimate the extra yield due to the added fertilizer (Norton *et al*., 2015) (Rob *et al.*, 2015). Such measures are normally only available on research plots, limiting their usefulness in non-research settings.

Fertilizer use efficiency reflects the recovery of applied by the crop; however, from the crop perspective, N (or other nutrient) use efficiency is a measure of biomass produced as a function of the N ( or other nutrient) available to that crop (Dobermann, 2007). Canopy architecture, function, and longevity determine the production of carbohydrate for grain filling and hence yield. A complication is the need for N by the grain during grain filling, a requirement fulfilled mainly by remobilization from the sensing (and hence decreasing functionally active) canopy(Abeledo *et al*., 2008) .

Soil fertility is a multifaceted discipline, cutting across biophysical, climate, and anthropogenic factors. Despite the massive investment in research and fertilizers, yields in smallholder fields are on a downward trend. The review of literature identified a dearth of critical research on the effect of limiting nutrients on the growth and yield of maize. From the published work on research done in other regions of SSA, it is evident that deteriorating soil fertility leads to depressed yields among stallholder farmers. Although poor maize yields are due to numerous interrelated bottlenecks such as climate change, nutrient mining remains one of the major impediments. It ultimately leads to the emergence of limiting nutrients. This problem is further compounded by the mismanagement of smallholder fields. Determining the limiting nutrients to maize growth and yield in Jimma is crucial in helping to develop solutions to arrest the dwindling soil fertility. Further establishment of management practices that influence the variability of nitrogen, phosphorus, and potassium in the soils of Jimma is important in developing local solutions.

# 3. MATERIALS AND METHODS

## 3.1 Study Area

The study was conducted on farmers' fields on Nitisols of Doyyo Yaayya and Biso Gombo Kebeles, Omo Nada district South-western Ethiopia (Figure 1) during the main cropping season of 2023.Geographically, nestled between 7°35′–8°00′N latitude and 36°46′–37°14′E longitude and altitude that ranges from 1740 to 2660 m.a.s.l and consists of 10% dega and 90 % woina dega, agro-ecological zones. The chosen experimental sites are recognized as prime maize-growing regions within Omo Nada. According to the data from Jimma Meteorological station (2022), the average minimum and maximum temperatures and mean annual rainfall of the experimental sites was 13.3 $^{0}$C, 27.18 $^{0}$C and 1198 mm, respectively. These soils are characterized by a reddish hue, moderately acidic pH, and low nutrient content. Specifically, nitrogen and phosphorus levels fall below the optimum range for maize cultivation, while potassium remains sufficient (Table 2). These deep, highly weathered soils exhibit good drainage and a sandy clay texture.

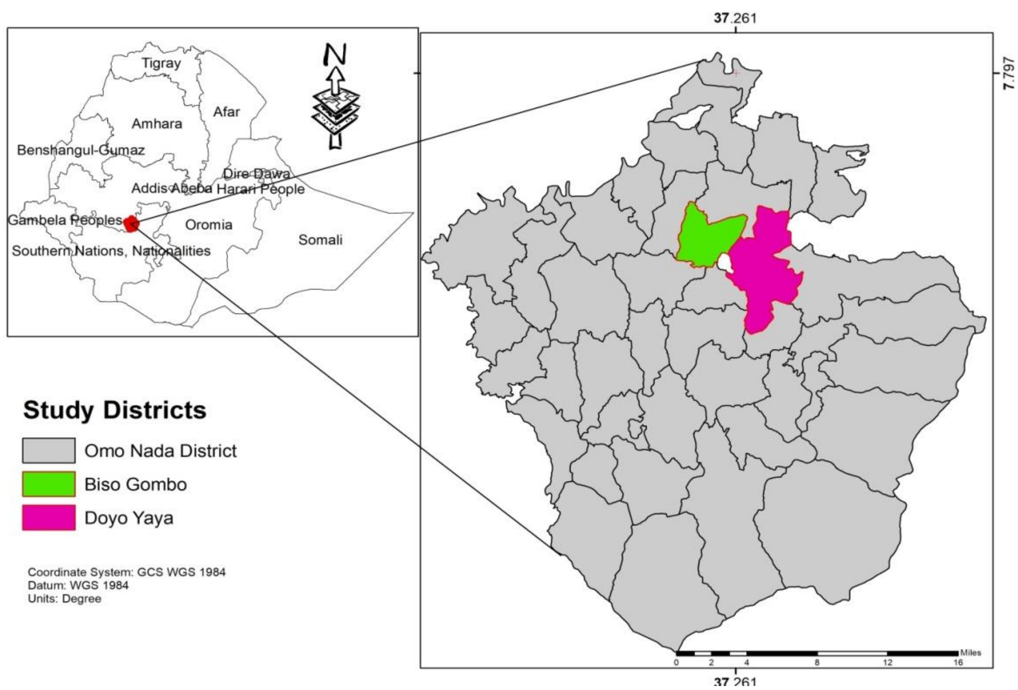


**Figure 1**: Location map of experimental site in Omo Nada district, Jimma, Oromia region, Ethiopia (Map developed by Melkamu Mamuye)

### 3.2. Experimental Design and Treatments

The nutrient omission trials (NOTs) consisted of six treatments (Table-1). And the treatments were laid out in a randomized complete block design (RCBD) with four replications. Each replication corresponded to an individual farmer's field within the study area.

**Table 1.**Treatment and nutrient amount

| No. | Treatments | NPK (kg ha$^{-1}$) |
|---|---|---|
| 1 | Control (- NPK) | 0-0-0 |
| 2 | PK (-N) | 0-46-50 |
| 3 | NK(-P) | 120-0-50 |
| 4 | NP(-K) | 120-46-0 |
| 5 | NPK | 120-46-50 |
| 6 | NPK+ Lime | 120-46-50 +3 ton of lime |

### 3.3. Experimental Procedures and Materials

The maize variety Bako hybrid (BH-661), which is a higher yielder than other improved maize varieties was used as test crop. BH-661 variety is highly preferable by growers over other cultivated varieties because of its high biomass and high yield.  An area with limited nutrients in the soil systematically and purposefully selected based on its maize production potential. After site selection, land preparation was performed by clearing unwanted weeds, grasses, and residual plants. The fields were prepared using a local plow (mersha) commonly used by farmers in the area. The experimental fields were plowed three times to a depth of 15–20 cm, and furrows were constructed using a hand-held hoe and harrowed by human labor to make the soil fine. Each gross plot was measured to have a size of 6 m×6 m= 36 m$^2$ accommodating 8 rows and a plant spacing of 75 cm (inter-row) and 30 cm (intra-row) was used to maintain a plant population of 44,444 plants ha$^{-1}$. The planting time was adjusted to the farmer’s frame. Two seeds of maize were planted per hill and later thinned to one seedling. Spacing between each plot was 0.5 m and the entire experimental area was 924 m$^2$.

## 3.4. Treatment application and crop management

The field was managed to ensure uniformity and optimal management. Uniformity in management was ensured, and the following standard agronomic practices were followed. The plots were regularly weeded to reduce any impact of weed effect on maize performance, and hilling was performed. Fertilizers were supplied depending on nutrient necessities to attain the expected attainable yield without shortage of nutrients in every field. Basal fertilizers were supplied by drilling the planting rows at sowing time. Half of the urea, total of TSP, and potassium chloride (KCl) were drilled and applied in the planting rows at planting.

