GROWTH, YIELD AND QUALITY OF GARLIC (*Allium sativum* L.) TO BLENDED NPS AND ZINC FERTILIZER RATES AT DEBRE BERHAN, CENTRAL HIGHLAND OF ETHIOPIA

MSc. THESIS

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GROWTH, YIELD AND QUALITY OF GARLIC (*Allium sativum* L.) TO BLENDED NPS AND ZINC FERTILIZER RATES AT DEBRE BERHAN, CENTRAL HIGHLAND OF ETHIOPIA

A Thesis Submitted to the Department of Horticulture

College of Agriculture and Natural Resource Sciences, College of Graduate Studies, Debre Berhan University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Horticulture

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Debre Berhan, Ethiopia

COLLEGE OF GRADUATE STUDIES

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DEBRE BERHAN UNIVERSITY

APPROVAL SHEET – I

This is to certify that the thesis entitled: **Growth, Yield and Quality of Garlic (*Allium sativum* L.) to Blended NPS and Zinc Fertilizer Rates at Debre Berhan, Central Highland of Ethiopia** submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in Horticulture of the Graduate Program in the department of horticulture, College of Agriculture and Natural Resource Sciences, Debre Berhan University and is a record of original research carried out by Abrham Kefelew, DBU1400516, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it to be accepted as fulfilling the thesis requirements.

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APPROVAL SHEET – II

We, the undersigned members of the board of the examiners of the final open defense by Abrham Kefelew have read and evaluated his thesis entitled: **Growth, Yield and Quality of Garlic (*Allium sativum* L.) to Blended NPS and Zinc Fertilizer Rates at Debre Berhan, Central Highland of Ethiopia**, and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Horticulture.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the Council of Graduate Studies (CGS) through the department graduate committee (DGC) of the candidate's major department.

DEDICATION

It is my great pleasure to dedicate this thesis to my beloved mother, Mrs. Abebech Yeshitla, who always support me and is eager to see my success. May God give her a long life!

STATEMENT OF THE AUTHOR

I, Abrham Kefelew, declare that, this thesis is my genuine work, and that all sources of materials used for this thesis have been profoundly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for Master of Science (MSc) at Debre Berhan University and it is deposited at the University library to be made available for users under the rule of the library. I intensely declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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BIOGRAPHICAL SKETCH

The author, Mr. Abrham Kefelew Gorefe was born on September 1, 1995, at Emegua Kebele, Menz Mama Midr Woreda, North Shewa Zone, Amhara National Regional State, Ethiopia. He attended his elementary, secondary and preparatory educations at Molale Primary, Molale Secondary (Abeto Negasi Kirstos Werede Kal) and Molale Higher Preparatory (Dej Azmach Kefelew Preparatory) Schools from 2003 to 2010, 2011 to 2012 and 2013 to 2014, respectively. He joined University of Gondar in 2015 and graduated with a BSc degree in Horticulture in July 2017. Following his graduation, in November 2017, he was employed by Debre Berhan University as Senior Technical Assistant where he served up to now.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
ATA	Agricultural Transformation Agency
CEC	Cation exchange capacity
CIMMYT	International Maize and Wheat Improvement Center
CSA	Central Statistical Agency
DBARC	Debre Berhan Agricultural Research Center
DMRT	Duncan’s Multiple Range Test
DZARC	Debre Zeit Agricultural Research Center
EARO	Ethiopian Agricultural Research Organization
EC	Electrical conductivity
EHPEA	Ethiopia Horticulture Producers and Exporters Association
EIA	Ethiopian Investment Agency
EIAR	Ethiopian Institute of Agricultural Research
ETB	Ethiopian's Birr
EthioSIS	Ethiopian Soil Information System
FAO	Food and agricultural organization
FAOSTAT	Food and Agriculture Organization Statistics
M. a. s. l	Meter above sea level
NPS	Nitrogen, Phosphorus and Sulfur
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
TSS	Total Soluble Solid

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GROWTH, YIELD AND QUALITY OF GARLIC (*Allium sativum* L.) TO BLENDED NPS AND ZINC FERTILIZER RATES AT DEBRE BERHAN, CENTRAL HIGHLAND OF ETHIOPIA

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ABSTRACT

Garlic (Allium sativum L.) is the second most important and widely grown Allium crop in many regions of Ethiopia. However, the average bulb yield is low compared to the crop's potential yield due to several factors including lack of improved varieties, the occurrence of diseases and insect pests, lack of improved post-harvest technologies, poor agronomic and cultural practices and inappropriate use of fertilizer rates. Among these, inappropriate applications of macro- and micronutrient fertilizers are the major agronomic practices that tremendously reduce the yield of the crop. Using proper types and rates of fertilizer is one of the measures to increase the crop productivity in the region. Hence, a field experiment was conducted to evaluate the effects of blended NPS and zinc fertilizer rates on the growth, yield, and quality of garlic during irrigation time of 2022/23. The treatments consisted of factorial combinations of four rates of NPS fertilizer (0, 121, 242 and 363 kg ha^{-1}) and four levels of Zn (0, 0.3, 0.6 and 0.9%). The experiment was laid down in a randomized complete block design with three replications using the garlic cultivar 'Qundi'. Data on different phenological, growth, bulb yield and quality-related variables were collected and analyzed using R- software. The analysis of variance showed that most of the studied parameters were significantly affected by the interaction of the two factors. Accordingly, the study revealed that the combined application rates of 242 kg ha^{-1} NPS and 0.6% zinc resulted in the widest neck diameter (1.52cm), longest bulb length (4.98cm), widest bulb diameter (4.44 cm), longest clove length (2.61 cm), widest clove diameter (1.59cm), highest average bulb weight (44.63g), highest average clove weight (5.93 g), highest total bulb yield (14.89g), highest harvest index (87.41%), and highest percent dry matter content (43.18%). The average bulb weight, percent dry matter content and total bulb yield due to 242 kg ha^{-1} of NPS and 0.6% of zinc fertilizer application was increased by15.17, 24.12 and 39.94%, respectively, as compared to 242 kg ha^{-1} NPS without zinc application. In addition, the highest net benefit (Birr 1,606,330 ha^{-1}) with an acceptable marginal rate of return (116.61%) was recorded from 242 kg ha^{-1} of NPS with 0.6% Zn rate application as *compared to the other treatments. Thus, it can be concluded that the combined application of NPS at a rate of 242 kg ha^{-1} and Zn at 0.6% rate could be recommended to enhance total bulb yield and quality of garlic in the study area and other similar agro-ecologies.*

Keywords: Garlic, Bulb, Clove, Blended fertilizer, Nutrient

1. INTRODUCTION

Garlic (*Allium sativum* L.) belongs to the family Alliaceae which is the second most widely grown bulb crops next to onion (Rubatzky and Yamaguchi, 1997; Hore *et al*., 2014). Garlic crop originated in Central Asia (India, Afghanistan, West China and Russia) and it spreads to other parts of the world through trade and colonization (Panthee *et al.,* 2006; Muneer *et al*., 2016). It has been known as a cultivated spice and medicinal plant for over 5000 years. Garlic has higher nutritional (Mishra and Vikram, 2017) and medicinal (Salomon, 2002) values than other bulbs. It is widely used as anti-inflammatory activity, an antioxidant and anti-infective properties of many human diseases (Lawrence and Lawrence, 2011; Elosta *et al*., 2017).

In recent years, the economic importance of garlic has increased considerably in the entire world including Ethiopia. It is a big demanded crop both locally and internationally and also the most paramount economic crop for low-income smallholder farmers (Getachew and Asefa, 2021). The total world production of garlic was 29,149437.66 tons, from 1662384 hectares of land with an average productivity of 17.53 t ha^{-1} (FAOSTAT, 2022). Among the top ten garlic producers, China is the largest producer accounting for nearly 73.39% of world production (21391340.27 tons) (FAOSTAT, 2022). Following China, other major producing countries were India, Bangladesh, South Korea, Egypt, Spain, Uzbekistan, Ukraine, Myanmar and Russia, respectively. In Africa, the total production of garlic is 948338.32 tons from 73390 hectares of land with average productivity of 12.92 t ha^{-1} (FAOSTAT, 2022). Ethiopia has ranked number 15 in the world ranking (FAOSTAT, 2022). In Ethiopia, the total production of garlic is 218806.97 tons from 29131 hectares of land with average productivity of 7.51 t ha^{-1} (FAOSTAT, 2022). Amhara National Regional State is also one of the potential areas for the production of garlic with a total production of 70220.72 tons from 11206.59 hectares of land and with average productivity of 6.27 t ha^{-1} (CSA, 2022). However, the average productivity of garlic in the country in general is below the potential. This low yield is due to the declining of soil fertility (Belay, 2015), the use of low-yielding varieties (Jafar, *et al*., 2021), insufficient and inefficient use of fertilizers (Workat *et al*., 2018), inappropriate clove size (Bizuayehu *et al*., 2021), poor agronomic and cultural practices (Shege *et al.,* 2021), occurrence of disease (Abraham *et al*., 2019) and lack of improved post-harvest technologies (Bizuayehu *et al*., 2021).

Among these, inadequate and unbalanced uses of fertilizer are the major constraints that limit its production.

Fertilizers offer the best means of increasing yield and quality and also maintaining soil fertility. The application of NPS fertilizer plays a significant role in improving the productivity of vegetables including garlic. Increasing NPS fertilizer application rates significantly enhanced growth, yield and marketable bulb proportions as well as bulb quality of garlic (Shege *et al*., 2017; Abera, 2020). The improvement in vegetative growth of garlic plant due to NPS fertilizer application also has direct relation with improvement of bulb weight which consequently increased bulb yield by their pivotal roles on the enhancement of physiological activity (Shege *et al*. 2021; Bewket, 2021).

In addition to N, P and S, the importance of micronutrients in agriculture is truly well recognized and their uses have significantly contributed to the increased productivity of several crops (Tirpathi *et al.*, 2015). Although their requirement is only in traces, they are essentially as important as macronutrients (Yadav *et al*., 2018), which play an active role in the plant metabolic process starting from cell wall development to respiration, photosynthesis, chlorophyll formation, enzyme activity and nitrogen fixation (Ballabh *et al*., 2013). Micronutrients play an essential role to have better growth, yield and improved quality of many crops (Alam *et al.*, 2010; Ballabh and Rana, 2012; Yadav *et al.*, 2018). They help for enhanced enzymatic and photosynthetic activity and greater translocation rate which consequently resulted in an increased growth and bulb yield of garlic (Yousuf *et al*., 2016). Among these, zinc is an effective micronutrient for the synthesis of plant hormones like auxin and carbohydrate formation (Alloway, 2008; Pankaj *et al*., 2018). It also plays a vital role in sulfur and nitrogen metabolism (Pandev *et al*., 2016). Foliar application of micronutrients during active crop growth stage was successfully used for correcting their deficits and improving the mineral status of the plants as well as increasing the crop yield and quality (Kolota and Osinska, 2001; Alam *et al*, 2010; Ali, 2013).

Most of the Ethiopian smallholder farmers around the highland area produce garlic partially for home self-consumption and mainly for marketing as an income generation. North Shoa zone of Amhara region also has tremendous potential for garlic cultivation and it has a total production of 15359.56 tons from 2166.37 hectares of land and with average productivity of 7.09 t ha^{-1} (CSA, 2022). However, despite its importance, great potential for production and high market demand, production and productivity of garlic particularly in Debre Berhan is limited and remains seasonal. Although numerous production problems accounted for the reduction of the yield, inappropriate application of macro- and micro-nutrients is one of the major constraints for garlic production. Specifically, micronutrients have received less attention in fertilizer management research, development and extension system, while it has a great role in the fertilizer program to achieve higher and sustainable crop yield by increasing the efficiency of the use of macronutrients (Fouda, 2017; Omesh and Vijay, 2021).

According to the atlas of soil fertility made by EthioSIS, seven soil nutrients (N, P, K, S, Zn, B and Cu) are found to be deficient in the soils of Amhara region (ATA, 2016). Currently, the nationally recommended fertilizer rate of 242 kg ha^{-1} NPS (92 kg ha^{-1} P_2O_5) as side dressing and 130 kg ha^{-1} Urea in the split application are used for 'Qundi' garlic cultivar (DBARC, 2021), with no consideration of soil types. However, farmers in the study area have no experience of applying the nationally recommended NPS fertilizer rate and Zn micro-nutrient rather they randomly practice undetermined fertilizer rates and types. Hence, yields have not increased as expected even when the recommended rates of NPS fertilizers are applied. This indicates that the use of inappropriate types and rates of fertilizer could reduce yield considerably. In addition, information on the use of micro-nutrients(Zn) in combination with NPS fertilizers for garlic is scanty in Ethiopia. Thus, the integrated nutrient supply approach is one of the opportunities for obtaining fairly high productivity with substantial fertilizer leading to sustainable agriculture (Bhagwan *et al.*, 2012). Considering the importance of garlic as one of the potential vegetable crops for both domestic consumption and export, it is imperative to increase its productivity along with the appropriate application of macro- and micro-nutrients. Therefore, there is a need to identify the correct and optimum fertilization for maximum yield and best possible quality of garlic. In view of these, the present study is initiated to find out optimum and economic rates of blended NPS and Zn fertilizers for increased garlic productivity at Debre Derhan.

1.1. Objectives

1.1.1. General Objective

- To evaluate the growth, yield and quality response of garlic to different rates of blended NPS and zinc fertilizers.

1.1.2. Specific Objectives

- ✓ To evaluate growth, yield and quality response of garlic to different rates of blended NPS fertilizer.
- ✓ To evaluate growth, yield and quality response of garlic to different rates of Zn fertilizer.
- ✓ To evaluate the growth, yield and quality response of garlic to the combined effect of blended NPS and Zn fertilizers application rates.
- ✓ To determine economically feasible rate of blended NPS and zinc fertilizers for garlic production in the study area.