The applied fertilizers were covered with some soil before placing the seeds to avoid direct contact of the seeds with the fertilizer. Nitrogen fertilizer was applied in two splits with half of it at planting and the remaining half (1/2) of urea was top dressed by spot application six weeks after emergence (45 DAE) for all plots receiving nitrogen, while phosphorus and potassium were applied at planting time. Fertilizers were calculated based on the recommendation of Balemi e*t al*., (2019) for Omo Nada district. Three (3) ton of lime ($CaCO_3$) per hectare was applied for the plot receiving lime based on the recommendation for the study area. Lime was applied one month before the planting date because it reacts with the soil and neutralizes the acidic soil before planting, making nutrients available for the crop.

## 3.5 Pre planting soil sampling and Analysis

Pre soil representative samples were collected from the experimental farmers' fields at the depth of 0-20cm by using zig-zag method before planting, after that the representative soil were composited and analyzed following standard laboratory procedures for some selected soil physic- chemical properties. The soil samples were analyzed for soil pH, total nitrogen, available phosphorus, available potassium, calcium, sodium, sulfur, magnesium, organic matter, organic carbon and carbon to nitrogen ratio. Selected soil physical and chemical properties were analyzed at Horticoop Ethiopia (Horticulture) PLC, Soil, Water and Plant Analysis Laboratory. The pH soil was measured using method of ES ISO 10390: 2014 (1:2.5). Organic carbon content was determined by the wet oxidation method of Walkley and Black.

The total available nitrogen content of the soil was determined by the Kjeldahl Method, Available phosphorus was determined by Olsens and Bray II Method and all others selected soil physico –chemical properties are described in the (Table 2)

### 3.5.1 Soil sampling and analysis

**Table 2:** Soil physiochemical properties of experimental site

| | Farm One | | Farm Two | | Farm Three | | Farm Four | | |
|---|---|---|---|---|---|---|---|---|---|
| **Soil properties** | **Value** | **Rating** | **Value** | **Rating** | **Value** | **Rating** | **Value** | **Rating** | **References** |
| pH-$H_2O$ | 5.60 | Moderately acidic | 5.68 | Moderately acidic | 5.30 | Strongly acidic | 5.26 | strongly acidic | Mehlich-3, Ethio SIS (2014) |
| pH-KCl | 4.34 | moderately acidic | 4.22 | moderately acidic | 3.91 | extremely acidic | 4.06 | Moderately acidic | Mehlich-3, Ethio SIS (2014) |
| Ca (mg/kg ) | 1,304.68 | Very high | 1,2634 | Very high | 1,632.43 | Very high | 1,315.6 | Very high | Mehlich-3, Ethio SIS (2014) |
| Mg (mg/kg) | 153.69 | Very high | 234.36 | Very high | 309.01 | Very high | 242.18 | Very high | Mehlich-3, Ethio SIS (2014) |
| Na (mg/kg) | 24.22 | Low | 23.50 | Low | 24.48 | Low | 23.72 | Low | Mehlich-3, Ethio SIS (2014) |
| K (mg/kg) | 426.91 | Optimum | 407.05 | Optimum | 331.12 | Optimum | 546.87 | Optimum | Mehlich-3, Ethio SIS (2014) |
| S (mg/kg) | 45.51 | Optimum | 24.37 | Optimum | 26.06 | Optimum | 33.95 | Optimum | Mehlich-3, Ethio SIS (2014) |
| "Avali. P (mg/kg) | 24.80 | Low | 11.55 | Very low | 16.20 | Low | 26.71 | Low | Olsens &Bray II Method EthioSIS (2014) |
| TN (%) | 0.11 | Low | 0.10 | Low | 0.12 | Low | 0.14 | Optimum | (Kjeldahl Method) |
| OC (%) | 1.25 | Low | 1.35 | Medium | 1.71 | Medium | 2.17 | Medium | EthioSIS(2014), Walkely And Black |
| OM (%) | 2.16 | Low | 2.33 | Low | 2.95 | Low | 3.74 | Optimum | Ethio SIS (2014) |
| C:N Ratio | 11.36 | Low | 13.50 | Low | 14.25 | Low | 14.47 | Low | Ethio SIS (2014) |

Where: OC= Organic Carbon, OM= Organic matter, C: N=Carbon to Nitrogen ratio, TN=total available nitrogen

## 3.6. Data Collection

Important plant parameters were recorded from the six middle rows (20.25$m^2$) out of the eight rows per plot (36 $m^2$). Plant parameters recorded include plant height, leaf number, leaf area, and leaf area index, ear number per plant, ear weight per plot, ear length, and row number per ear, seed number per row, ear diameter, harvest index, total biomass, thousand seed weight, and grain yield.

### 3.6.1 Growth Parameters

*Plant height*

Plant height was measured from the base of the plant to the tip of the plant. To ensure a representative measurement, six middle rows of plants were selected from each plot, excluding the border rows. The height of twelve plants within each selected row was measured, and the average of these twelve measurements was calculated to represent the plant height for that plot.

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**Figure 2:** Measurement of plant height (cm) of maize by tape meter in study area

***Leaf number***

Leaf number was exactly determined at the flowering stage. Six middle rows of plants were selected from each plot, ensuring a representative sample. For each selected plant, the total number of leaves was counted manually. This careful counting process was conducted prior to any leaf defoliation, ensuring an accurate representation of the plant's leaf production. The average leaf count across all selected plants within a plot was then calculated to represent the mean leaf number per plant for that plot.

***Leaf area***

Leaf area was calculated from six middle rows plants per plot using the formula of leaf area. Length (m) *Width (m)*maize coefficient 0.75 (Jordan-Meille and Pellerin, 2004).

***Leaf area index***

The leaf area index was determined by dividing the total leaf area per plant by the total area of the plant ($m^2$) inter row * intra row spacing (Jordan-Meille and Pellerin, 2004).

### 3.6.2 .Yield and yield related parameters

***Cob number***

Cob number per plant was exactly determined at harvest.  To ensure a representative sample, six middle rows of plants were selected from each plot, excluding the border rows. Each plant within these selected rows was carefully marked, and the total number of cobs present was counted manually. The average cob count across all selected plants within a plant was then calculated to represent the mean cob number per plant

***Cob weight***

Cob weight per plot was determined using a standardized sampling method. Six middle rows were selected from each plot, and a representative sample of mature maize cobs was harvested from these rows. The harvested cobs were then transported to the JUCAVM, agronomy laboratory, where they were carefully weighed using a sensitive balance.

***Cob length***

Cob length was measured from a representative sample of maize plants within the plot.  Mature maize cobs were carefully harvested from the selected plants, and the husk was removed to expose the entire cob.  Using a ruler, cob length was measured from the base of the cob, where it attaches to the stalk, to the tip of the cob, where the silks emerge.

***Number of row per cob***

To determine the number of rows per cob, a representative sample of maize cobs was randomly selected from the six middle rows of plants from experimental plots. Each cob was carefully examined, and the number of kernel rows was manually counted. The mean number of rows per cob was then calculated by averaging the counts from all sampled cobs.

***Seed per row***

The number of seeds per row was determined by manually counting seeds on a representative sample of randomly selected cobs and calculating the average.

***Cob diameter***

Cob diameter was meticulously measured; twelve cobs were randomly selected from each plot to ensure a representative sample. A caliper was used to accurately measure the diameter of each cob at its widest point. The measurements from the twelve cobs were then averaged to determine the mean cob diameter for each plot.