2. LITERATURE REVIEW

2.1. The Garlic Crop

Garlic originated in Central Asia and spread to other parts of the world through trade and colonization (Panthee *et al.,* 2006; Muneer *et al*., 2016). Garlic (*Allium sativum* L.) belongs to the family Alliaceae and the genus Allium, which contains more than 600 species and it is the most important widely consumed vegetable and ranks second next to onion in the world (Rubatzky and Yamaguchi, 1997; Ovesná *et al.,* 2011; Hore *et al*., 2014). The generic name Allium is the Latin word for garlic and the type of species for the genus is *Allium sativum*, which means cultivated garlic (Gledhill, 2008). It is shallow rooted bulb-forming biennial herbaceous grown as an annual spice having a chromosome number 2n =2X=16 with umbellate inflorescence (Kamenetsky and Rabinowitch, 2001; Ovesná *et al*., 2011; Hamma *et al.,* 2013; Hassan, 2015). Its relatives include edible onions (*Allium. cepa*), shallots (*Allium. ascalonicum*), leeks (*Allium. ampeloprasum* L.) and chives (*Allium. schoenoprasum*) (Allen, 2009; Hussena *et al.,* 2014; Nicastro *et al*., 2015). Leek is a tetraploid (2n=32), the other three species like garlic are diploid with the basic chromosome number of 2n=16 (Currah and Rabinowitch, 2002).

Garlic is a diploid species of obligated apomixes. Hence, it is a sterile species, produces sterile flowers which does not produce seeds and propagated only vegetatively through its cloves (Ipek *et al*., 2005). It produces hermaphrodite flowers mainly pollinated by bees, butterflies, moths, and other insects (Meredith *et al.,* 2014). Garlic plants have thin tape shaped leaves (flat and very slender) about 30 cm to 60cm long and 5.0 to 7.5 cm wide depending on the cultivars. The roots are a shallow adventitious system and reaches up to 50 cm in depth or a little more. Heads or bulbs are white skinned, divided into sections called cloves, which are the main economic organ of the garlic crop. Each head could have 6 to 12 cloves, which are covered with a white or reddish papery layer or “skin” (Hector *et al.,* 2012). Depending on where they are grown, the size, shape, color, and flavor will differ. Colors can range from white to red to purple or pink (Dayi, 2008).

2.2. Use and Importance of Garlic

Garlic is considered as one of the most important vegetable and spice crops, rightly called the “queen of kitchen” (Amin *et al.,* 2014). Nowadays, it is widely produced Allium for its cloves, primarily used for home consumption as a seasoning in various forms for cooking as either a spice or condiment (Hamma *et al*., 2013; Sung *et al.*, 2014; Hassan, 2015). It is consumed both fresh (green tops and bulbs) as well as in dried form as an important ingredient for flavoring various vegetarian and non-vegetarian dishes (Dufoo-Hurtado *et al.*, 2015). Garlic has higher nutritive value as compared to other bulbous crops. It is produced for its medicinal and nutritional properties and has been recognized in almost all cultures for its culinary properties. It is an excellent source of several minerals and vitamins that are essential for health and has had a medicinal role for centuries such as antibacterial, antioxidant, antifungal, antiviral, antitumor and antiseptic properties (Govind *et al*., 2015; Elosta *et al.*, 2017). It can produce organosulfur compounds, such as allicin and diallyl disulfide (DADS), which account for their pungency, lachrymatory effects and spicy aroma (Mansoub, 2011).

In Ethiopia, it is one of the important bulb crops produced for home consumption and is a source of income for many peasant farmers in many parts of the country (Getachew and Asfaw, 2000). It has a significant role in many small-scale farmers due to its major economic and dietary importance in addition to fresh consumption. The production of dried and processed garlic products for use in food preparation and as dietary health-food supplements is an important industry. In Tigray Ethiopia, garlic is one of the high value vegetable crops produced during the cold season, in rotation with pulses that have contributed in breaking the life cycle of pest problems and improve soil fertility (Gebremedhin *et al.*, 2010).

2.3. Opportunity and Challenges of Garlic Production in Ethiopia

Ethiopia has a diverse soil and climate comprising several agro-ecological regions which provide ample opportunity to grow a variety of horticulture crops. Its topographical differences result in different climatic zones which make Ethiopia an attractive country for different kinds of agricultural production systems including vegetables (garlic) throughout the year (Ashebre, 2015). Besides, the country has tremendous surface irrigation water potential which is estimated to be 122 Billion M^3 (EHPEA, 2013) and underground water potential is estimated to be 40 billion M^3 (Abiti, 2011).

Additionally, Ethiopia has a comparative advantage in a number of horticultural commodities due to its proximity to European and Middle Eastern markets and cheap labour (EIA, 2012) and also both in Europe and the Middle East a growing interest exists for products from Ethiopia. The Government of Ethiopia also gives high priority to the development of the horticulture sector and in 2008 the Horticultural Development Agency has been established with a specific focus to promote and support the further development of the horticulture sector (Wiersinga and de Jager, 2009). In order to encourage private investment, the Ethiopian Government has developed a package of incentives under Regulations No.84/2003 for investors engaged in new enterprises and expansions across a range of sectors (EIA, 2012).

Despite its importance, high market demand and great production potential in different agro-ecologies, the production, and productivity of garlic crop in Ethiopia is very low, due to a number of problems associated with biotic and abiotic stresses as well as improper agronomic practices. From those, lack of proper planting material (improved varieties), inappropriate agronomic practices, absence of proper pest and disease management practices, and lower soil fertility status in many soil types are major production constraints (Getachew and Asfaw, 2000). Among the various challenges, major production bottlenecks of all vegetable crops, particularly garlic crop are biotic factors, such as fungal disease is the most widespread and destructive pathogens of cultivated garlic crops (Getachew and Asfaw, 2000; Selvaraj *et al.,* 2014). Though there is no effective and sustainable method reported so far (Lourenco *et al*., 2018), once established in a field, the pathogen is difficult to manage and it permanently renders the field unusable for garlic production for long period of time (Wu *et al.,* 2010). Deficiency of soil nutrients during the past growing season has grown in both, magnitude and extent. This also becomes a major constraint to production and productivity of vegetables in general and garlic in particular. Ethiopian soils are exposed to rapid depletion of macro and micronutrient or deficiencies (Achieng *et al*., 2010) that closely associated with the yield and quality of crops. Generally, farmers produce horticultural crops with traditional farming system that led to low production and productivity (Alemayehu *et al.,* 2015).

2.4. Nutrient Requirements of Garlic

In many crop-producing areas, lack of available nutrients is frequently one of the most limiting factors due to continuous cultivation of the land and degradation of soils fertilizers which is one of the bases to produce more crop output from existing land under cultivation. However, the economic and environmental implications of excessive nutrient use by crops call for balanced fertilization and the nutrient needs of crops according to their physiological requirements and expected yields (Ryan, 2008). Balanced fertilizer application is essential for vegetative growth and thus, for producing crops with top quality and high yields, especially on soils that are cultivated continuously (Chintala *et al*., 2012).

Nutrient requirements of garlic crops vary with the fertility status of the soil, availability of soil moisture, variety of the crop and purpose for which the crop is grown. Of many factors, the fertility status of the soil significantly affects garlic crop yield (Diriba, 2016). Garlic has a moderate to high fertilizer requirement depending on the nutrient status of the soil. The major factors determining the level of soil fertility for improving the productivity and quality of garlic are organic matter content, availability of macro and micronutrients, soil reaction and soil physical characteristics (Tisdale *et al*., 1995). The effects of these factors are expressed in terms of nutrient availability to plants and fertility requirements as well as the level of crop production (Brewster, 1994). Garlic crops have low nutrient extraction capacity because of their shallowness and lack of root hairs or un-branched root system. Adequate nutrient supply is essential for healthy crop growth and for attaining higher yield in sustainable way (Cantwell *et al*., 2006; Jones *et al*., 2011). Thus, it needs optimum and regular nutrient application. Hence, high yield and good quality of garlic can therefore be obtained through efficient and balanced use of macro and micro nutrients (Shukla *et al*., 2018).

2.4.1. Role of nitrogen in garlic growth, yield and quality

Nitrogen (N) is important for chlorophyll, enzymes and protein synthesis in plants. Its availability in soil is of prime importance for growing plants as it is a major and indispensible constituent of protein and nucleic acid molecules (Yadav, 2003; Farooqui *et al*., 2009). The availability of N in soil is associated with vigorous vegetative growth where more carbohydrates are synthesized and thus increases the bulb weight and the total yield of garlic (Amin *et al*., 1995).

The application of N at the proper time and amount is a necessary and important consideration for increasing the growth, yield and quality of garlic (Kakar *et al*., 2002). Excessive application of N at a later vegetative stage of garlic crop can limit yields and increases storage losses, while inadequate nitrogen can hasten maturity and limit yield (Batal *et al*., 1994). Thus, adequate application of different sources and rates of N during the sprouting stage plays an important role in the production of vigorous vegetative and optimum leaf expansion of crops and influences bulb size produced (Stork *et al*., 2004). It is best not to apply N when the bulbs are beginning to enlarge since it will encourage excessive leaf growth and reduce bulb size (Bachmann, 2001).

Growth parameters in garlic were influenced with an increased application rate of N up to 200 kg ha^{-1}, while further increase in the level of nitrogen up to 250 kg ha^{-1} decreased most of the growth parameters (Zaman *et al*., 2011). In addition, all yield components of garlic were positively influenced by the application of N up to 200 kg ha^{-1}, but it was statistically similar with 150 kg ha^{-1} of nitrogen fertilizer application (Zaman *et al*., 2011). Similarly, an increased level of nitrogen up to 150 kg ha^{-1} increased the growth and yield attributes in garlic like plant height and neck thickness, bulb diameter, number of cloves per bulb, fresh weight of cloves, dry weight of cloves, fresh weight of bulb, dry weight of bulb and total bulb yield (Farooqui *et al*., 2009).

Abreham *et al*. (2014) reported that the application of nitrogen fertilizer significantly affected the bulb yield along with all growth as well as yield components of garlic. Plant height, bulb diameter, bulb weight and dry matter per bulb in garlic were increased with an increased rate of nitrogen fertilizer from 0 to 120 kg ha^{-1} (Gebrehaweria and Nigussie, 2007). Similarly, most of the growth parameters were influenced with an increased application rate of N up to 120 kg ha^{-1} (ElHifny, 2010). Kilgori *et al*. (2007) also reported a significantly increased cured bulb yield of garlic from the increased rate of nitrogen from 0 to 60 and 120 kg ha^{-1}. However, higher dosages of nitrogen up to 180 and 240 kg ha^{-1} reduced the bulb yield of garlic.

2.4.2. Role of phosphorus in garlic growth, yield and quality

Phosphorus (P) is a constituent of nucleic acids, phospholipids, the coenzymes DNA and NADP, and most importantly ATP. It activates coenzymes for amino acid production used in protein synthesis; it decomposes carbohydrates produced in photosynthesis and it is involved in many other metabolic processes required for normal growth, such as photosynthesis, glycolysis, respiration, and fatty acid synthesis. Phosphorus plays an important role in plant nutrition, particularly it helps to increase early crop growth (Jenkins *et al*., 1999). The application of different levels of P enhanced the growth and yields of garlic in comparison to the control. Whereas, limited phosphorus fertilizers in bulb crops reduced root growth, leaf growth, bulb size and yield (Stone *et al*., 2001). When the levels of phosphors become increased, yield in garlic crop also become increased. The application of phosphorus at a rate of 75 kg ha^{-1} significantly increased the neck thickness of bulb, bulb diameter, number of cloves per bulb, length of clove, average bulb weight, bulb yield, total soluble solids in garlic over control, 25 and 50 kg ha^{-1} of P fertilizer application (Meena *et al*., 2019).

The highest plant height, leaf number, leaf area and bulb yield of garlic was recorded at the rate of 69 P_2O_5 kg ha^{-1} (Tibebu *et al*., 2014) and 40 P_2O_5 kg ha^{-1} (Geleta, 2014). Further, Geleta (2014) showed that phosphorus application at the rate of 40 kg P_2O_5 ha^{-1} led to the production of heavier cloves, highest bulb diameter and bulb weight in garlic. Alemu (2014) also reported that the maximum plant height, leaf number, clove weight and leaf area index of garlic was recorded from the application rate of 92 phosphorus kg ha^{-1}. The application of 46 to 92 kg P_2O_5 ha^{-1} increased bulb yield of garlic by 48.3% as compared to the control (Workat *et al*., 2018). Shege (2015) figured out that the maximum bulb yield of garlic was recorded from the application rate of 122.6 P_2O_5 kg ha^{-1}.

2.4.3. Role of sulfur in garlic growth, yield and quality

Sulfur (S) has an important role in protein synthesis and some hormones formation. It is also necessary for enzymatic action, chlorophyll formation, synthesis of certain amino acids and vitamins, hence it help to have a good vegetative growth leading to get high yield (El-Shafie and El-Gamaily, 2002). Appropriate application of S results in an increased photosynthetic rate in garlic leaves, while enhancing the antioxidant enzyme and nitrate reductase activities of the leaves (Liu *et al*., 2010). It helps to enhance the availability and uptake of other nutrients (N, P, K, and Ca) which promote the growth and development of plants. It has also a direct effect on soil properties as it- may reduce soil pH which may improve the availability of micro elements such as Fe, Zn, Mn and Cu (Tantawy and Beik, 2009). Sulfur deficiency may also result poor utilization of nitrogen, phosphorus, potash and a significant reduction of catalase activities at all age of plants (Nasereen *et al.*, 2003).

Sulfur application has a significant influence on the bulb diameter of garlic. The application of S at rate of 40 to 60 kg ha^{-1} favored plant growth and development which resulted large sized bulb in garlic (Veer *et al.*, 2021). Jaggi and Raina, (2008) reported the increased in fresh and the dry yield of garlic bulbs through S application up to 45 kg ha^{-1}. Surendra (2008) also reported an increase in bulb yield of garlic by 1.88 t ha^{-1} with higher S use efficiency due to the application of S up to 40 kg ha^{-1} over the recommended dose of NPK fertilizers. The increase in bulb yield of garlic with the application of higher levels of Sulphur might be due to its importance in enhanced protein synthesis and translocation of photosynthates in to the bulbs (Chandra and Pandey, 2013 and Cheng *et al*., 2015). Similarly, the application of 60 kg S ha^{-1} significantly increased growth and yield attributes like plant height, number of leaves per plant, neck thickness, bulb diameter, number of cloves per bulb, fresh and dry weight of cloves, fresh and dry weight of bulb and bulb yield as compared to lower doses of Sulfur (Farooqui *et al*., 2009). Significantly increased growth, bulb and foliage yields and other yield and quality attributes in garlic from application of Sulfur ranging from 20 to 60 kg ha^{-1} over the control was reported by different scholars (Nagaich *et al*., 2003; Losak and Wisniowska-kielian, 2006; Farooqui *et al*. 2009; Hore *et al*., 2014; Diriba *et al*., 2015).

2.4.4. The role of NPS fertilizer on garlic growth, yield and quality

In Ethiopia, the rates of application of plant nutrients are far less than the requirements and blanket recommendations (Fikreyohannes, 2005), but farmers use frequently most important mineral fertilizers like N, P and K for producing most crops (Yohannes, 1994; Rao *et al*., 1998). Although, the crop nutrient requirements vary with species, variety, soil type, rate and season, bulbous crops are heavy feeders requiring optimum supplies of N, P, K and S as well as other nutrients which might have synergistic role in providing balanced supply of nutrients that adversely affect growth and yield of garlic bulbs (Amin *et al.*, 2007; Diriba *et al*., 2015; Kumar *et al*., 2019). The application of sulfur containing fertilizers like NPS modifies soil pH, improves soil-water relation and increases the availability of plant nutrients like P, Zn, Mn and Fe which may increase the bulb yield of garlic (Marschner, 1995). Garlic is a nutrient exhaustive crop and removes a good amount of nutrients from the soil. Uptake of sufficient nutrient, N, P and S by the garlic crop is important to improve growth, marketable yield as well as quality of the crop (Nai-hua *et al*., 1998). Thus, an adequate supply of nutrients like N, P and S particularly in crop root zone might have improved the chemical and biological properties of soil and enabled plant roots to proliferate and resulting in better utilization of nutrients by crop (Bhandari *et al*., 2012). The application of NPS fertilizer significantly influenced the growth, yield and yield components of garlic crops (Shege *et al*., 2017; 2015; Abera, 2020 and Bewket, 2021).

A significant increase in growth attributes of various vegetables including garlic in response to NPS fertilizer application was reported by several authors (Shege *et al*., 2017; Minwyelet, 2017; Maritu, 2019; Getachew and Temesgen, 2020 and Chala *et al.*, 2022). The increased rate of blended NPS fertilizer application leads to the increased plant height, leaf length and leaf diameter of garlic (Shege, *et al*., 2017; Abera, 2020 and Bewket, 2021) and onion (Muluneh *et al*., 2018; Shura *et al.*, 2022). An increased level of NPS till 200 kg ha^{-1} increased the growth attributes of shallot like plant height, leaf length and leaf number with a delayed day to maturity (Merga, 2022). On the other hand, other author (Mohamed and Wagi, 2021) revealed that an increased level of NPS up to 250 kg ha^{-1} caused a higher percentage of variation in leaf length, neck diameter and dry weight of above ground biomass in onion.

The highest fresh and dry weights of aboveground biomass in garlic (Shege *et al*., 2017) and onion (Muluneh *et al*., 2018) was observed from 105:122.6: 22.6 kg ha^{-1} of N: P_2O_5: S and 136.5:119.6:22 kg ha^{-1} N: P_2O_5: S fertilizer application respectively.

NPS fertilizer had a significant effect on yield and yield contributing characters of garlic crop. Shege *et al*. (2017) conducted an experiment and indicated that NPS fertilizer required for successful garlic production and an increased rate of blended NPS fertilizer results the higher marketable (17.42 t ha^{-1}) and total bulb yield (17.8 t ha^{-1}) of garlic. The application of NPS fertilizer at the rate of 57: 114: 21 kg ha^{-1} resulted in the highest average bulb weight and bulb yield of garlic (Bewket, 2021). The maximum bulb weight, highest marketable bulb yield and total bulb yields of onion was observed from the application of N: P_2O_5: S fertilizer at a rate of 105:119.6:22 kg ha^{-1}, which was significantly superior over the control (Muluneh *et al*., 2018).

As NPS fertilizer levels increased from 0 kg ha^{-1} to 200 kg ha^{-1}, total bulb yield in onion also increased significantly. The highest total bulb yield (29.35 t ha^{-1}) of onion was recorded from NPS fertilizer application at a rate of 200 kg ha^{-1} (Chala *et al.*, 2022). On the other hand, Shura *et al.* (2022) indicated the increase in bulb diameter, total dry biomass and average bulb weight was observed from the highest NPS fertilizer application at a rate of 363 kg ha^{-1}. However, bulb length in onion was increased only by the application of 242 kg ha^{-1} of NPS fertilizer. Hence, increasing the rate of NPS fertilizer increased the average bulb weight of garlic which consequently increased bulb yield. This is because of the highest nitrogen, phosphorus, and sulfur contribute to the metabolic process such as the formation of nucleic acids, phospholipids, coenzymes, and chlorophyll that in turn enhances the bulb weight of garlic plants (El-Shafie and El-Gamaily, 2002).

Quality attributes of different vegetables like total soluble solid (TSS) were also significantly influenced by NPS fertilizer application (Nardos, 2021; Shura *et al.*, 2022 and Merga, 2022). Dry matter content of Potato was significant influenced by NPS fertilizer application (Amin, 2018). Abera, (2020) found that the increased in NPS (305.5 kg ha^{-1}) fertilizer resulted the higher harvest indices (73.81%) in garlic.

2.4.5. The role of zinc fertilizer on garlic growth, yield and quality

Micronutrients are to be necessarily taken up by the plants from soil or supplemented through foliar application for improving vegetative growth and yield of crops. Foliar application of micronutrients during crop growth shows better efficiency than soil application as the uptake and assimilation of micronutrients by later method take more time (Pandev *et al.,* 2016) and thus, this method successfully used for correcting their deficits and improving the mineral status of plants as well as increasing the crop yield and quality (Kolota and Osinska, 2001). Due to some soil properties, such as high pH and lime or heavy texture crop roots are unable to absorb some important nutrients such as zinc, thus foliar spraying of micro nutrients is better as compared to soil application (Zhimomi, 2022). Likewise, the foliar application of micronutrients reduces the cost of owing to the lesser requirement of nutrients and better absorption through the foliage (Choyal *et al*., 2022).

The application of micronutrients significantly influences the improvement of garlic crop productivity by taking an active part in photosynthesis, which ultimately helps towards an increase in weight of bulbs. This is because of micronutrients had an essential role in enhancing the translocation of carbohydrates from the site of synthesis to the storage organ that improve growth, yield and quality of the crop (Alam *et al*., 2010; Chanchan *et al*., 2013; Choudhary *et al*., 2014; Choyal *et al.*,2022).

Zinc has important functions in the synthesis of auxin or indole acetic acid (IAA) from tryptophan as well as in biochemical reactions required for the formation of chlorophyll and carbohydrates which noticeably regulates plant growth. It also regulates the functions of stomata by retaining the potassium content of protective cells. The crop yield and quality of produce can be affected by deficiency of Zn (Jamali *et al.*, 2011; Pankaj *et al*., 2018). Plants uptake Zn as a divalent cation (Zn^{2+}), however only a very minute amount of Zn is readily available as soluble Zn for plant uptake (Gao *et al*., 2009).

Micronutrients(Zn) play an eminent role in plant growth, development and plant metabolism. However, their deficiencies may induce several physiological disorders and diseases in plants and later, can reduce the quantity as well as quality of vegetable crops (Sharma and Kumar, 2016). Zinc deficiencies become so extensive that it ranks next to N and P (Takkar and Randhawa, 1980). Its deficiency is significant and widespread deficiency compared to other micronutrients, which affects the rate of photosynthesis in various crops (Barman *et al*., 2018) which leads to discoloration of leaf, and this condition is termed chlorosis (Sharma *et al*., 2013). Hence, farmers should carefully follow recommendations to avoid unnecessary costs, possible toxic effects and deleterious interactions with other nutrients (Omesh and Vijay, 2021).

Foliar application of zinc sulphate ($ZnSO_4$) significantly influenced growth, yield and quality attributes of the garlic crop (Srivastava *et al*., 2005; Chanchan *et al.*, 2013; Choyal *et al*., 2022 and Kulthe *et al*., 2022). The maximum plant height, number of leaves per plant, average clove and bulb weight and bulb yield of garlic was obtained from 0.6% of $ZnSO_4$ as compared to the control treatment (Choyal *et al*., 2022). Similarly, the highest values in plant height, number of leaves, shoot fresh and dry weight, bulb diameter, number of cloves per bulbs, bulb and clove weight, clove length, clove diameter and total bulb yield was recorded from foliar application of ZnSO4 at a rate of 0.5% (Kulthe *et al*., 2022).

In addition, the increased in growth and yield contributing characters of onion like plant height, number of leaves per plant, leaf fresh weight, bulb fresh weight, total dry matter production and bulb yield were observed from the application of 0.5% $ZnSO_4$ fertilizer (Acharya *et al*., 2015). Foliar application of Zn also significantly affected quality parameters like total soluble solids and pyruvic acid content (Abd El-Samad *et al*., 2011). Foliar application of zinc sulphate (0.5%) was an effective practice to deal with the low productivity of the crop due to zinc deficiency (Sharma and Singh, 2018). Other author Zhimomi, (2022) revealed that an increased level of Zinc till 2.5% caused the highest value in plant height, number of leaves per plant, leaf length, neck thickness, polar diameter, equatorial diameter, average weight of bulb, number of cloves per bulb, marketable bulb yield, total bulb yield, TSS and ascorbic acid content in garlic.

2.4.6. The interaction role of NPS and zinc fertilizers on garlic growth, yield and quality

Although the requirement of micronutrients is only in traces, it is essentially as important as macronutrients to have better growth, yield and quality in plants (Yadav *et al*., 2018). In addition to nitrogen, phosphorus, potassium and Sulphur application, zinc as a micronutrient has great role in the fertilization program to achieve higher and sustainable bulb yields and quality (Singh and Tiwari, 1995; Rafie *et al*., 2017). Improvement of management for macro and micronutrients in the soil could improve yields and quality of vegetables (Diriba *et al*., 2013). Thus, the use of integrated sources of nutrients to obtain maximum yield and good quality bulbs is an important practice in today's garlic production. The combinations of different nutrients can influence growth, yield and quality in garlic by increasing maturity of the crops which attributed to the availability of ideal nutrients that may have led to prolonged maturity through enhanced leaf growth and photosynthetic activities thereby increasing partition of assimilates to the bulb growth (Alemu *et al*., 2016). Hence, the availability of balanced macro and micronutrients in the soil is essential for optimum growth, yield and best possible quality of the crops which differs with fertility status of the soil and cropping seasons (Teklu *et al*., 2004).

Bulbous crops are heavy feeders, requiring optimum supplies of nitrogen, phosphorus, potassium, zinc, sulphur and other nutrients which can adversely affect the growth, yield and quality of bulbs under sub-optimal levels in the soil (Gubb and Tavis, 2002). Different combinations of macro and micro nutrients played important roles in growth, yield and quality of garlic crop. This is mainly due to the fact that micronutrients are essential for better absorption of water, macronutrients uptake and metabolism which ultimately resulted in significantly higher bulb yield of garlic (Yousuf *et al*., 2016; Pandev *et al*., 2016).

The combined application of nutrients leads to an increased bulb weight of garlic, which might be attributed to the increased uptake of adequate nutrients and buildup of sufficient photosynthesis that enables the increase in the size of bulbs (Singh and Singh, 2017). Thus, application of balanced nutrients can improve soil fertility and eliminate the effect of nutrient deficiencies beyond improving the productivity and quality of garlic (Lujiu *et al*., 2004). The combined application of macro and micronutrients plays an important role in improving the vegetative growth and yield of garlic (Shukla *et al*., 2018). The longest plant height (65.20 cm), leaf length (51.93 cm), highest marketable bulb yield (34.87 t ha^{-1}), lowest unmarketable yield (0.33 t ha^{-1}), highest total bulb yield (35.04 t ha^{-1}) and highest net benefit (908,628.89 ETB ha^{-1}) with an acceptable MRR (313.64%) in onion were recorded from the combined application of 242 kg ha^{-1}NPS and 0.75% $ZnSO_4$ (Kelem *et al*., 2024). Hence, NPS and Zn fertilizer could have a synergistic effect and their combined application is the most suitable for maximum growth, yield and quality attribute of garlic.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted under irrigation conditions at Debre Berhan University, College of Agriculture and Natural Resource Sciences research site during the growing season of 2022/23. The study area is located at 130 Km from the capital city of Addis Ababa with latitude and longitude of 9^0 39'24''N and $39^0$31'17'' E, respectively and an elevation of 2840 m.a.s.l.

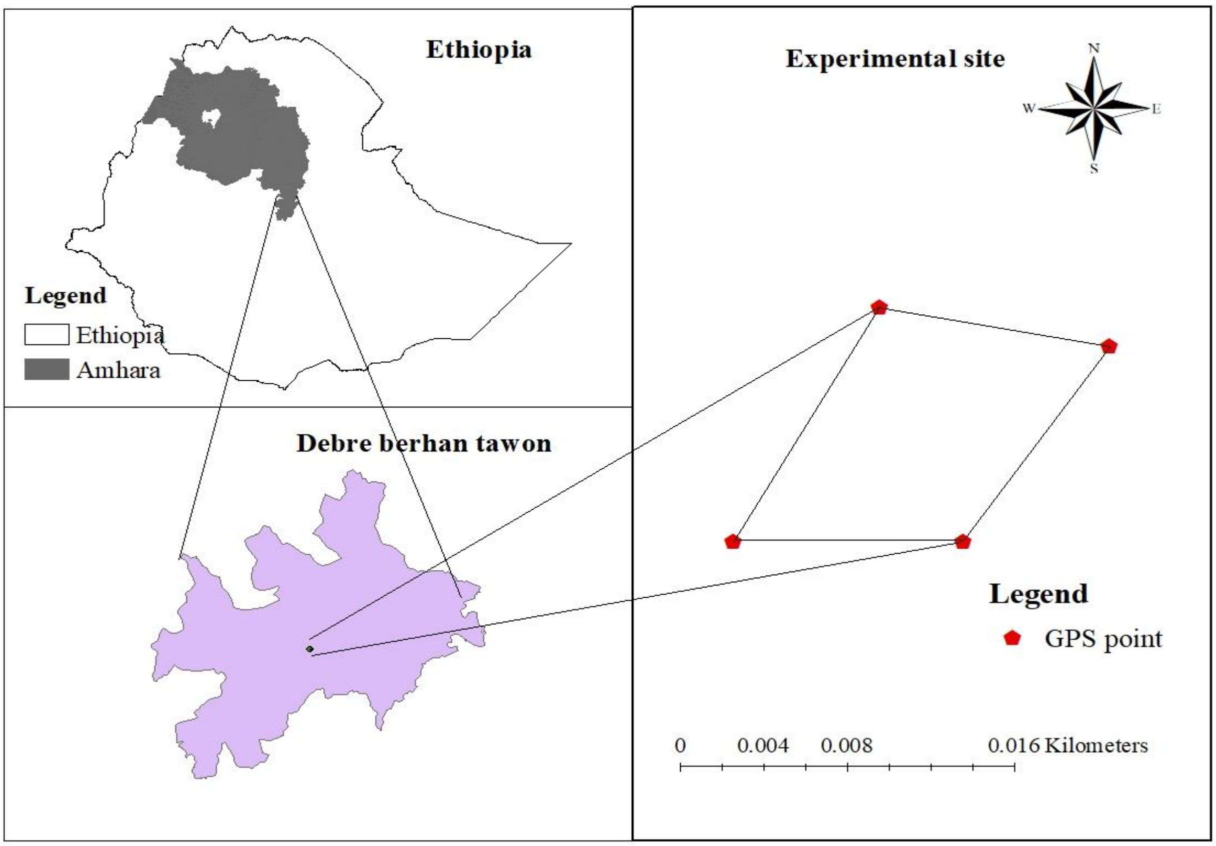

Figure 1. Map of the study area

Major crops grown in the study area are wheat, barely, pea, haricot bean, potato, carrot and garlic. In the mixed crop livestock, the farming practices in the area is dominated by sole cropping. The data obtained from the Ethiopian National Meteorological Agency indicated that the study area receives a mean annual rainfall of 927.10mm and is characterized by a bimodal rainfall pattern with a maximum (293.02mm) and minimum (4.72mm) peaks in August and December, respectively. The average monthly maximum and minimum temperatures range from 18.3 ^{O}C to 21.8 ^{O}C and from 2.4 to 8.9 ^{O}C, respectively. The most dominant soil type in the area is vertisol (FAO, 1984).