***Above ground biomass***

Above-ground biomass was determined from the middle six rows from each plot and harvested at maturity. The harvested plants were then air-dried in direct sunlight for a period exceeding one week to ensure thorough moisture removal. Once dried, the total above-ground biomass of each plant was weighed. These individual plant biomass values were then averaged and extrapolated to a per hectare basis, providing an estimate of biological yield in tons per hectare.

***Thousand grain weight***

Thousand-grain weight was determined using a standardized procedure. Seeds were collected from six middle rows of randomly selected plants. The collected seeds were weighed using a sensitive balance in the agronomy laboratory at JUCAVM. To account for variations in seed moisture content, the measured weight was adjusted to a standard moisture content of 12.5%, a widely accepted standard for cereal crops. This adjustment is crucial because seed moisture content significantly influences thousand-grain weight. The final adjusted weight represents the thousand-grain weight for the given sample.

***Grain yield***

Grain yield was determined from six middle rows of plants from each plot and harvested upon reaching maturity. The harvested plants were then manually threshed to separate the grains from the cobs. The separated grains from each sample were carefully weighed to determine the initial grain weight. To account for variability in moisture content due to drying conditions, the initial grain weight was adjusted to a standard moisture content of 12.5%, a widely accepted standard for cereal crops. This adjustment ensures accurate comparisons across different samples. Finally, the adjusted grain weight was extrapolated to a per hectare basis to represent the overall grain yield.

***Harvest Index***

The harvest index was determined as the ratio of grain yield to above-ground biomass yield multiplied by 100 on a dry weight basis(Singh and Stoskopf, 1971).

$$HI = \frac{\text{Grain yield}}{\text{Biological yield}} * 100 \quad (1)$$

Agronomic efficiency

Agronomic efficiency was calculated by the following formula for nitrogen, phosphorus and potassium

$$AE = \frac{\text{Grain yield of fertilized - Grain yield of unfertlized}}{\text{Totall nutrient applied}} \quad (2)$$

## 3.7. Statistical Analysis

All measured parameters were subjected to analysis of variance (ANOVA). Interpretation was made following the procedure described by (Gomez and Gomez, 1984). The means were separated using least significant difference (LSD) whenever ANOVA showed significant differences. The SAS, 9.3 versions was used for statistical analysis. For each response variable, the validity of model assumptions (normal distribution and constant variance assumptions on the error terms) was verified by normal probability plot of the residuals and plot of the residuals vs. fitted values, respectively (Montgomery and Runger, 2020). Independence assumptions were met through randomization of the treatments within each farm. The treatment effect was declared significant at the 5% level of significance for all response variables. Therefore, multiple means comparison was completed using Fisher's LSD method at 5% level of significance to generate letter groupings(Montgomery and Runger, 2020).

# 4. RESULTS AND DISCUSSION

## 4.1. Effect of nutrients on maize growth

Plant height in maize was significantly affected by nutrient application ($p < 0.0001$), as shown in (Table 3). The tallest plants were observed in plots treated with NPK + Lime (294.575 cm), followed by NPK (291.1 cm) and NP (281.9 cm). In contrast, the shortest plants were found in the control treatment (232.375 cm), followed by PK (259.325 cm) and NK (267.18 cm) (Table 2). The reduction in plant height due to nutrient omission followed a clear trend: control > N omission > P omission > K omission. The increase in plant height observed in nutrient-rich treatments can be attributed to enhanced cell elongation and increased vegetative growth, both of which are stimulated by the optimal application of essential macronutrients. As Atnafu *et al*. (2021) note, plant growth and development are significantly hindered when soil nutrients are insufficient or imbalanced. Our results support this finding, demonstrating that a well-balanced nutrient supply significantly improves maize vegetative growth, particularly plant height, compared to unbalanced treatments. The superior plant height observed with NPK + Lime application is likely due to the synergistic effects of these nutrients. Nitrogen plays a critical role in photosynthesis, a fundamental process for plant growth. Plants with adequate nitrogen exhibit higher rates of photosynthesis, leading to more vigorous growth and development compared to those with limited or no nitrogen. Nitrogen also enhances chlorophyll activity, further contributing to increased plant height.

Phosphorus is essential for shoot and root development, particularly during periods of rapid metabolism and cell division. Potassium plays a crucial role in stomata regulation, substance transport, and water regulation, all of which contribute to efficient photosynthesis and overall plant growth. Lime, while not a direct nutrient source indirectly supports plant height by improving soil conditions for nutrient uptake, root development, and stress tolerance. This finding align with those of Adekayode and Ogunkoya (2010), who also reported significant differences in maize plant height between plots receiving sufficient fertilizer and control plots. The consistent observation of improved plant height with balanced nutrient application underscores the importance of proper nutrient management for maximizing maize growth and yield

#### 4.1.3. Number of leaves

The experimental results demonstrated a highly significant effect of nutrient omission on the number of leaves per plant ($P < 0.001$). The highest leaf count was observed in plots receiving NPK fertilizer (12.26 leaves per plant), while the lowest counts were recorded in the control (8.69 leaves per plant) and N-omitted plots (8.9 leaves per plant). This stark difference highlights the critical role of essential nutrients, particularly nitrogen, phosphorus, and potassium, in leaf development. Interestingly, while the application of NPK + lime resulted in a numerically higher leaf count compared to NPK alone, this difference was not statistically significant. This observation suggests that while lime application, through its positive effects on soil pH, cation exchange capacity, and nutrient availability, may contribute to increased leaf production, its impact might be less pronounced than the direct effect of the primary macronutrients (N, P, and K).

The omission of primary nutrients (control treatment) resulted in a substantial 29% reduction in leaf number compared to the NPK treatment, emphasizing the detrimental consequences of nutrient deficiency on vegetative growth. This reduction was strongly associated with the specific omission of essential nutrients: N omission led to a 26.67% decrease, P omission resulted in a 12.3% decrease, and K omission caused a 6.5% decrease, all compared to the NPK treatment. Lime omission, in contrast, led to a smaller reduction of 2.77% compared to the NPK + Lime treatment. These findings are consistent with those of Onasanya *et al.* (2009), who reported a maximum leaf count of 11.28 at seven weeks after planting with the application of 120 kg N/ha + 20 kg P/ha in southern Nigeria. This agreement further underscores the importance of balanced nutrient application for optimal leaf production in maize, a key determinant of photosynthetic capacity and ultimately, yield potential.

#### 4.1.4. Leaf area

The experimental results clearly demonstrate the significant impact of nutrient omission on leaf area ($P < 0.001$, Table 2). The application of NPK fertilizer resulted in the largest leaf area (0.98

$m^2$), highlighting the importance of these essential nutrients for leaf development. In contrast, the smallest leaf areas were observed in the control (0.53 $m^2$) and PK (0.64 $m^2$) plots, underscoring the detrimental effects of nutrient deficiencies. While the NPK + lime treatment exhibited a numerically higher leaf area than NPK alone, this difference was not statistically significant. This suggests that while lime application can contribute to leaf area expansion by improving soil conditions, its effect might be less pronounced than the direct impact of N, P, and K.

The omission of primary nutrients (control) led to a substantial 45.9% reduction in leaf area compared to the NPK treatment, emphasizing the critical role of balanced fertilization for optimal leaf development. This reduction was directly linked to the specific omission of essential nutrients: N omission resulted in a 34.69% decrease, P omission caused a 10.2% decrease, and K omission led to a 6.12% decrease, all compared to the NPK treatment. Lime omission, on the other hand, resulted in a smaller reduction of 5.76% compared to the NPK + Lime treatment. These findings align with those of Onasanya *et al*. (2009), who reported the largest leaf area (0.096$m^2$) with the application of 120 kg N/ha + 20 kg P/ha in southern Nigeria. This consistency highlights the universal importance of balanced nutrient application for maximizing leaf area in maize, a key determinant of photosynthetic capacity.

### 4.1.5. Leaf area index

The LAI, a critical factor for maximizing maize yield, was also significantly affected by nutrient omission ($P < 0.001$, Table 3). The highest LAI (4.59) was recorded in the NPK + lime treatment, followed closely by NPK (4.34). In contrast, the lowest LAIs were observed in the control (2.35) and nitrogen-omitted (2.83) plots. The omission of nitrogen alone led to a significant 34.79% reduction in LAI compared to the NPK treatment, highlighting the crucial role of nitrogen in leaf development and overall canopy expansion. Phosphorus omission resulted in a 9.91% reduction in LAI compared to the NPK treatment, demonstrating its importance for supporting rapid canopy development and root cell division. The addition of lime to the NPK treatment resulted in a 5.45% increase in LAI, indicating its potential to enhance nutrient availability and create a more favorable soil environment for maize growth.

The considerable reduction in LAI observed in nutrient-deficient treatments underscores the detrimental effects of unbalanced fertilization on maize growth. A lower LAI translates to reduced photosynthetic capacity, ultimately limiting energy production and hindering yield potential. These findings align with those of Kumar *et al*. (2012), who reported significant differences in maize LAI based on fertilizer application, with the highest LAI observed in the NPK treatment. This consistency further emphasizes the importance of optimizing LAI through balanced nutrient application to enhance maize productivity.

**Table 3:** Effect of nutrient omission on plant height (cm), leaf number, leaf area, and leaf area index

| Treatments | Plant height(cm) | Leaf number | Leaf area($m^2$) | Leaf area index |
|---|---|---|---|---|
| Control | 232.38$^{d}$ | 8.63c | 0.53$^{e}$ | 2.35$^{e}$ |
| PK (-N) | 253.33$^{c}$ | 10.53$^{b}$ | 0.64$^{d}$ | 2.83$^{d}$ |
| NK(-P) | 267.18$^{b}$ | 11.19$^{b}$ | 0.88$^{c}$ | 3.91$^{c}$ |
| NP(-K) | 281.90$^{a}$ | 12.24$^{a}$ | 0.92$^{bc}$ | 4.08$^{bc}$ |
| NPK | 291.10$^{a}$ | 12.26a | 0.98$^{ab}$ | 4.34$^{ab}$ |
| NPK+ Lime | 294.58$^{a}$ | 12.60$^{a}$ | 1.04$^{a}$ | 4.59$^{a}$ |
| LSD (0.05) | 12.81 | 0.99 | 0.09 | 0.42 |
| CV (%) | 3.15 | 6.07 | 7.25 | 7.59 |

**Whereas:** Means followed by the same letter/s within a column are not significantly different at $p<0.05$

## 4.2. Effect of Nutrients on maize yield and yield components

### 4.2.1. Row per cob

The experimental results revealed a highly significant effect of nutrient omission on the number of rows per cob ($p < 0.001$). The highest number of rows per cob was observed in plots receiving NPK (13.8 rows) and NPK + Lime (13.9 rows), emphasizing the importance of these nutrients for cob development. Conversely, the lowest number of rows per cob (11.2) was recorded in the control, nitrogen-omitted (11.4), and phosphorus-omitted plots (Table 3).This reduction in rows per cob is directly linked to the omission of essential nutrients. Compared to the NPK treatment, the control, nitrogen-omitted, and phosphorus-omitted plots showed reductions of 19.42%, 17.93%, and 14.33%, respectively. This underscores the importance of balanced fertilization in maximizing cob development, as highlighted by Kogbe and Adediran (2003), who found that maize production, relies heavily on the availability of primary nutrients.

#### 4.2.2. Cob length

Similar to the number of rows per cob, cob length was significantly affected by nutrient omission ($P < 0.001$). The longest cob length (21.6 cm) was observed in the NPK + Lime treatment, statistically equivalent to NPK (21.0 cm) and NP (20.4 cm). Conversely, the shortest cob lengths (14.6 cm and 15.59 cm) were recorded in the control and nitrogen-omitted plots, respectively. This difference in cob length can be attributed to the impact of nutrient availability on photosynthetic activity. The longer cob lengths in nutrient-rich treatments are likely due to increased photosynthetic activities resulting from sufficient nitrogen and phosphorus supply. Conversely, the shorter cob lengths in nutrient-deficient treatments are likely caused by limitations in photosynthesis due to insufficient nitrogen and phosphorus.

These findings align with those of Ahmad *et al*. (2018), who reported a significant improvement in cob length with increased nitrogen and phosphorus application. Nitrogen is essential for cob growth, particularly when the soil is well-nourished with mineral nutrients, as these nutrients directly influence yield. Split applications of nitrogen can ensure a sufficient supply of assimilates during grain filling, leading to increased cob length (Arif *et al.,* 2010). Furthermore, optimal environmental conditions that allow for maximum utilization of solar radiation can lead to greater assimilation production, ultimately resulting in longer cob lengths (Derby *et al*., 2004).

#### . 4.2.3. Grain yield per cob

Nutrient omission also significantly impacted grain yield per cob ($p < 0.001$). The highest grain yield per cob (630.5 g) was observed in the NPK + Lime treatment, statistically equivalent to NPK (599.66 g). The lowest yield (358.98 g) was recorded in the control plot, followed by the nitrogen-omitted plot (390.71 g). The omission of N, P, and K led to reductions in grain yield per cob of 34.84%, 15.62%, and 4.98%, respectively, compared to the NPK treatment. This reduction can be attributed to decreases in the number of grains per row, cob length, and rows per cob caused by the omission of these essential nutrients and the resulting unbalanced fertilization. Chapagain and Gurung (2010) highlighted the importance of balanced fertilizer application for maximizing growth indices, including cob length, leading to higher grain numbers per cob. While there was a numerically higher grain yield per cob in the NPK + lime treatment compared to NPK alone (4.8% difference), this difference was not statistically significant. This suggests that the addition of lime, while potentially beneficial, might not have as pronounced an effect as the primary macronutrients on this particular yield parameter. These results are consistent with those of Weldegebriel *et al.* (2018), who reported the highest grain yields with the application of primary macronutrients (NPK).

#### 4.2.4. Cob diameter

The experimental results demonstrated a highly significant effect of nutrient treatments on cob diameter (P = 0.0063, Table 3). The largest cob diameter (4.9 cm) was observed in the NPK + Lime treatment, statistically equivalent to NPK and NP treatments. The smallest cob diameter (4.18 cm) was recorded in the control plot, followed by the nitrogen-omitted plot (4.25 cm). This enhancement in cob diameter with NPK application can be attributed to increased cell activity, specifically boosted cell multiplication and expansion, leading to more robust growth. This aligns with the findings of Amanolahi-Baharvand *et al.* (2014), who reported that cob diameter, in maize improved with increasing rates of inorganic fertilizers. In conclusion, these findings highlight the critical role of balanced nutrient application in optimizing maize cob characteristics. Ensuring adequate levels of N, P, and K is essential for maximizing cob development, ultimately leading to improved grain yield and overall productivity.