3.2. Experimental Materials

Garlic cultivar (Qundi), the newly released cultivar by DBARC and adapted to the agro-ecology of the area and obtained from DBARC was used for the study area. The fertilizer sources NPS (19% N, 38% P_2O_5 and 7% S), urea [CO (NH2)2] (46% N) and zinc sulfate ($ZnSO_4$) (99%) were used for the study. Zinc sulphate is widely applied as source of zinc because of its high solubility and low cost (Roohani *et al.*, 2013) and foliar sprays have no residual effect (Hafeez *et al.*, 2013) on subsequent cropping.

Table 1. Agromorphological characteristics of 'Qundi' (NG0048/04) garlic cultivar.

Cultivar	Year of release (GC)	Maturity time (days)	Rainfall (mm)	Altitude (m a.s.l)	Fertilizer rate (kg ha^{-1})	Foliage color	Skin color	Flesh color	Breeder/ Maintainer
Qundi (NG-0048/04)	2021	138	934-1700	2850 to 3145	242 NPS &130 Urea	Green	White	Creamy	DBARC/ ARARI
Bulb Yield (t ha^{-1})	Research field		13.03						
	Farmers' field		6.68-14.62						

Source: Debre Berhan Agricultural Research Center (2021).

3.3. Treatments and Experimental Design

The treatments consisted of a 4x4 factorial combination of NPS fertilizer rates (0, 121, 242 and 363 kg ha^{-1}) and Zn rates (0, 0.3, 0.6 and 0.9% w/v). The treatments were arranged in a randomized complete block design (RCBD) with three replications. The blended NPS fertilizer rates were calculated based on the blanket recommendation rate of 242 Kg ha^{-1} of NPS and 130 Kg ha^{-1} of Urea for Qundi, cultivar (DBARC, 2021) and foliar application of $ZnSO_4$ were calculated based on the recommendation rate of 0.6%, which was significantly enhanced growth, yield and quality in garlic

(Srivastava *et al.*, 2005; Choyal *et al.*, 2022). After calculating the nutrients in the blanket recommendation, 50% of nutrients were added and subtracted.

3.4. Experimental Procedures

The land was ploughed by the tractor and harrowed to break down large clods in order to make the land to a fine tilth. All the stubbles and uprooted weeds were removed. The land was leveled using a rake and ridges at 20 cm in height, then plots was marked and rows for planting was lined. In accordance with the specification of the design, each block contains a complete set of the treatments which was allotted to the plots within each block at random. The total area for the experiment was 26.7m * 6.5 m (173.55 m^2). The plot size was 1.2 m * 1.5 m (1.8 m^2) accommodating five rows and 12 plants in a row. The distance between blocks and plots was 1 m and 0.5 m respectively. Each plot contained 60 garlic plants. The outer single rows at both sides of the plot and one plant at both ends of the rows were considered border plants. The central three rows were used as the net plot area for all data collection. Thus, the net plot size was 1m * 0.9m (0.9 m^2).

Cloves (2- 2.5 g) used for the propagation purpose were prepared from clean, well-developed and dry bulbs. The cloves were directly planted on prepared plots at a spacing of 30 cm x 10 cm between rows and plants, respectively, by sticking the clove into the raised bed by hand. One-third of urea was applied at planting and the remaining was applied in split, half at active vegetative growth (three weeks after emergence) and the rest six weeks later after emergence (before bulbing) as a side dressing (DZARC, 2003). The NPS as per the treatment was applied at planting in a single dose whereas, the micronutrients namely zinc as zinc sulphate was applied by foliar spray three times at monthly intervals starting from 30 days after planting (Manna, 2013). All the recommended agronomic practices like irrigation, weeding, inter-cultivation and ridging were done uniformly for all treatments, at the appropriate time to facilitate root, vegetative growth and bulb development (Asfaw and Eshetu, 2015).

3. 5. Soil Sampling and Analysis

Soil samples (0-20 cm depth) were collected from the entire experimental field by Auger sampler using a zigzag pattern before planting. The samples were composite into one, dried by air under shade, ground into small crumbs with a pestle and mortar, mixed thoroughly and sieved through a 2-mm sieve. From this mixture, a sample weighing one-kilo gram was taken and filled into a plastic bag for the analysis of soil texture, soil pH, CEC, EC, organic carbon (OC), organic matter content (OM), total N, available P, exchangeable K, available S, available Zn, exchangeable Ca, Mg and Na. Standard laboratory procedures were followed in the analysis of such soil physico-chemical properties.

The textural class was determined by using the hydrometer method of Bouyoucos (Bouyoucous, 1962). The soil pH was estimated from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (Jones, 2003). Soil cation exchange capacity (CEC) was determined by ammonium acetate method (Cottenie, 1980). The soil OC was determined by using wet digestion and oxidation method (Walkley and Black, 1934) and its content was used to estimate the OM content by multiplying OC by 1.724 (Broadbent, 1953; Pribyl, 2010). Total N content was determined using the modified micro Kjeldhal method (Cottenie *et al.,* 1982), the available P was determined using the Olsen method as described by Olsen *et al*. (1954) and exchangeable K was determined by using neutral normal ammonium acetate method (Schollenberger and Simon, 1945). The exchangeable Ca, Mg and Na was determined by using ammonium acetate method. The S content was determined by monocalcium phosphate extraction method or turbidmetrically using a spectrophotometer method (Chesnin and Yien, 1951; Johnson and Fixen, 1990). Available Zn was determined by using AD-DTPA (dietylene triamine penta acetic acid) method (Ryan *et al.,* 2001). A soil analysis was conducted at Debre Berhan Agricultural Research Center Soil Laboratory.

3.6. Data Collected

3.6.1. Phenological parameters

Days to emergence (day): Days to 50% emergence was recorded when 50% of the cloves sprout and emerges out of the soil in each plot. The average of days to emergence on each plot for all replications was taken as the actual number of days to emergence.

Days to 75% physiological maturity (day): It was recorded as the number of days required from planting to the time when 75 % of the leaves in each plot become yellow, dry and show senescence.

3.6.2. Growth parameters

Plant height (cm): The average length of ten randomly taken plants in each net plot was measured from the soil surface to the tip at physiological maturity and the average was considered for statistical analysis.

Leaf length (cm): The length of the longest leaf from the leaf sheath to the tip of the leaf at physiological maturity was measured from ten randomly taken plants and their average was expressed as leaf length.

Leaf diameter (cm): One leaf from each sample plant was measured from the widest part of the leaves during physiological maturity. The average diameter of leaves was considered from ten randomly selected plants in the three central rows.

Number of leaves per plant (No): The total number of healthy leaves was counted from ten randomly selected plants from the central three rows at physiological maturity and the mean value was computed.

Neck diameter (cm): The thickness of the neck was determined from ten randomly selected plants of the three central rows. It was measured by using a caliper after curing.

Shoot dry weight (g): The shoot fresh mass was oven-dried until a constant weight is achieved at a temperature of 65^0C and its dry matter yield was determined.

3.6.3. Yield parameters

Average bulb weight (g): The average mature bulb weight per plant was registered after the weighing of cured bulbs produced in the net plot area by using sensitive balance and divided by the number of bulbs.

Bulb length (cm): It was determined from ten randomly selected plants of the three central rows and it was measured longitudinally from the bottom to the top using a caliper after curing.

Bulb diameter (cm): It was determined from ten randomly selected of the three central rows. It was measured at the middle cross section of the bulb by using caliper after curing.

Clove length (cm): The average clove length of five randomly taken bulbs from the net plot area was taken and measured from the base to the tip of the clove using a caliper after curing.

Clove diameter (cm): The average clove diameter of five randomly taken bulbs from net plot area was measured from the middle portion of the clove using a caliper after curing.

Average clove weight (g): Clove weight of ten randomly selected plants from the net plot area was measured after curing by using sensitive balance and dividing by the number of cloves and their mean was taken as average clove weight.

Clove number per bulb (No): The number of cloves produced from ten randomly selected plants in the net pot area was counted and divided by the number of bulbs; their mean was taken as clove number per bulb.

Total dry biomass (g): This was determined by taking the total biomass weight of sampled plants from the net plot area which included dried bulbs, leaves, stems, and roots after drying in an oven at 70^0c until a constant weight was attained.

Total bulb yield (t ha^{-1}): The bulb weight of plants harvested from three central rows was weighed after curing for 10 days under shade in ambient conditions and converted to tons per hectare.

Harvest index (%): It was calculated as the ratio of dry bulb yield weight to biological yield and multiplied by 100.

HI **(%)** = (EY/BY) *100

Where**:** EY: Weight of dry bulb (Economic Yield)

BY: Weight of biological yield (above-and below-ground dry weight).

3.6.4. Quality parameters

Clove size category: Cloves of five bulbs from randomly taken bulb ware categorized in to four market clove sizes and one unmarketable clove sizes (very small) on the basis of clove weight as very large size (greater than 2.5 g), large size (2.00-2.50 g), medium size (1.50-1.99 g), small size/ scarcely marketable cloves (1.00-1.49 g) and very small cloves with weight of less than one gram (Fikreyohannes, 2005).

Bulb dry matter content (%DM): Cloves from five randomly selected bulbs were chopped into small pieces with the help of stainless steel knife, mixed thoroughly and the exact weight of each sample was determined and recorded as fresh weight. The samples were placed in paper bags and dried in an oven at 65 ^{0}C until constant weight is obtained. Each sample was immediately weighed using digital sensitive balance and recorded as dry weight. Percent dry matter content for each sample was calculated by the following formula:

$$\mathrm{DM} = \frac{[(\mathrm{DW}+\mathrm{CW})-\mathrm{CW})}{[(\mathrm{FW}+\mathrm{CW})-\mathrm{CW}]} \times 100\%$$

Where: DM = dry matter, DW= dry weight, CW=container weight, FW= fresh weight

Total soluble solid (TSS) (^{0}Brix): An aliquot of juice was extracted using a juice extractor and 100ml of the slurry was filtered using muslin cloth. The total soluble solids of garlic were determined using a digital refractometer with a range of 0 to 32 °Brix and a resolution of 0.2 °Brix by placing 2 drops of clear juice on the prism. Between samples, the prism of the refractometer was washed with distilled water and dried before use and was expressed as ^{0}Brix (Robert and Bradley, 2010).

3.6.5. Partial budget analysis

A partial budget was employed for economic analysis of fertilizer application and it was carried out for combined bulb yield data. The costs of fertilizers and labor costs for fertilizers were considered as variable cost. The cost of land preparation, field management, seed cost, harvest, transportation, storage, post-harvest and other extra expenses was not included in the calculation; the economic analysis was done as per the formula developed by CIMMYT (1988).

Marginal rate of return (%) = Changes in net benefit/Change in total cost*100.
A treatment having a marginal rate of return (MRR) greater than or equal to 100% is said to be economically profitable.

3.7. Data Analysis

Data obtained were subjected to Analysis of Variance (ANOVA) using the general linear model (GLM) of R – software. All significant pairs of treatment means were compared using Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984) at a 5% level of significance. A Pearson correlation was computed to understand the association between selected growth, yield and quality parameters.

4. RESULTS AND DISCUSSION

4.1. Soil Physico-chemical Properties of the Experimental Site before Planting

The results of the soil analysis before the experiment indicated that soil of the study site was dominantly clay (Table 2). The soil pH (6.09) of the study area was slightly acidic, as rated by Tekalign (1991). Bachmann (2001) indicated that pH in the range of 5 to 7.5 is favorable for garlic production, while soil that is too acidic or too alkaline causes slow growth and late maturity. Soil pH has a vital role in determining several chemical reactions that influence plant growth by affecting the activity of soil microorganisms and altering the solubility and availability of most of the essential plant nutrients, particularly the micronutrients such as Fe, Zn, B, Cu and Mn (Sumner, 2000). EC of the soil was 0.093 (ds m^{-1}) which was non-saline (USSLS, 1954). Hazelton and Murphy (2007) described that less than 2 d S m^{-1} soil is non-saline, 2 - 4 d S m^{-1} slightly saline, 4 - 8 d S m^{-1} moderately saline and 8-16 d S m^{-1} highly saline and greater than 16 d S m^{-1} extremely saline. They further reported that the soil salinity effect below 2.0 d S m^{-1} is mostly negligible for most crops.

The CEC of the soil was 25.45 cmol (+) kg^{-1} which was high (Landon, 1991; Hazelton and Murphy (2007). Hazelton and Murphy (2007) described that CEC (cmol (+) kg^{-1}) of the soil less than 5 is rated as very low, 5-15 is rated as low, 15-25 is rated as medium, 25- 40 is rated as high and greater than 40 is rated as very high, thus high CEC values imply that the soil has high buffering capacity against induced chemical changes. High CEC indicates that the soils can strongly hold nutrients and is mainly due to its high clay content. Organic carbon of the soil was 1.6% which was medium. Tekalign (1991) described that the OC (%) of the soil less than 0.5 is rated as very low,0.5-1.5 is rated as low, 1.5-3 is rated as medium and greater than 3 is rated as high. Organic matter of the soil was 2.76% which was medium. Tekalign (1991) described that the OM (%) of the soil less than 0.86 is rated as very low,0.86-2.59 is rated as low, 2.59-5.17 is rated as medium and greater than 5.17 is rated as high. Potgieter (2006) showed that the soil with over 2% of organic matter content was good for plant growth and development.

The total nitrogen content TN (%) of soil was medium 0.19 % (Table 2). Tekalign (1991) and Goronski *et al*. (2010) described that the TN (%) of the soil less than 0.01 is rated as very low,0.01 - 0.12 is rated as low, 0.12 - 0.25 is rated as medium and greater than 0.25 is rated as high. The available P (mg kg-

^{1}) content of the soil was 8.67 mg kg^{-1} which was low. According to Olsen *et al*. (1954), the available P of the soil less than 5 is rated as very low, 5-9 is rated as low, 10-17 is rated as medium, 18-25 is rated as high and greater than 25 is rated as very high. The exchangeable K (cmol (+) kg^{-1}) content of the soil was 1.55 (cmol (+) kg^{-1}) which was very high. Hazelton and Murphy (2007) and FAO (2006) described that the Exchangeable K of the soil less than 0.2 are rated as very low, 0. 2 - 0.3 are rated as low, 0.3 - 0.6 are rated as medium, 0.6-1.2 are rated as high and greater than 1.2 are rated as very high. The soil available sulfur of the experimental area was 11.37 mg kg^{-1}. Bashour and Sayegh (2007) reported that soils with Sulfur content of <0-10 are very low, 10-20 is low, 20-35 is medium, 35-45 is high and > 45 is very high. Thus, it has been rated as low.

Available Zn (mg kg^{-1}) content of the soil was 1.02 mg kg^{-1} which was medium. According to Lindsay and Norvell (1978), the available Zn (mg ha^{-1}) of the soil is less than 0.5 very low, 0.6 - 1.0 low, 1.0-3.0 medium, 3.0-6.0 high and >6.0 very high. The exchangeable Ca (cmol (+) kg^{-1}) content of the soil was 19.72 (cmol (+) kg^{-1}) which was high. Hazelton and Murphy (2007) and FAO (2006) described that the Exchangeable Ca of the soil less than 2 is rated as very low, 2 - 5 are rated as low, 5 -10 are rated as medium, 10 - 20 are rated as high and greater than 20 are rated as very high. The exchangeable Mg (cmol (+) kg^{-1}) content of the soil was 6.92 (cmol (+) kg^{-1}) which was high. Hazelton and Murphy (2007) and FAO (2006) described that the Exchangeable Mg of soil less than 0.3 is rated as very low, 0.3 – 1.0 is rated as low, 1.0 – 3.0 is rated as medium, 3.0 – 8.0 are rated as high and greater than 8.0 are rated as very high. The exchangeable Na (cmol (+) kg^{-1}) content of the soil was 0.48 (cmol (+) kg^{-1}) which was medium. FAO (2006) described that the Exchangeable Na of the soil less than 0.10 is rated as very low, 0.1 - 0.3 is rated as low, 0.3 - 0.7 is rated as medium, 0.7 - 2.0 is rated as high and greater than 2.0 are rated as very high.

Table 2. Physico-chemical characteristics of the soil in the experimental site.

Parameter	Value	Rating	Reference
Sand (%)	18		
Silt (%)	34		
Clay (%)	48		
Textural class	Clay		
pH	6.09	Slightly acidic	Tekalign (1991)
Organic carbon (%)	1.6	Medium	Tekalign (1991)
Organic matter (%)	2.76	Medium	Tekalign (1991)
Total nitrogen (%)	0.19	Medium	Tekalign (1991); Goronski *et al*. (2010)
Available P (mg kg^{-1})	8.67	Low	Olsen *et al*. (1954)
Exchangeable K (Cmol(+) kg^{-1})	1.55	Very high	Hazelton and Murphy (2007)
Available S (mg kg^{-1})	11.37	Low	Bashour and Sayegh (2007)
Zn (mg kg^{-1})	1.02	Medium	Lindsay and Norvell (1978)
EC (ds ml^{-1})	0.093	Non-saline	USSLS, (1954)
CEC (Cmol(+) kg^{-1}	25.45	High	Landon (1991); Hazelton and Murphy (2007)
Ca^{2+} Cmol(+) kg^{-1}	19.72	High	Hazelton and Murphy (2007)
Mg^{2+} Cmol(+) kg^{-1}	6.92	High	Hazelton and Murphy (2007)
Na^{+} Cmol(+) kg^{-1}	0.48	Medium	FAO (2006)

Where: - pH= Potential of Hydrogen, OC = Organic Carbon; OM= Organic matter; N = Nitrogen; P = Phosphorus; S= Sulphur; Zn= Zinc; CEC = Cation Exchange Capacity; Ca = Calcium; Mg = Magnesium and Na = Sodium.

4.2. Phenological Parameters

4.2.1. Days to emergence

The main effect of the NPS rate significantly ($P \leq 0.001$) affected the number of days required for emergence. However, the main effect of the Zn rate and the interaction effect of NPS and Zn rate did not significantly affect this parameter (Appendix Table 1). The earlier days to emergence (13.91) was recorded from the application of the highest (363 kg ha^{-1}) rate of NPS fertilizer, while the delayed day for emergence was recorded from the control treatment. The application of the highest rate of NPS (363 kg ha^{-1}) shortened days to emergence by 0.75 and 3.75 days as compared to the application of 242 and 0 kg ha^{-1} of NPS fertilizer, respectively (Table 3). The hastened duration of emergence by the highest amount of NPS application might be attributed to the sufficient supply of nutrients that could facilitate root initiation and development which consequently led to early shoot emergence. In line with this finding, Getachew and Temesgen (2021) reported early emergence in garlic by the application of 105: 92: 17 kg ha^{-1} NPS. In contrary to the current finding, Abera (2020) indicated that NPS fertilizer application did not significantly affect days to emergence.

Table 3. Effect of NPS fertilizer rates on days to emergence and maturity of garlic

NPS rate (kg ha^{-1})	Days to emergence (day)	Days to maturity (day)
0	17.66^{a}	139.33^{d}
121	15.25^{b}	145.00^{c}
242	14.66^{c}	148.67^{b}
363	13.91^{d}	154.17^{a}
Significance level	***	***
CV (%)	3.00	2.42

Means in the table followed by the different letter are significantly different to each other *** = significant at $P \leq 0.001$; CV= coefficient of variation.

4.2.2. Days to maturity

Days to maturity was significantly ($P \leq 0.001$) influenced by the main effect of NPS rate. On the other hand, the main effect of Zn rate and the interaction effect of NPS and zinc rate did not significantly affect this parameter (Appendix Table 1). The shortest days to maturity (139.33) was recorded from the nil fertilizer application while the longest days to maturity (154.17) was recorded from the application of the highest (363 kg ha^{-1}) NPS fertilizer (Table 3). When the application of

NPS fertilizer was increased from the lowest to the highest rates, the number of days required to maturity was significantly and linearly increased. The application of NPS fertilizer at all levels resulted in a delay in maturity as compared to the control treatment. Garlic plants, which were not fertilized with NPS had shortened days to maturity by 9.34 days as compared to the application of 242 kg ha^{-1} NPS fertilizer (Table 3). This could be due to the increased vegetative growth in response to NPS application which extended physiological activities and continued in photosynthesis thereby increasing the production of assimilates that caused a delay in maturity.

In agreement with this, Shura *et al.* (2022) reported that the shortest days to maturity of onion were recorded from 0 to 121 kg ha^{-1} of NPS fertilizer levels while the longest days to maturity were recorded from 242 to 363 kg ha^{-1} of NPS. Similarly, Maritu (2019) reported that the application of the highest NPS (361.5 kg ha^{-1}) fertilizer in onion crop resulted in a delay in maturity by 4.04 days as compared to the control treatment. In addition, Mohamed and Wagi (2021) stated that the longest days to maturity in onions were recorded in plots supplied with 250 kg ha^{-1} NPS fertilizer which was increased by 5 days compared with the control. Moreover, Chala *et al.* (2022) also reported that the day to physiological maturity in onion crop was delayed at higher level of NPS (200 kg ha^{-1}) fertilizer application than the control treatment. However, Shege *et al.* (2017) described that NPS fertilizer did not significantly affect days to maturity of garlic.

4.3. Growth Parameters

4.3.1. Plant height

Plant height of garlic was significantly ($P \leq 0.001$) affected by the main effects of NPS and Zn rates but, their interaction did not significantly affect this parameter (Appendix Table 1). The longest plant height (66.28 cm) was recorded from the application rate of 363 kg ha^{-1} NPS, whereas the shortest plant height (51.26 cm) was recorded from the control (0 kg ha^{-1} of NPS) treatment (Table 4). The increase in plant height due to the application of the highest rate of NPS fertilizer was by 5.54 and 29.30% as compared to the application rate of 242 and 0 kg ha^{-1} of NPS fertilizer, respectively. The positive effect of NPS on plant height could be attributed to the favorable effects of those three abundantly available nutrients on assimilates production that favors vigorous vegetative growth. This ultimately caused an increase in plant height. This result was in agreement with the finding of Bewket

(2021) who reported that the highest plant height was obtained from the highest rate of NPS fertilizer (57 :114: 21 kg ha^{-1}) application while the lowest value was recorded from the control treatment. Shege (2015) also found that the application of N: P_2O_5: S (105:122.6: 22.6 kg ha^{-1}) resulted in maximum plant height in garlic as compared to the control treatment. Similarly, Muluneh *et al*. (2018) describe that the longest plant height in onion was observed by the application of NPS fertilizer at the rate of 73.5:92:16.95 kg ha^{-1} N: P_2O_5: S. In addition, Chala *et al.* (2022) described that NPS fertilizer significantly affected the plant height of garlic.

The tallest plant height (61.98 cm) in garlic was observed from the application of Zn at 0.6% rate, which was statistically similar to the application of 0.3 and 0.9 % Zn rate. On the other hand, the shortest plant height (55.23 cm) was recorded from the control treatment (Table 4). This might be ascribed to the role of zinc in assimilates production that favors vigorous vegetative growth. This eventually resulted in higher plant height. In line with this, Choyal *et al*. (2022) and Acharya *et al*. (2015) reported a maximum plant height in garlic and onion from foliar application of zinc sulphate at 0.6% and 0.5% rate, respectively. Similarly, Srivastava *et al*. (2005) stated the tallest plant height in garlic at 60 days after planting from 0.6 % zinc sulphate application. In addition, Kulthe *et al*. (2022) found a significantly maximum plant height of garlic from foliar application of $ZnSO_4$ at 0.5% while the lowest plant height was recorded from the control treatment. Moreover, Manna *et al.* (2014) reported that the highest plant height in onion was recorded from the application of 0.5% $ZnSO_4$ while the lowest was recorded from the control treatment.

4.3.2. Leaf length

Leaf length of garlic was significantly ($P \leq 0.001$) affected by the main effects of NPS and Zn application rates. However, the interaction of both had responded none significantly (Appendix Table 1). The application of 363 kg ha^{-1} of NPS resulted in the longest leaf length (44.02 cm) of garlic which was statistically similar with the application of 242 kg ha^{-1} NPS, whereas the control treatment resulted in the shortest leaf length (35.29 cm) (Table 4). The increase in leaf length due to the application of large amount of NPS was by 0.96 and 24.74% as compared to the recommended NPS (242 kg ha^{-1}) and the control treatment, respectively. The increase in leaf length due to the higher NPS fertilizer application might be attributed to more availability of nutrients which had an stimulative effect on root development and vegetative growth that caused a higher leaf length. In line with this, Mohamed and Wagi (2021) observed the longest leaf length in onion from the highest rate of NPS (250 kg ha^{-1}) fertilizer application. Similarly, Bewket (2021) found that the highest leaf length was recorded from NPS fertilizer at a rate of 57:114: 21 kg ha^{-1} while the lowest leaf length was recorded from the control treatment. Shege (2015) also reported that the longest leaf length of garlic was obtained from NPS application at a rate of 105:122.6:22.6 kg ha^{-1} while the shortest leaf length was obtained from nil application. In addition, Muluneh *et al*. (2018) reported that the longest leaf length in onions was recorded from the highest NPS fertilizer level.

The application of zinc fertilizer at a rate of 0.6% resulted in the tallest leaf length (42.50 cm) which was statistically similar to the application of zinc at a rate of 0.9%. However, the shortest leaf length (39.14 cm) was recorded from the control treatment (Table 4). The increase in leaf length due to the application of zinc fertilizer was by 8.58 % as compared to the control treatment. There was an increasing trend in leaf length as zinc rate increased from 0 up to 0.6%, but further increasing up to 0.9% decreased the leaf length to 41.66 cm (Table 4). The increment in leaf length could be attributed to the role of zinc in assimilates production that favors vigorous vegetative growth. This eventually resulted in higher leaf length. Similarly, Khan *et al*. (2007) found that the maximum leaf length in onion was obtained from the application rate of 10 kg ha^{-1} Zn fertilizer, while the minimum leaf length was obtained from the control treatment. Tisdale *et al*. (1985) also reported that zinc is involved in auxin metabolism and other enzymatic reactions that increase the leaf length. These results are also supported by the findings of Rohidas *et al.* (2010) and Alam *et al*. (2019) who reported the significant influence of zinc n on leaf length of garlic.

Table 4. Effect of NPS and zinc fertilizers on plant height, leaf length, leaf diameter and leaf number of garlic

NPS rate (kg ha^{-1})	Plant height (cm)	Leaf length (cm)	Leaf diameter (cm)	Leaf number
0	51.26^{d}	35.29^{c}	2.18^{c}	8.30^{c}
121	58.85^{c}	40.89^{b}	2.40^{b}	9.07^{b}
242	62.80^{b}	43.60^{a}	2.51^{ab}	9.68^{a}
363	66.28^{a}	44.02^{a}	2.54^{a}	9.92^{a}
Significance level	***	***	***	***
Zn rate (%)				
0	55.23^{b}	39.14^{c}	2.17^{c}	8.55^{c}
0.3	60.71^{a}	40.52^{b}	2.36^{b}	9.13^{b}
0.6	61.98^{a}	42.50^{a}	2.54^{a}	9.70^{a}
0.9	61.29^{a}	41.66^{ab}	2.56^{a}	9.58^{ab}
Significance level	***	***	***	**
CV(%)	5.45	3.45	6.81	6.91

Means in the table followed by the different letter(s) are significantly different to each other *** = significant at $P \leq 0.001$; ** = significant at $P \leq 0.01$; CV= coefficient of variation.