**Table 4: Effect of nutrients on the number of rows and grains, cob length, and cob diameter of maize and grain yield per cob**

| Treatments | $NCP^{-1}$ | CL(cm) | CD (cm) | $RC^{-1}$ | $CWP^{-1}$(kg) | $GYcob^{-1}$ |
|---|---|---|---|---|---|---|
| Control | $1.0^{c}$ | $14.6^{c}$ | $4.2^{b}$ | $11.2^{b}$ | $0.95^{c}$ | $358.98^{d}$ |
| PK (-N) | $1.0^{c}$ | $15.6^{c}$ | $4.3^{b}$ | $11.4^{b}$ | $1.14^{c}$ | $390.71^{d}$ |
| NK (-P) | $1.1b^{c}$ | $17.8^{b}$ | $4.6^{ab}$ | $11.9^{b}$ | $1.56^{b}$ | $506.00^{c}$ |
| NP (-K) | $1.2^{b}$ | $20.4^{a}$ | $4.7^{a}$ | $13.2^{a}$ | $1.6^{b}$ | $569.80^{b}$ |
| NPK | $1.3^{a}$ | $21.0^{a}$ | $4.8^{a}$ | $13.89^{a}$ | $1.69^{ab}$ | $599.66^{ab}$ |
| NPK+ lime | $1.4^{a}$ | $21.6^{a}$ | $4.9^{a}$ | $13.9^{a}$ | $1.86^{a}$ | $630.50^{a}$ |
| LSD(0.05 | 0.17 | 1.25 | 0.38 | 0.77 | 0.19 | 46.63 |
| CV (%) | 9.59 | 4.47 | 5.55 | 4.08 | 8.81 | 6.08 |

**Whereas:** Means followed by the same letter/s within a column are not significantly different at P<0.05; NCP=number of cobs/plant, CL= Cob length, CD=Cob diameter, CWP= Cob weight /plot, GYC-1=grain yield per cob.

#### 4.2.5. Grain yield

The result revealed that highly significant effect of nutrient treatments on maize yield ($p < 0.0001$, Table 5). Grain yield varied significantly across all nutrient combinations. The highest maize grain yield (10.89 ton/ha) was obtained from the NPK + lime treatment, followed by NPK (9.70 ton/ha) and NP (9.58 ton/ha), respectively. In contrast, the lowest maize grain yield was obtained from the control plots (2.68 ton/ha) and the PK treatment (3.94 ton/ha), where nitrogen was omitted. These findings corroborate the observations of Riar and Coventry (2012), who found that maize grain yield, was positively and significantly correlated with yield components. This indicates that nitrogen was the most limiting nutrient for grain yield in this study. This result aligns with the findings of Balemi *et al.* (2019), who also recorded the highest maize grain yield with NPK treatments compared to other treatments in both Bako Tibe and four districts of Jimma Zones.

Treatments such as PK, NK, and NP, which lacked at least one primary macronutrient (nitrogen, phosphorus, or potassium), induced specific nutrient deficiency stress, hindering the overall growth of maize and consequently limiting yield. The results indicated a substantial yield reduction of 5.76 ton/ha (59.38%) due to nitrogen omission and a reduction of 3.93 ton/ha (40.52%) due to phosphorus omission, both compared to the NPK treatment. However, no significant yield reduction was observed due to potassium omission. This suggests that the soil likely contained sufficient potassium levels to meet the crop's demands. The yield difference among nutrient omission trials is summarized in (Table 5). The yield increase attributed to potassium fertilization was non-significant compared to the yield reductions caused by nitrogen and phosphorus omission, likely due to optimum soil potassium levels already sufficient for crop requirements.

The NPK + lime treatment resulted in a significant yield increase of 1.19 ton/ha (10.93%) compared to the NPK treatment. This can be attributed to the beneficial effects of lime application. Lime improves nutrient availability, making essential elements like phosphorus, potassium, calcium, and magnesium more accessible to plants. These nutrients are crucial for various growth processes, from photosynthesis to grain development. Moreover, lime neutralizes soil acidity, raising the pH to optimal levels and increasing cation exchange capacity. The application of lime and mineral phosphorus fertilizer has been shown to enhance phosphorus availability and reduce exchangeable acidity and aluminum levels (Opala, 2017). This study's results clearly demonstrate the importance of supplementing NPK fertilization with lime to increase maize yield.

The positive influence of calcium carbonate on maize grain yield in Omo Nadda is evident. The highest economic yields in the NPK+ lime and NPK applied plots can be attributed to maximized plant height (294.58 cm), leaf area index (4.59), and harvest index (47.68), respectively. These parameters collectively contribute to a more robust and productive crop, ultimately resulting in higher yields. In conclusion, this study underscores the importance of balanced nutrient application, particularly nitrogen, phosphorus, and potassium, in achieving optimal maize grain yield. Furthermore, it highlights the significant benefits of incorporating lime into the fertilization strategy to further enhance nutrient availability and maximize yield potential in study area.

**Table 5: Yield reduction difference among nutrient omission trial compared with NPK and NPK+ lime**

| Treatments | Yield difference compared to NPK (%) | Yield difference compared to NPK+ Lime (%) |
|---|---|---|
| Control | 72.37 | 75.39 |
| PK | 59.38 | 60.61 |
| NK | 40.52 | 47.02 |
| NP | 1.24 | 1.19 |
| NPK | - | 10.93 |
| NPK+ Lime | - | - |

### 4.2.6. Thousand grain weight

The experimental results revealed that nutrients trials showed that there was a significant effect of nutrient treatments on the thousand grain weight of maize (table -4). The highest reductions of thousand grain weights were obtained from the control plot, nitrogen omission and phosphorus omission, respectively. The highest thousand grain weight was obtained from NPK+ lime (248.73g) and NPK (240.35g) treatments. This is might be due to higher nitrogen availability promotes protein synthesis in the grain, contributing to a larger grain size and weight and application of lime, by increasing the pH and cation exchange capacity , lime makes essential nutrients like phosphorus, potassium, calcium, and magnesium more available for plant uptake. This enhanced nutrient absorption supports robust plant growth, including grain development. While the lowest thousand grain weight was obtained from control plots (169.85g) and N omitted plots (190.25g), respectively, this might be due to omission of essential nutrients from the treatments. This results agreement with the findings ofOnasanya *et al.,* (2009) who reported that the highest(265.67g) grain yield was obtained from the 120kgN/ha + 40kgP/ha) treatments and the lowest(220.93) one was recorded from the control plots in Southern Nigeria.

**Table 6: Effect of nutrients on total biomass, thousand grain weight, grain yield**

| Treatments | BM ton/ha | TGW(g) | GY ton/ ha |
|---|---|---|---|
| Control | 4.94[c] | 169.85[e] | 2.68[e] |
| PK | 6.34[bc] | 190.25[d] | 3.94[d] |
| NK (-P) | 7.65[b] | 208.96[c] | 5.77[c] |
| NP (-K) | 11.29[a] | 228.35[b] | 9.58[b] |
| NPK | 11.41[a] | 240.35[ab] | 9.70[b] |
| NPK+ lime | 12.43[a] | 248.73[a] | 10.89[a] |
| LSD=0.05 | 1.42 | 17.58 | 0.79 |
| CV (%) | 10.49 | 5.44 | 7.35 |

**Where:** Means followed by the same letter/s within a column are not significantly different at P<0.05; BM=total aboveground biomass, TGW=Thousand grain weight, GY= Grain yield per hectare

### 4.2.7. Biomass

Biomass was also significantly affected by the nutrient trial treatments ($P$<0.0001). The greatest biomass reduction was observed in the control (7.03 ton/ha), nitrogen omitted (4.9 ton/ha), and phosphorus omission (3.61 ton/ha) plots, respectively, when compared with the application of NPK treatments. These results indicate that nitrogen and phosphorus omission significantly limited biomass yield of the tested crop, while the omission of potassium did not have a significant effect on biomass yields compared to nitrogen and phosphorus. This may be due to the presence of optimum potassium levels in the soil of the study area. However, the biomass yield from the control plots and nitrogen omitted treatments was significantly reduced compared with any of the other treatments (Table 5). This may be because nitrogen is a key component of chlorophyll, the pigment essential for photosynthesis. Without sufficient nitrogen, chlorophyll production is limited, which reduces the plant's ability to convert sunlight into energy for growth, resulting in stunted plants with lower overall biomass**.** There was no significant difference in biomass yield between the NPK+ lime and NPK treatments in this study. These results disagree with those of Atnafu *et al.* (2021), who reported that biomass yield is strongly related to potassium application and was significantly reduced (by 21.5%) in the absence of potassium compared to NPK.

### 4.2.8. Harvest index

The impact of nutrient trial treatments on the harvest index of maize was found to be statistically significant (P=0.0398), as shown in Table 5. The application of NPK+ lime resulted in the maximum harvest index of 46.61%, which was comparable to the values obtained from NP (46.31%) and NPK (45.93%) treatments. This suggests that the combined application of nitrogen, phosphorus, and lime positively influenced the harvest index of maize. Although lime does not directly affect the harvest index, it plays an indirect role by enhancing nutrient availability and root health, ultimately contributing to improved plant growth and development.

Conversely, the unfertilized plots and nitrogen-omitted treatment plots exhibited the minimum harvest index of 35.28% and 38.55%, respectively. These results align with the reported range of harvest index (40 to 60%) for maize by Hay (1995). It underscores the importance of providing optimal macronutrients to promote the efficient allocation of dry matter between grain and other parts of the maize plant, ultimately impacting biomass and economic yield. The findings are consistent with Atnafu *et al*. (2021), who observed that the application of NPK + CaMgSZnB resulted in a maximum harvest index of 47.36%, while unfertilized and N-omitted plots on similar soil types recorded minimum harvest indices of 33% and 34%, respectively. This highlights the crucial role of balanced nutrient management in maximizing the harvest index of maize, leading to enhanced crop productivity and economic yield. Overall, these results emphasize the significance of optimizing nutrient applications to promote efficient biomass production and grain yield in maize, ultimately contributing to a higher harvest index.

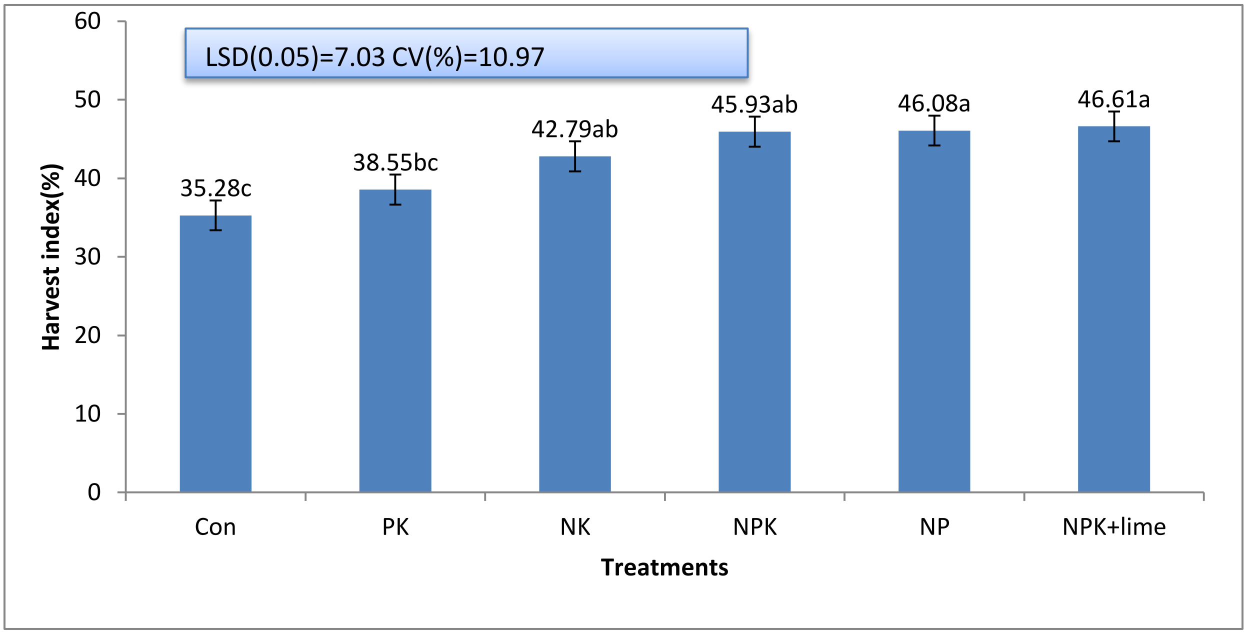


**Figure 3: Effect of omitting different nutrients on maize harvest Index**

## 4.3 Pearson Correlations among Yield and Yield Components of Maize

All the independent parameters showed a considerable positive and linear relationship with grain yield (Table -5). The correlation analyses showed that, there was a highly significant ($P < 0.0001$) positive correlation between grain yield and yield related agronomic parameters of maize. Grain yield was highly significant and positively correlated with biomass yield(r= 0.907***), leaf area index(r=0.882**) and harvest index(r=0.706***). Biomass yield was significant and positively correlated with harvest index(r=0.402**), highly significant association with Plant height(r=0.731***) and highly significant and positive association with the leaf area index(r=0.849***). This showed that, increasing grain yield and biomass yield can increase yield components of maize and reciprocal. This results is agree with the findings of (Katsura *et al*., 2008, Solomon *et al*., 2015). All this suggests that enhancing above-ground plant biomass while maintaining a high yield harvest index could have significant benefits in further increasing maize grain yield. The same results were observed by Riar and Coventry, (2012) that grain yield of maize was positively and considerably correlated with yield components

**Table 7:** Correlation among growth parameters, yield, and yield components of maize in the Omo Nadda District

| Variables | GY | BM | HI | PH | LAI |
|---|---|---|---|---|---|
| GY | 1 | 0.907*** | 0.706*** | 0.759*** | 0.882** |
| BM | | 1.00 | 0.402** | 0.731*** | 0.849*** |
| HI | | | 1.00 | 0.594** | 0.646** |
| PH | | | | 1.00 | .668** |
| LAI | | | | | 1.00 |

**Whereas:** GY= Grain Yield; BM= Biomass; HI= Harvest Index; PH= Plant Height and LAI= Leaf Area Index.

## 4.4. Agronomic Efficiency of NPK Nutrients

The agronomic efficiency of the nutrients was significantly affected by the nutrient omission trials (Table 7). The experiment results indicated that the maximum agronomic efficiencies of all nitrogen, Phosphorus and potassium were obtained for the NPK+ lime treatment followed by the NPK treatments.