4.3.3. Leaf diameter

The main effects of NPS and Zn significantly ($P \leq 0.001$) influenced leaf diameter. However, the interaction effect of both did not significantly affect this parameter (Appendix Table 1). The widest leaf (2.54 cm) was recorded from the application of 363 kg ha^{-1} NPS which was statistically similar to the application rate of 242 kg ha^{-1} NPS. On the other hand, the narrowest leaf (2.18 cm) was recorded from the control treatment (Table 4). The increase in leaf diameter due to the application of the highest rate of NPS fertilization was by 16.51% as compared to the control treatment (Table 4). This could be due to the availability of a balanced amount of N, P and S which promotes vigorous vegetative growth. This in turn might led to a higher amount of assimilates production and partitioning to the plant parts that eventually caused an increase in leaf diameter. The result is in close conformity with the findings of Muluneh *et al.* (2018) who reported the widest leaf diameter in onion from 136.5:119.6:22 kg ha^{-1} of N, P_2O_5 and S fertilizer application, respectively.

The application of zinc fertilizer at the highest rate (0.9%) resulted in the widest leaf (2.56 cm) which was statistically similar to the application of zinc at a rate of 0.6%. However, the narrowest leaf (2.17cm) was recorded from the control treatment (Table 4). The increase in leaf diameter due to the application of the highest rate of zinc was 17.97% as compared to the control treatment. This might be ascribed to the role of zinc in assimilates production that favors vigorous vegetative growth. This in turn led to a wider leaf diameter. Khan *et al*. (2007) and Arif *et al.* (2016) reported the importance of zinc for enhanced vegetative growth in garlic and onion crops, respectively.

4.3.4. Leaf number per plant

Leaf number in garlic was significantly ($P \leq 0.05$) affected by the main effects of NPS and zinc while the interaction of both did not significantly affect this parameter (Appendix Table 1). The application of the highest NPS (363 kg ha^{-1}) fertilizer resulted in the highest leaf number (9.92) of garlic which was statistically similar to 242 kg ha^{-1} NPS application, whereas the control treatment resulted in the lowest (8.30) (Table 4). The leaf number increased by 19.52% due to the application of the highest rate of NPS fertilizer as compared to the control treatment. Such increment by the highest amount of NPS fertilizer might be due to the sufficiently available nutrients that enhance vigorous vegetative growth. This consequently caused an increase in the number of leaves per plant. In agreement with this, Abera (2020) reported that the highest leaf number was recorded from 305.5 kg ha^{-1} NPS fertilizer application, while the lowest leaf number was recorded from nil application. Similarly, Bewket (2021) observed that the highest and lowest leaf numbers were recorded from 57:114: 21 kg ha^{-1} NPS fertilizer application and the control treatment, respectively. In addition, Shege *et al*. (2017) reported that the highest number of leaf in garlic was obtained from the application of 140:122.6: 22.6 kg ha^{-1} of N: P_2O_5: S fertilizer. Further, Maritu (2019) reported that the highest number of onion leaves was recorded from the application of 271.12 kg ha^{-1} NPS and the lowest number of leaves was recorded from the control treatment. On the contrary, Muluneh *et al.* (2018) stated that the application of NPS fertilizer did not significantly influence leaf number in onion crops.

The application of zinc fertilizer at the rate of 0.6% resulted in the highest leaf number (9.7) which was statistically similar to the application of 0.9%. However, the lowest leaf number (8.55) was recorded from the control treatment (Table 4). The increase in leaf number due to the application of zinc (0.6%) fertilizer was by 13.45% as compared to the control treatment. This increment in leaf number in response to zinc application could be ascribed to its role on photosynthetic activity and assimilates production and partitioning to the plant parts. This eventually caused an increased number of leaves. In agreement with this study, Acharya *et al.* (2015) and Choyal *et al*. (2022) found the maximum number of leaves per plant in onion and garlic from foliar application of zinc sulphate at

0.5 and 0.6%, respectively. Similarly, Kulthe *et al*. (2022) found a significantly increased number of leaves in garlic from foliar application of $ZnSO_4$ at 0.5%, while the lowest leaf number was recorded from the control treatment. On the contrary, Manna *et al*. (2014) and Kelem *et al*. (2024) indicated that the application of zinc fertilizer did not significantly influence the leaf number of onion.

4.3.5. Neck diameter

Neck diameter was significantly influenced by the main effects of NPS and zinc as well as by their interaction effect (Appendix Table 1). The widest neck diameter (1.52 cm) was measured from the combined application of 242 kg ha^{-1} of NPS and 0.6% of zinc fertilizers which was statistically similar to 242 kg ha^{-1} of NPS with 0.3% zinc and 363 kg ha^{-1} of NPS with 0.3% and 0.6% zinc applications. On the other hand, the narrowest neck diameter (1.04 cm) was recorded from the control treatment (Table 5). The increase in neck diameter due to the application of 242 kg ha^{-1} NPS and 0.6% of zinc fertilizers was by 7.04 and 46.15% as compared to the application of 242 kg ha^{-1} NPS without zinc and the control treatment, respectively. The increment in neck diameter due to the combined application of NPS and Zn might be attributed to the availability of those nutrients increased chlorophyll synthesis which increased the photosynthetic area that led to vigorous vegetative growth. This, in turn, resulted in the maximum number of leaves that produced maximum photosynthates accumulation and translocation into the pseudo stem and ensured higher neck thickness of garlic. Similarly, Guesh (2015) reported that the vigorous growth of plants due to sufficient growth resources resulted in the highest bulb neck diameter of onion. Adekpe *et al*. (2007) indicated that garlic plants, which attained higher vegetative growth earlier possibly, had developed larger neck diameter. In addition, Mohamed and Wagi (2021) reported that the widest neck thickness in onion was obtained by application of 250 kg ha^{-1} NPS fertilizer rate.

The reduced neck diameter beyond the application of 243 kg ha^{-1} of NPS fertilizer and 0.6% of zinc might be ascribed to excess application of nutrients that caused a luxurious vegetative growth and consequently led to partitioning of assimilates mainly to the vegetative parts that eventually resulted in reducing of neck diameter. In agreement, Akuamoah-Boateng (2016) reported that the neck thickness of onion bulbs was reduced as the application of organic and inorganic fertilizer increased which might cause vigorous vegetative growth and then ultimately cause distribution of photosynthates principally to the vegetative parts.

Srivastava *et al*., (2005) observed the thickest neck in garlic at 90 days after planting under 0.6% zinc sulphate application. Similarly, Babaleshwar *et al*. (2017) reported that the highest value in neck thickness in onion was measured from foliar application of zinc sulphate at a rate of 0.5% while the lowest value in neck thickness was measured from the control treatment. In addition, Zhimomi (2022) described that the maximum neck thickness of garlic bulb was obtained from zinc application up to 2.5% rate and the minimum neck thickness was obtained from the control treatment. However, Chanchan *et al*. (2013) observed that the neck thickness of garlic was not influenced by the different levels of micro-nutrient application.

Table 5. The interaction effect of NPS and zinc fertilizers on neck diameter of garlic

NPS rate (kg ha^{-1})	Zn rate (%)	Neck diameter (cm)
0	0	1.04^{j}
	0.3	1.12^{i}
	0.6	1.24^{h}
	0.9	1.30^{g}
121	0	1.36^{g}
	0.3	1.37^{ef}
	0.6	1.41^{c-f}
	0.9	1.38^{d-f}
242	0	1.42^{c-f}
	0.3	1.50^{ab}
	0.6	1.52^{a}
	0.9	1.44^{b-d}
363	0	1.43^{b-d}
	0.3	1.47^{a-c}
	0.6	1.47^{a-c}
	0.9	1.45^{b-d}
Significance level		***
CV(%)		2.66

Means in the table followed by the different letter(s) are significantly different to each other at *** = significant at $P \leq 0.001$, CV- coefficient of variation.

4.3.6. Shoot dry weight

The main effects of NPS and zinc significantly ($P \leq 0.001$) affected the shoot dry weight of garlic, while their interaction did not significantly affect this parameter (Appendix Table 1). The highest shoot dry weight (9.05 g) was obtained from the application of 242 kg ha^{-1} of NPS which was statistically similar to the application of NPS at a rate of 363 kg ha^{-1}. However, the lowest shoot dry weight (5.52 g) was obtained from the control treatment (Table 6). The increase in shoot dry weight due to the recommended rate of NPS fertilizer application was by 63.95% as compared to the control treatment. The increase in shoot dry weight of garlic could be due to the increased application of NPS that might have attributed to the maximum vegetative growth, assimilates production and accumulation of carbohydrates which increased shoot dry weight of garlic. In agreement with this, Abera (2020) reported that the application of blended NPS fertilizer improved root growth and increased the uptake of nutrients that favor better vegetative growth and delayed senescence of leaves which resulted in the maximum above ground dry biomass per plant. Mohamed and Wagi (2021) also reported that the highest dry weight of above ground biomass in onion was obtained from the application of 250 kg ha^{-1} NPS fertilizer while the lowest value was observed from the control treatment. On the contrary, Muluneh *et al.* (2018) indicated that the application of NPS fertilizer did not significantly influence the shoot dry weight of onion.

The application of zinc fertilizer at the rate of 0.6% resulted in the highest shoot dry weight (8.34 g), which was statistically similar with the application of 0.9% zinc rate. On the other hand, the lowest shoot dry weight (7 g) was recorded from the control treatment but statistically similar to the application of 0.3% zinc rate (Table 6). The increase in shoot dry weight due to the application of zinc (0.6%) fertilizer was by 19.14% as compared to the control treatment. This increment in shoot dry weight in response to Zn application could be due to its role on photosynthetic activity and assimilates production and partitioning to the plant parts. This eventually caused an increased dry matter accumulation in the shoot. In agreement with this, Kulthe *et al*. (2022) stated that foliar application of $ZnSO_4$ at a rate of 0.5% resulted in maximum shoot dry weight in garlic, while the lowest was recorded from the control treatment. Arif *et al*. (2016) also indicated that garlic plants attained higher leaves dry weight in response to zinc application.

Table 6. Effect of NPS and zinc fertilizers on shoot dry weight of garlic

NPS rate (kg ha^{-1})	Shoot dry weight(g)
0	5.52^{c}
121	7.66^{b}
242	9.05^{a}
363	8.95^{a}
Significance level	***
Zn rate (%)	
0	7.00^{c}
0.3	7.63^{bc}
0.6	8.34^{a}
0.9	8.21^{ab}
Significance level	***
CV (%)	8.22

Means in the table followed by the different letter(s) are significantly different to each other, *** = significant at $P \leq 0.001$; CV= coefficient of variation.

4.4. Yield and Yield Components

4.4.1. Bulb length

Bulb length was significantly influenced by the main and interaction effects of NPS and zinc fertilizers application rates (Appendix Table 2). The longest bulb length (4.98 cm) was measured from the combined application of 242 kg ha^{-1} NPS and 0.6% zinc fertilizers, which was statistically similar with the application of 363 kg ha^{-1} NPS with 0.6% zinc. However, the smallest bulb length (2.95 cm) was recorded from the control treatment, which was statistically similar to the application of different zinc rates alone (Table 7). The increase in bulb length due to the application of 242 kg ha^{-1} of NPS with 0.6% of zinc was by 28.5% and 68.81% as compared to the application of 242 kg ha^{-1} NPS without zinc and the control treatment, respectively. The increase in bulb length by the application of the higher amount of NPS and Zn ascribed to the more availability of nutrients which caused vigorous vegetative growth and increased assimilates production that led to accelerated translocation of assimilates in to bulbs. This consequently resulted in an increased bulb length. In agreement with this, Maritu (2019) reported that the highest bulb length in onion was obtained from the application of 271.12 kg ha^{-1} NPS, whereas the lowest was obtained from the control treatment.

Similarly, Mohamed and Wagi (2021) described that the highest onion bulb length was obtained from the highest NPS (250 kg ha^{-1}) fertilizer application while the lowest bulb length was from the control treatment. In addition, Shura *et al.* (2022) stated that the longest bulb length in onion was recorded from the application of 242 kg ha^{-1} NPS fertilizer. However, Shege (2015) and Muluneh *et al*. (2018) described that NPS fertilizer did not significantly affect the bulb length of garlic and onion, respectively.

Begum *et al*. (2015) reported that the application of Zn at 4 kg ha^{-1} had a significant positive effect on onion bulb length. In agreement with this, Rohidas *et al*. (2010) and Choyal *et al*. (2022) indicated that the increase in average bulb weight of garlic with the increased level of Zn fertilizer application and in turn caused an increased bulb length of garlic.

4.4.2. Bulb diameter

Bulb diameter was also significantly influenced by the main and interaction effects of NPS and zinc application rates (Appendix Table 2). The widest bulb diameter (4.44 cm) was measured from the combined application of 242 kg ha^{-1} NPS and 0.6% zinc fertilizers application, which was statistically similar to the application of 242 kg ha^{-1} of NPS and 0.3% zinc fertilizers application. On the other hand, the narrowest bulb diameter (2.60 cm) was recorded from the control treatment (Table 7). The application of NPS at a rate of 242 kg ha^{-1} with 0.6% zinc increased bulb diameter by 17.77% as compared to the application of 242 kg ha^{-1} NPS and 0% Zn fertilizers. The increment in bulb diameter might be due to the higher amount of NPS application that could have been attributed to the synergetic role played by the three nutrients in providing a balanced supply of nutrients to the crop. The application of a balanced amount of N, P and S as well as Zn had a great effect on the vegetative growth and assimilate production that in turn led to the increased translocation of assimilates into bulbs, which resulted in increased bulb diameter.

Similarly, Shege *et al*. (2017) reported that the widest bulb diameter in garlic was achieved by the application of the highest rate of NPS fertilizer (140:122.6:22.60 N: P_2O_5: S kg ha^{-1}), while the narrowest bulb diameter was obtained from the control treatment. Shura *et al*. (2022) also stated that the widest bulb diameter in onion was obtained from the highest NPS (363 kg ha^{-1}) fertilizer rate, which was statistically similar to the application of 242 kg ha^{-1} NPS, whereas the lowest bulb diameter was recorded from the control treatment. However, Muluneh *et al*. (2018) stated that the diameter of onion bulb was not significantly influenced by the application of different NPS fertilizer rates.