**Table 8:** Agronomic efficiency of nitrogen, Phosphorus and potassium as influenced by nutrients omission

| Treatments | Agronomic efficiency (kg grain kg-1nutrient applied) | | |
|---|---|---|---|
| | **AgE N** | **AgE P** | **AgE K** |
| **Control** | - | - | - |
| **PK** | - | 27.28$^{c}$ | 25.1$^{d}$ |
| **NK(-P)** | 25.71$^{c}$ | - | 61$^{c}$ |
| **NP(-K)** | 57.56$^{b}$ | 150.16$^{b}$ | - |
| **NPK** | 58.52$^{b}$ | 152.66$^{b}$ | 140.45$^{b}$ |
| **NPK+L** | 68.39$^{a}$ | 178.42$^{a}$ | 164.15$^{a}$ |
| LSD=0.05 | 7.04 | 17.76 | 14.36 |
| **CV (%)** | 13.34 | 13.90 | 14.61 |

**Where:** Means followed by the same letter/s within a column are not significantly different at P<0.05; AgE N= agronomic efficiency of nitrogen, AgE P= agronomic efficiency of phosphorus, AgE K= agronomic efficiency of potassium

The impact of N, P, and K on agronomic efficiency was found to be significant (*p*<0.0001) in nutrient trials (Table-7). The agronomic efficiency of nitrogen varied from 25.71 (for NK treatment) to an impressive 68.39 kg of grain per kg of applied N (for NPK+ lime treatment). The highest AEN was achieved through the application of NPK+ lime treatment, highlighting its effectiveness in enhancing crop yield. Conversely, the lowest AEN was observed with the NK treatment, underscoring the importance of balanced nutrient application. Research by Xu *et al.* (2014) indicated that cereals could achieve an AEN exceeding 30 kg/kg with proper agronomic management practices in developing countries, emphasizing the potential for optimizing nutrient utilization. The agronomic efficiency of phosphorus ranged from 27.28 (for PK treatment) to a remarkable 178.42 (for NPK + lime treatment) kg of grain per kg of applied P, showcasing the substantial impact of phosphorus supplementation on crop productivity.

In contrast, omitting nitrogen fertilizers (as in the PK treatment) significantly reduced phosphorus use efficiency by approximately 82.13% compared to the NPK treatment, highlighting the synergistic relationship between different nutrients in enhancing agronomic performance. Similarly, the agronomic efficiency of potassium varied from 25.1 (for PK treatment) to 164.15 (for NPK + lime treatment) kg of grain per kg of applied K, with the highest AEK observed in plots treated with NPK+ lime. Notably, the omission of nitrogen in the PK treatment led to an 82.12% reduction in potassium use efficiency compared to the NPK treatment, underscoring the interconnected nature of nutrient interactions in agricultural systems. These findings underscore the pivotal role of nitrogen in optimizing the agronomic efficiency of potassium, emphasizing the importance of balanced nutrient management practices.

Obreza and Rhoads (1988) highlighted the significance of achieving maximum agronomic efficiency of N, P, and K at lower rates, emphasizing the importance of precision nutrient application for optimal crop performance. Furthermore, the omission of phosphorus fertilizers (as in the NK treatment) resulted in a substantial decrease in nitrogen use efficiency by approximately 56.07% compared to the NPK treatment, underscoring the critical role of phosphorus in enhancing nitrogen utilization efficiency. In conclusion, these results suggest that minimal yield response to individual nutrients may indicate higher soil nutrient availability or fertility, resulting in lower agronomic efficiency. Conversely, a robust yield response signifies lower soil nutrient levels and higher agronomic efficiency, highlighting the complex interplay between soil fertility, nutrient management, and crop productivity.

## 4. 5 Economic Analysis

To estimate the economic significance of N, P and K fertilizer treatments, partial budget analysis (CIMMYT, 1988) was employed to calculate the marginal rate of return (MRR) on maize production. Economic analysis was done on N, P and K for nutrient omission trial treatments. Before economic analysis, the total grain yield of maize was adjusted down by 10% to minimize the effect of researcher managed small plots that may differ from the yield level on farmers' field. The farm gate price of 38.24 ETB per 1 kg of maize was used and this was the actual average price of maize during the year 2016 E.C. harvesting season at Omo Nadda market. The price of 100kg fertilizer during the current season was 3583 ETB for Urea, 3317 ETB for NPS and 2700ETB for potassium chloride and hence for this particular study, the above listed prices of fertilizers were used for the economic analysis. Urea, TSP (Triple Super Phosphate) and KCl were used as source of N, P and K, respectively. Since TSP fertilizer is not available in local markets, the price of NPS was considered as a base for the price of TSP for economic analysis in this particular study and the price information about KCl fertilizer was obtained from National Fertilizers Industry Agency. Costs of agronomic practice and harvesting were assumed to be 200 ETB per day. These prices were directly used in the partial budget analysis. The average market price (38.24 birr/kg) as per local market price survey in the 2016E.C. production season was used for the analysis. The marginal rate of return (MRR %) is used as basis for fertilizer recommendation. Treatments with lower net benefit than treatments of lower cost are dominated, and are not included in the partial budget analysis.

**Table 9:** Partial budget analysis of N-P-K fertilizer omission trial of maize using the price at Omo Nadda town by the year of 2016

| Trt | TYR t/ha | ATF t/ha | TS | LPC | SC | FC | WC | HC | TCP | NB | MRR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Con | 2.68 | 2.4 | 91776 | 5000 | 4800 | - | 8000 | 10000 | 27800 | 63976 | - |
| PK | 3.94 | 3.55 | 135752 | 5000 | 4800 | 6713 | 8000 | 10000 | 34513 | 101,238 | 555 |
| NK | 5.77 | 5.12 | 198656 | 5000 | 4800 | 7000 | 8000 | 10000 | 34800 | 163856 | 21861 |
| NP | 9.58 | 8.62 | 329628.8 | 5000 | 4800 | 8313 | 8000 | 10000 | 36113 | 293515 | 9874 |
| NPK | 9.7 | 8.73 | 333835.2 | 5000 | 4800 | 11,013 | 8000 | 10000 | 38813 | 295022 | 55.8 |
| NPKL | 10.89 | 9.8 | 374,752 | 5000 | 4800 | 23013 | 8000 | 10000 | 50813 | 323939 | 241 |

**Whereas:** TYR= total yield at researcher field, ATF= Attainable yield at Farmer filed, TS=total sell, LPC= cost of land preparation, SC=seed cost, FC= fertilizer cost, WC= weeding cost, HC= harvest cost, TCP= total cost of production, NB= net benefit, MRR= marginal rate of return

The economic analysis of this study revealed that the economic optimum level of maize grain yield was obtained with application of NPK+ lime with the highest net benefit of 323939 ETB per hectare (Table 9). High net return from the fore going treatments could be attributed to high yield and the low net return was attributed to low yield. From the economic point of view, it was apparent that NPK + lime, NPK and NP are more profitable than the rest of treatment combinations; whereas, it was lowest with omission NPK nutrients (63976ETB).