Babaleshwar *et al*. (2017) reported that the application of zinc fertilizer at a rate of 0.5% resulted in the widest bulb diameter and the control treatment resulted in the narrowest bulb diameter (5.4 cm) of onion. Kelem *et al*. (2024) also found that the widest bulb diameter in onion was obtained from foliar application of ZnSO4 at 0.75%, which was statistically similar to the application of 0.5%, whereas the lowest bulb diameter was recorded from the control. Similarly, Bhat *et al*. (2018) reported that the widest bulb diameter of onion was recorded from the application of zinc at a rate of 7.5 kg ha^{-1} and the narrowest bulb diameter was recorded from the control treatment.

Table 7. Interaction effect of NPS and zinc fertilizers on bulb length, bulb diameter, clove length and diameter of garlic

NPS rate (kg ha^{-1})	Zn rate (%)	Bulb length (cm)	Bulb diameter (cm)	Clove length (cm)	Clove diameter (cm)
0	0	2.95^{g}	2.60^{f}	2.17^{l}	1.02^{i}
	0.3	3.32^{fg}	3.33^{e}	2.29^{j}	1.09^{gh}
	0.6	3.34^{fg}	3.80^{cd}	2.33^{ij}	1.15^{fg}
	0.9	3.27^{fg}	3.43^{de}	2.22^{k}	1.08^{hi}
121	0	3.65^{ef}	3.80^{cd}	2.32^{ij}	1.20^{ef}
	0.3	3.94^{de}	3.83^{cd}	2.38^{gh}	1.21^{ef}
	0.6	3.89^{de}	3.77^{cd}	2.38^{gh}	1.24^{e}
	0.9	3.88^{de}	3.88^{bc}	2.34^{ih}	1.21^{ef}
242	0	3.88^{de}	3.77^{cd}	2.42^{fg}	1.26^{e}
	0.3	4.51^{bc}	4.29^{ab}	2.57^{ab}	1.51^{b}
	0.6	4.98^{a}	4.44^{a}	2.61^{a}	1.59^{a}
	0.9	4.28^{cd}	3.97^{bc}	2.49^{de}	1.36^{cd}
363	0	3.60^{ef}	3.60^{c-e}	2.45^{ef}	1.33^{d}
	0.3	4.48^{bc}	4.0^{bc}	2.54^{bc}	1.42^{c}
	0.6	4.88^{ab}	4.03^{bc}	2.51^{cd}	1.42^{c}
	0.9	4.48^{bc}	3.89^{bc}	2.47^{de}	1.34^{d}
Significance level		*	*	*	***
CV (%)		6.27	6.00	1.04	3.20

Means in the table followed by the different letter(s) are significantly different to each other at * = significant at $P \leq 0.05$; ***= significant at $P \leq 0.001$; CV= coefficient of variation.

4.4.3. Clove length

The main effects of NPS and zinc application rates as well as their interaction significantly influenced clove length (Appendix Table 2). The longest clove length (2.61 cm) was obtained by the combined application of 242 kg ha^{-1} NPS and 0.6% zinc, which was statistically similar to 242 kg ha^{-1} NPS and 0.3% zinc application rates. However, the narrowest clove length (2.17 cm) was recorded from the control treatment (Table 7). The increase in clove length due to the combined application of 242 kg ha^{-1} NPS and 0.6% zinc was 7.85 and 20.28% as compared to 242 kg ha^{-1} NPS without zinc and the control treatment, respectively. This could be due to the combined application of NPS and Zn that favored the maximum clove length by enhancing physiological activity and metabolic process which increased vegetative growth, dry matter production and translocation of photosynthates that contributed to the enlargement of bulbs and resulted in increased clove length. In agreement with this, Bewket (2021) described that the increased level of NPS fertilizer application promoted vigorous vegetative growth and increased production of assimilates and translocation to bulbs that ultimately resulted in larger bulb weight. This in turn caused an increased clove length of garlic.

Kulthe *et al*. (2022) reported that foliar application of $ZnSO_4$ at a rate of 0.5% significantly influenced clove length in garlic. They also stated that the maximum value in clove length was recorded from foliar application of $ZnSO_4$ at a rate of 0.5%, while the lowest clove length was recorded from the control treatment. Significantly increase the clove length of garlic due to the application of zinc sulfate (0.25%) also reported by Chanchan *et al*. (2013). Similarly, Rohidas *et al*. (2010) indicated the significant increment of clove length of garlic due to the application of zinc micronutrient.

4.4.4. Clove diameter

The main as well as their interaction effect of NPS and zinc fertilizers application rates significantly ($P \leq 0.001$) influenced clove diameter (Appendix Table 2). The widest clove diameter (1.59 cm) was recorded by the combined application of 242 kg ha^{-1} NPS and 0.6% zinc, which was followed by the application of 242 kg ha^{-1} NPS and 0.3% zinc application rates. However, the narrowest clove diameter (1.02 cm) was recorded from the control treatment (Table 7). The increase in clove diameter due to the combined application of 242 kg ha^{-1} NPS and 0.6% zinc application rates were 26.19 and 55.88% as compared to the application of 242 kg ha^{-1} NPS without zinc and the control treatment, respectively. The increase in clove diameter might be attributed to the application of higher amount of NPS and Zn which increased the vegetative growth and produces good quality foliage that promotes carbohydrate synthesis through photosynthesis and translocation that ultimately increased clove size of garlic that in turn resulted in wider clove diameter. In agreement with this, Bewket (2021) described that the increased level of NPS fertilizer application promoted vigorous vegetative growth and increased production of assimilates and translocation to bulb that ultimately resulted in larger bulb weight. This in turn increased the clove diameter of the garlic.

Kulthe *et al*. (2022) reported that foliar application of $ZnSO_4$ at a rate of 0.5% resulted in maximum clove diameter in garlic which was superior over the control. Similarly, Rohidas *et al*. (2010) indicated the significant increment of clove diameter of garlic due to the application of zinc micronutrient.

Clove number per bulb was significantly ($P \leq 0.001$) influenced by the main effects of NPS and zinc application rates, while the interaction of both did not significantly affect this parameter (Appendix Table 2). The highest clove number per bulb (15.02) was recorded by the application of 242 kg ha^{-1} NPS fertilizer which was statistically similar to the application of 363 kg ha^{-1} NPS. However, the lowest clove number per bulb (9.42) was recorded from the control treatment (Table 8). The increase in clove number due to the application of 242 kg ha^{-1} NPS was by 59.45% as compared to the control treatment. The increase in clove number in response to the increased NPS application might be due to the application of a balanced amount of N, P and S that had a great effect on the vegetative growth and assimilates production. This eventually led to the increased translocation of the assimilates into cloves which resulted in an increased number of cloves. In agreement with this, Mekides *et al.* (2020) reported the significant effect of blended NPS fertilizer on tuber number of potato. They observed that the maximum tuber number per hill was recorded from the application of NPS (55.5: 89.7:16.52 kg ha^{-1}) fertilizer, while the lowest tuber number per hill was recorded from unfertilized treatment. However, the current finding is in contrast with the finding of Abera (2020) who reported the non-significant influence of NPS fertilizer on cloves number per bulb of garlic.

The application of zinc fertilizer at a rate of 0.6% resulted in the highest clove number (14.57) which was statistically similar to the application rate of 0.3% zinc. However, the lowest clove number (11.67) was recorded from the control treatment (Table 8). The increase in clove number due to the application of zinc (0.6%) fertilizer was by 24.85% as compared to the control treatment. This could be due to the function of zinc in translocation of photosynthates from one plant part to the other, mainly for rapid translocation and storage of food material in the bulb which ultimately increased the number of cloves per bulb in garlic. In line with this, Kulthe *et al*. (2022) reported that the maximum number of cloves per bulb was obtained from foliar application of ZnSO4 at 0.5%, while the lowest number of cloves per bulb was recorded from the control treatment. Arif *et al*. (2016) also suggested the increased number of cloves per bulb in garlic in response to zinc application. However, Srivastava *et al*. (2005) observed that the number of cloves per bulb in garlic was not influenced by the foliar application of zinc micronutrient.

Table 8. Effect of NPS and zinc fertilizer rates on clove number and total dry biomass of garlic

NPS rate (kg ha^{-1})	Clove number	Total dry biomass(g)
0	9.42^{c}	30.82^{d}
121	13.95^{b}	38.56^{c}
242	15.02^{a}	42.26^{b}
363	14.91^{a}	46.10^{a}
Significance level	***	***
Zn rate (%)		
0	11.67^{c}	35.06^{c}
0.3	14.15^{a}	38.57^{b}
0.6	14.57^{a}	42.30^{a}
0.9	12.91^{b}	41.81^{a}
Significance level	***	***
CV (%)	6.83	5.92

Means in the table followed by the different letter are significantly different to each other at *** = significant at $P \leq 0.001$, CV- coefficient of variation.

4.4.6. Total dry biomass

The main effects of NPS and zinc significantly ($P \leq 0.001$) influenced total dry biomass, while the interaction of both did not significantly affect this parameter (Appendix Table 3). The highest total dry biomass (46.10 g) was attained from the application of the highest NPS rate (363 kg ha^{-1}), which was followed by the application of 242 kg ha^{-1} of NPS (42.25 g). On the other hand, the lowest total dry biomass (30.82 g) was recorded from the control treatment (Table 8). The increment in total dry biomass was by 9.11 and 49.58 % as compared to the application of 242 kg ha^{-1} NPS fertilizer and the control treatment, respectively. This might be because NPS fertilizer application improves the dry weight of garlic by enhancing an increased photosynthetic area that helped for enhanced assimilates production and partitioning to the plant parts. In agreement with this, Shura *et al.* (2022) reported that the highest value of total dry biomass in onion was recorded by the application of NPS at a rate of 363 kg ha^{-1}. On the other hand, the lowest value of total dry biomass was obtained by applying 0 kg ha^{-1} of NPS level. In agreement with this, Shege *et al.* (2017) reported that the highest above ground biomass per plant was recorded from N: P_2O_5: S at the rate of 105:122.6:22.6 kg ha^{-1}, while the lowest was recorded from the control treatment. Likewise, Mekides *et al*. (2020) reported that the application of 55.5:89.7:16.52 kg ha^{-1} of NPS fertilizer increased the total dry biomass of potatoes by 74.8% as compared to the control treatment. On the contrary, Muluneh *et al*. (2018) observed that fresh and dry weights of aboveground biomass in onion crop was not significantly influenced due to the application of NPS fertilizer.

The application zinc fertilizer at the rate of 0.6% resulted in the highest total dry biomass (42.30 g) which was statistically similar to the application of 0.9% zinc rate. However, the lowest total dry biomass (35.06 g) was recorded from the control treatment (Table 8). The increase in total dry biomass due to the application of the zinc fertilizer was 20.65% as compared to the control treatment. The favorable influence of Zn application on the total dry biomass of garlic could be attributed to its role in various physiological and metabolic processes and also in translocation of photosynthates to the plant parts thereby leading to higher total dry biomass of the crop. In line with this, Kulthe *et al*. (2022) and Srivastava *et al*. (2005) reported the significant influence of Zn nutrient on vegetative growth and yield attributes of garlic, resulting in higher total dry biomass. In addition, Gurmani *et al*. (2012) described the increase in total dry biomass of tomato crop in response to zinc (10 kg ha^{-1}) fertilizer application.

4.4.7. Average bulb weight

The main effects of NPS and zinc as well as their interaction significantly ($P \leq 0.05$) influenced average bulb weight (Appendix Table 3). The highest average bulb weight (44.63g) was measured from the combined application of 242 kg ha^{-1} of NPS and 0.6% of zinc rate which was statistically similar to the application of 242 kg ha^{-1} of NPS with 0.3% and also from 363 kg ha^{-1} of NPS with 0.3% and 0.6% zinc rate application. However, the lowest average bulb weight (24.56 g) was obtained from the control treatment (Table 9). The increase in average bulb weight due to the application of 242 kg ha^{-1} of NPS and 0.6% of zinc was by15.17 and 81.72% as compared to the application of the 242 kg ha^{-1} NPS without zinc and the control treatment, respectively. This might be due to the balanced amount of N, P, S & Zn for increased vegetative growth and photosynthesis rate which produce a higher amount of photo-assimilates and translocation to the bulbs that consequently increased the average bulb weight of garlic.

In line with this, Shura *et al.* (2022) found that the highest value of average bulb weight in onion was recorded from the highest level of NPS (363 kg ha^{-1}) fertilizer, which was statistically similar to 242 kg ha^{-1} NPS while the lowest values of average bulb weight was recorded from the control treatment. Similarly, Bewket (2021) noted that the highest average bulb weight of garlic was recorded from the highest (57:114:21 kg ha^{-1}) level of NPS fertilizer. Consistent with this study, Muluneh *et al*. (2018) observed that bulb weight in onion was significantly influenced by different NPS fertilizer rates in which the application of 105:119.6:22 kg ha^{-1} N: P_2O_5: S fertilizer rate was 50.1% bigger than the control treatment.

Bhat *et al*. (2018) reported that the average bulb weight of onion was maximum from the application of rate 7.5 kg ha^{-1} Zn and the minimum from the control treatment. This was also supported by the finding of Rohidas *et al*. (2010) who reported that the highest bulb weight of garlic was obtained by zinc application. In addition, Acharya *et al.* (2015) and Choyal *et al*. (2022) found the maximum average bulb weight in onion and garlic from foliar application of zinc sulphate at 0.5 and 0.6%, respectively.

4.4.8. Average clove weight

The main effects of NPS and zinc as well as their interaction effect significantly ($P \leq 0.01$) influenced average clove weight (Appendix Table 3). The highest average clove weight (5.93 g) was obtained from the combined application rate of 242 kg ha^{-1} of NPS and 0.6% of zinc fertilizers which was statistically similar to the combined application rate of 242 kg ha^{-1} of NPS and 0.9% of zinc. However, the lowest average clove weight (2.13 g) was recorded from the control treatment (Table 9). The increase in average clove weight due to the application of 242 kg ha^{-1} of NPS with 0.6% zinc was by 36.95 and 178.40 % as compared to the application of 242 kg ha^{-1} NPS without zinc and the control treatment, respectively.

The favorable effects of these combined application, which resulted in increasing the average clove weight, might be attributed to the synergetic effect of NPS and zinc combination, in which the availability of those nutrients at optimum level led to an increase in number and weight of cloves through facilitating improved leaf growth and photosynthetic activities thereby increasing partitioning of assimilates to the storage organ. This higher photosynthate accumulation in the bulbs would ensure higher individual clove weight and number which collectively increases the average clove weight. In agreement, Bewket (2021) reported that the increase in average bulb weight of garlic with the increased level of NPS fertilizer application and that consequently resulted in maximum clove weight of garlic.