# 5. SUMMARYAND CONCLUSIONS

The study conducted in Nitisols of Doyyo Yayya and Biso Gombo Kebeles, Omo Nadda district in South-western Ethiopia during the main cropping season of 2023 reveals the crucial role of nitrogen and phosphorus nutrients in enhancing maize growth and yield. The application of NPK in combination with lime resulted in the highest mean grain yield of 10.89 tons/ha and biomass yield of 12.43 tons/ha for maize, showcasing the significant impact of balanced nutrient management on crop productivity. Furthermore, the study highlights that nitrogen deficiency was the main limiting factor for maize production in the study area, with omission of nitrogen leading to a substantial reduction in grain yield.

In contrast, the reduction in grain yield due to potassium fertilizer was found to be non-significant compared to nitrogen and phosphorus fertilizers. Importantly, the results demonstrate strong correlations between grain yield, biomass yield, leaf area index, and harvest index, underscoring the interconnectedness of these factors in maize production. Additionally, the application of lime was shown to significantly enhance growth, yield, and yield components of maize.

Notably, the highest agronomic efficiency of nitrogen and phosphorus was achieved with the application of NPK combined with lime, emphasizing the importance of balanced nutrient management for maximizing crop yield. Conversely, lower agronomic efficiency values were observed with other nutrient combinations, highlighting the need for strategic nutrient applications to optimize maize production. In conclusion, this study underscores the critical role of nitrogen, phosphorus and lime in promoting maize growth and yield in Omo Nadda, providing valuable insights for sustainable agricultural practices and improved maize productivity in the region Based on the results from study, it is evident that the soil in the study area has sufficient potassium levels, eliminating the need for potassium fertilizer application. The primary limiting factors for maize productions were identified as low nitrogen supply, followed by phosphorus deficiency and high soil acidity, all of which negatively impacted maize yields. Therefore, the best recommendation based on this result is to focus on the application of a balanced rate of nitrogen and phosphorus, along with lime (calcium carbonate) to address the soil acidity issue and enhance maize productivity. Given that potassium levels in the soil are already optimal, there is no need for additional potassium fertilizer application.It is crucial for farmers in the study area to adopt a nutrient management strategy that includes a balanced NP (nitrogen and phosphorus) + Lime approach to improve maize productivity. By addressing the soil acidity and providing the necessary nutrients, farmers can overcome the yield limitations caused by nutrient deficiencies and acidic soil conditions. Furthermore, we recommend conducting further studies on nutrient omission trials across multiple seasons and various farmers' fields to gain a deeper understanding of nutrient requirements and optimize crop production practices in the study area. This will help in developing tailored nutrient management strategies for sustainable maize production and increased yields in the region.

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# 7. APPENDICES

**App Table 1:** Average of the 2022 and 2023 years meteorological data of Omo Nada district

| Months | Maximum Daily Temperature (°C) | Minimum Daily Temperature (°C) | Mean Daily Temperature (°C) | Average Monthly Rain Fall (mm) |
|---|---|---|---|---|
| January | 31.2 | 13.4 | 22.3 | 10.4 |
| February | 28.0 | 13.4 | 20.7 | 31.7 |
| March | 28.0 | 13.8 | 20.9 | 60.3 |
| April | 28.1 | 13.5 | 20.8 | 129.2 |
| May | 28.1 | 13.4 | 20.7 | 65.1 |
| June | 27.8 | 13.0 | 20.4 | 139.1 |
| July | 27.6 | 13.2 | 20.4 | 307.9 |
| August | 26.5 | 12.6 | 19.5 | 301.7 |
| September | 26.7 | 13.0 | 19.8 | 184.8 |
| October | 26.8 | 12.9 | 19.8 | 87.5 |
| November | 27.2 | 13.2 | 20.2 | 40.6 |
| December | 27.9 | 14.2 | 21.0 | 13.5 |
| Average | 27.8 | 13.3 | 20.6 | 114.3 |

Source: Jimma Meteorological Office (JMO, 2022)

**App Table 2:** ANOVA for mean square values of Plant height, Leaf numbers, Leaf area and leaf area index of maize affected by nutrient omission trails on Nitisol of Omo Nada in 2023 cropping season.

| | | Mean square | | | |
|---|---|---|---|---|---|
| Source of variation | DF | PH | LN | LA | LAI (%) |
| Treatment | 5 | 2313.89182*** | 6.94070417*** | 0.16245417** | 3.17077667** |
| Replications | 3 | 4077.92374*** | 5.17125972** | 0.00133750$^{ns}$ | 0.02916111$^{ns}$ |
| Error | 15 | 72.23874 | 0.43857639 | 0.00362750 | 0.07821444 |

Where: ns = non-significant, *** highly significant, **and * were significant at 0.1%, 0.001% and 0.05% level of significance respectively and D.F = degree of freedom, PH=Plant height, LN=Leaf number, LA=Leaf area and LAI= Leaf area index.

**App Table 3:** ANOVA for mean square values of number of cob per plant, Cob length, Cob diameter, Row per cob, Cob weight per plot and grain yield per cob of maize affected by nutrient omission trails on Nitisol of Omo Nada in 2023 cropping season

| | | Mean square | | | | | |
|---|---|---|---|---|---|---|---|
| Source of variation | DF | $NCP^{-1}$ | CL(cm) | CD(cm) | $RC^{-1}$ | $CWP^{-1}$ | $GYC^{-1}$ |
| Treatment | 5 | 0.09** | 34.96*** | 0.32** | 5.89*** | 0.48*** | 50549.11*** |
| Replications | 3 | $0.001^{ns}$ | 5.85** | 0.23** | $0.79^{ns}$ | 0.25*** | 7040.34** |
| Error | 15 | 0.01 | 0.68 | 0.06 | 0.26 | 0.02 | 957.39 |

**Where:** ns = non-significant, *** highly significant, **and * were significant at 0.1%, 0.001% and0.05% level of significance respectively and D.F = degree of freedom, $NCP^{-1}$=Number of cob per plant, CL (cm) = Cob length, CD (cm) = Cob diameter, $RC^{-1}$= Row per cob, $CWP^{-1}$, cob weight per plot and $GYC^{-1}$ =Grain yield per cob

**App Table 4:** ANOVA for mean square values of Total biomass, thousand seed weight, grain yield per hectare and harvest index of maize affected by nutrient omission trails on Nitisol of Omo Nada in 2023 cropping season.

| | | Mean square | | | |
|---|---|---|---|---|---|
| Source of variation | DF | BM ton $ha^{-1}$ | TGW(g) | GY ton $ha^{-1}$ | HI (%) |
| Treatment | 5 | 38.42*** | 3715.21*** | 43.56*** | 82.51** |
| Replications | 3 | $1.79^{ns}$ | $331.85^{ns}$ | 3.34*** | $27.29^{ns}$ |
| Error | 15 | 2.32 | 136.01 | 0.18 | 26.46 |

Where: ns = non-significant, *** highly significant, **and * were significant at 0.1%, <0.0001% and 0.05% level of significance respectively and D.F = degree of freedom, BM t $ha^{-1}$totally biomass per hectare in ton, TGW (g) =Thousand grain weight in gram =GY ton $ha^{-1}$=Grain yield per hectare in ton and HI (%) =Harvest index in percentage


**App Figure 1:** A few picture taken from study area, Omo Nadda district, Jimma Zone