Kulthe *et al*. (2022) stated that foliar application of ZnSO4 at a rate of 0.5% resulted in the maximum clove weight in garlic which was superior to the control treatment. Choyal *et al*. (2022) also found the maximum average clove weight in garlic from foliar application of zinc sulphate at 0.6%**.**

Table 9. Interaction effect of NPS and zinc fertilizers on average bulb weight, average clove weight, total bulb yield and harvest index of garlic

NPS rate (kg ha^{-1})	Zn rate (%)	Average bulb weight (g)	Average clove weight (g)	Total bulb yield (t ha^{-1})	Harvest index (%)
0	0	24.56^{i}	2.13^{g}	8.15^{i}	85.60^{f}
	0.3	25.67^{i}	3.83^{ef}	8.67^{hi}	86.33^{e}
	0.6	28.97^{h}	3.93^{ef}	9.93^{f-h}	86.80^{cd}
	0.9	25.53^{i}	2.33^{g}	8.80^{hi}	86.57^{de}
121	0	31.13^{g}	3.30^{f}	9.65^{gh}	86.80^{cd}
	0.3	35.27^{e}	4.33^{de}	10.33^{fg}	86.83^{cd}
	0.6	36.87^{de}	4.13e	11.37^{d-f}	86.77^{cd}
	0.9	33.12^{f}	4.03^{e}	10.85^{fg}	86.87^{cd}
242	0	38.75^{cd}	4.33^{de}	10.64^{fg}	86.77^{cd}
	0.3	43.64^{a}	5.03^{bcd}	14.36^{ab}	87.27^{ab}
	0.6	44.63^{a}	5.93^{a}	14.89^{a}	87.41^{a}
	0.9	41.67^{b}	5.73^{ab}	12.69^{cd}	86.97^{bc}
363	0	36.44^{e}	4.07^{e}	10.99^{e-g}	86.73^{cd}
	0.3	43.88^{a}	4.87^{cd}	13.49^{bc}	87.00^{bc}
	0.6	44.08^{a}	5.10^{bc}	13.34^{bc}	87.03^{bc}
	0.9	39.82^{bc}	5.23^{bc}	12.35^{c-e}	86.87^{cd}
Significance level		*	**	*	***
CV (%)		3.21	9.10	7.00	0.22

Means in the table followed by the different letter(s) are significantly different to each other at * = significant at $P \leq 0.05$; **= significant at $P \leq 0.01$; ***= significant at $P \leq 0.001$; CV- coefficient of variation.

4.4.9. Total bulb yield

The main as well as the interaction effects of NPS and zinc significantly ($P \leq 0.05$) influenced the total bulb yield of garlic (Appendix Table 3). The highest total bulb yield (14.8 9 t ha^{-1}) was measured from the combined application of 242 kg ha^{-1} of NPS and 0.6% of zinc rate which was statistically similar to the application of 242 kg ha^{-1} of NPS and 0.3% zinc rate. However, the lowest bulb yield (8.15 t ha^{-1}) was obtained from the control treatment (Table 9). The increase in total bulb yield due to the application of 242 kg ha^{-1} of NPS and 0.6% of zinc fertilizer was by 39.94 and 82.70 % as compared to the application of 242 NPS kg ha^{-1} without zinc and the control treatment, respectively. The increment in bulb yield due to the combined application of NPS and Zn fertilizers could be due to the role of those abundantly available nutrients that could have enhanced vigorous vegetative growth and increased photosynthetic rate which increased the amount of assimilates that could be partitioned to the storage organs which consequently increased the bulb yield. In agreement with this, Kelem *et al*. (2024) reported that the highest total bulb yield in onion was obtained from the combined application of 242 kg ha^{-1} of NPS and 0.75% $ZnSO_4$, while the lowest was obtained from the control treatment.

Bewket (2021) found that significantly higher bulb yield of garlic was recorded from NPS (57: 114: 21 kg ha^{-1}) fertilizer application, which was 65% higher than the control treatment. Similarly, Muluneh *et al*. (2018) reported that the highest total bulb yield of onion was obtained from NPS fertilizer application at rate of 105:119.6:22 kg ha^{-1} N: P_2O_5: S, while the lowest was obtained from the control treatment. Chala *et al.* (2022) also observed the maximum total bulb yield of onion due to the application of 200 kg ha^{-1} of NPS while the minimum total bulb yield was obtained from 0 kg ha^{-1} NPS fertilizer application.

The application of zinc sulphate at a rate of 0.6% produced a significantly maximum bulb yield in garlic, which increased by about 14.71% over the control treatment (Choyal *et al*. 2022). Similarly, Kulthe *et al*. (2022) reported that the maximum bulb yield per hectare of garlic was obtained from foliar application of $ZnSO_4$ at a rate of 0.5%, while the lowest yield per hectare was recorded from the control treatment. In addition, Babaleshwar *et al*. (2017) stated that the highest total bulb yield of onion was recorded from the application of 0.5% Zn rate and the lowest total bulb yield was recorded from the control treatment. However, Zhimomi (2022) indicated that zinc application up to 2.5% rate resulted in the highest total bulb yield of garlic while the minimum was recorded from the control treatment.

4.4.10. Harvest index

The main effects of NPS and zinc as well as their interaction significantly affected harvest index of garlic (Appendix Table 3). The highest harvest index (87.41%) was measured from the combined application of 242 kg ha^{-1} of NPS with 0.6% zinc which was statistically similar with the combined application of 242 kg ha^{-1} of NPS and 0.3% zinc rate. However, the lowest harvest index (85.60%) was obtained from the control treatment (Table 9). The increase in harvest index due to the application of 242 kg ha^{-1} of NPS with 0.6% zinc was by 0.74 and 2.11% as compared to 242 kg ha^{-1} NPS without zinc application and the control treatment, respectively. The increase in harvest index due to the balanced amount of N, P, S & Zn application might be ascribed to the role of those abundantly available nutrients that enhanced vigorous vegetative growth and increased photosynthetic rate which increased the amount of assimilates that could be partitioned to the storage organs which consequently increased the harvest index. In consistent with this, Diriba (2014) reported that the highest harvest index of garlic was recorded due to the increased rate of N, P and S fertilizer. Similarly, Abera (2020) found that the maximum harvest index in garlic was due to the application of 305.5 kg ha^{-1} blended NPS fertilizer and the lowest from the control treatment. On the other hand, Mekides *et al*. (2020) described that the increased in the rate of NPS fertilizer led to lower harvest indices.

4.5. Quality Parameters

4.5.1. Percent dry matter

Percent dry matter content was significantly ($P \leq 0.05$) affected by the main effects of NPS and zinc as well as by their interaction effect (Appendix Table 4). The highest percent dry matter content (43.18) was attained from the combined application of 242 kg ha^{-1} of NPS with 0.6% zinc rate which was statistically similar with different treatment combinations. However, the lowest percent dry matter content (25.67) was obtained from the control treatment (Table 10). The increase in percent dry matter content due to the application of 242 kg ha^{-1} of NPS and 0.6% zinc fertilizer was by 24.12 and 68.21% as compared to the application of 242 kg ha^{-1} of NPS without zinc and the control treatment, respectively. This might be ascribed to the higher amount of available nutrients in NPS and Zn that resulted in vigorous vegetative growth of the plant and ultimately resulted in higher production of photo-assimilates or dry matter and translocation to the bulbs that in turn increased dry matter content of the bulbs.

In line with this, Amin (2018) described that the highest dry matter content of Potato was obtained from the application of highest NPS (150 kg ha^{-1}) blended fertilizer and the lowest dry matter content was obtained from the control treatment. Similarly, Minwyelet (2017) and Melkamu and Minwyelet (2018) reported that the increased in tuber dry matter content of potato was due to the increased rate of NPS fertilizer application of 272 kg ha^{-1} and 283.75 kg ha^{-1}, respectively. Acharya *et al*. (2015) reported that foliar application of ZnSO4 at a rate of 0.5% significantly influenced dry mater production in onion. Manna *et al.* (2014) also reported that the dry matter content in bulb was significantly increased with the application of 0.5% zinc rate as compared to the control treatment. In addition, Solanki *et al.* (2018) reported that the increased dry mater production of onion crop in response to zinc (4 kg ha^{-1}) fertilizer application.

Table 10. Interaction effects of NPS and zinc fertilizers on percent dry matter content of garlic

NPS rate (kg ha^{-1})	Zn rate (%)	Dry matter content (%)
0	0	25.67^{h}
	0.3	29.55^{fg}
	0.6	31.57^{ef}
	0.9	27.72^{gh}
121	0	32.44^{d-f}
	0.3	34.81^{cd}
	0.6	35.69^{c}
	0.9	33.57^{c-e}
242	0	34.79^{cd}
	0.3	42.28^{ab}
	0.6	43.18^{a}
	0.9	36.28^{c}
363	0	39.73^{b}
	0.3	40.55^{ab}
	0.6	41.60^{ab}
	0.9	40.29^{ab}
Significance level		*
CV(%)		4.68

Means in the table followed by the different letter(s) are significantly different to each other at * = significant at $P \leq 0.05$; CV- coefficient of variation.

4.5.2. Total soluble solid

The main effects of NPS and Zn significantly ($P \leq 0.001$) affected total soluble solids of garlic, whereas their interaction did not significantly affect this parameter (Appendix Table 4). The highest total soluble solid (15.52°Brix) was measured from the application of 242 kg ha^{-1} of NPS which was followed by the application of 363 kg ha^{-1} NPS. However, the lowest value for total soluble solid (13.44°Brix) was obtained from the control treatment (Table 11). The increase in total soluble solid was by 15.48% as compared to the control treatment. The increase in TSS might be due to the role of balanced amount of NPS that increased vegetative growth and photosynthesis rate which produce a higher amount of photo assimilates (dry matter) and translocation to the bulbs that consequently increased TSS content of garlic bulbs. In line with this, Shura *et al*. (2022) found that the highest TSS value in onion was obtained from the highest application rate of NPS (363 kg ha^{-1}) fertilizer, which was statistically similar with 242 kg ha^{-1} of NPS and the lowest TSS value was recorded from the control treatment. Merga (2022) also reported that the highest TSS in shallot was recorded from the application of 200 kg ha^{-1} NPS fertilizer and the lowest was recorded from the nil NPS fertilizer application. In addition, Nardos (2021) reported that the highest and the lowest values of total soluble solid in tomato fruit was obtained by the application rate of 240 kg ha^{-1} of NPS and the control treatment, respectively.

Table 11. Effect of NPS and zinc fertilizers on TSS of garlic

NPS rate (kg ha^{-1})	**TSS (%)**
0	13.44^{c}
121	13.89^{c}
242	15.52^{a}
363	14.99^{b}
Significance level	***
Zn rate (%)	
0	13.77^{b}
0.3	14.97^{a}
0.6	15.08^{a}
0.9	14.02^{b}
Significance level	***
CV(%)	4.19

Means in the table followed by the different letter(s) are significantly different from each other *** = significant at $P \leq 0.001$, CV = coefficient of variation.

The application of Zn fertilizer at the rate of 0.6% resulted in the highest total soluble solid (15.08 °Brix), which was statistically similar with the application rate of 0.3% Zn. On the other hand, the lowest total soluble solid (13.77°Brix) was recorded from the control treatment but statistically similar to the application rate of 0.9% Zn (Table 11). The increase in total soluble solid due to the application rate of Zn fertilizer was 9.51 % as compared to the control treatment. The increased in TSS due to the contribution of micronutrient (Zn) for quality traits like total soluble solid might be owing to its role in increased carbohydrate production during photosynthesis and consequently more translocation of photoassimilates towards the bulb. In agreement with this, Manna *et al*. (2014) reported that zinc fertilizer at a rate of 0.5% exhibited the best quality in terms of total soluble solid attributes in onion. Similarly, Babaleshwar *et al*. (2017) also stated that the highest TSS of onion was recorded from the application rate of $ZnSO_4$ at 0.5% while the lowest TSS was recorded from the control treatment. Furthermore, Bhat *et al*. (2018) also reported a significant response of vegetable crops to zinc application, in which increased zinc levels significantly increased the TSS value in onion. However, Zhimomi (2022) found the highest value of TSS in garlic from the application rate of zinc at 2.5% while the lowest was recorded from the control treatment.

4.6. Clove Size Category

4.6.1. Marketable clove size (MC, >2.5 g)

The main effects of NPS and Zn as well as their interaction significantly affected very large size marketable clove (MC, >2.5 g) of garlic both in weight and number (Appendix Table 5). The highest marketable clove size (MC, >2.5 g) both in weight (92.44g) and in number (30.00) was measured from the combined application of 242 kg ha^{-1} of NPS and 0.6% of zinc. However, the lowest marketable clove size in weight (35.97 g) and number (11.67) was obtained from the control treatment (Table 12). The increment of marketable clove size due to 242 kg ha^{-1} of NPS with 0.6% of zinc fertilizer application might be attributed to the supply of sufficient nutrients that promoted vigorous vegetative growth which resulted in increased photosynthesis and production of assimilates and translocation towards cloves that might led to the increase in weight which resulted in higher proportion of marketable clove size. In agreement, Adekpe *et al,* (2007) indicated that garlic plants which attained higher vegetative growth earlier possibly had developed higher marketable clove size. Shege (2017) also reported that the increased marketable bulb yield of garlic due to the application of the increased fertilizer rate ultimately led to a higher proportion of marketable clove size.

4.6.2. Marketable clove size (MC, 2.0- 2.5g)

The main effect NPS and Zn as well as their interaction significantly affected large size marketable clove (MC, 2.0-2.5 g) of garlic both in weight and in number (Appendix Table 5). The highest marketable clove size (MC, 2.0-2.5g) both in weight (37.56g) and in number (18.00) was measured from the combined application of 242 kg ha^{-1} of NPS and 0.6% of Zn. However, the lowest marketable clove size both in weight (5.84g) and in number (2.67) was obtained from the control treatment (Table 12). The increment of marketable clove size due to 242 kg ha^{-1} of NPS with 0.6% of Zn fertilizer application might be attributed to the supply of sufficient nutrients that promoted vigorous vegetative growth which resulted in increased photosynthesis and production of assimilates and translocation towards cloves that might lead to the increase in weight which resulted in higher proportion of marketable clove size. Similarly, Adekpe *et al.* (2007) indicated that garlic plants which attained higher vegetative growth earlier possibly had developed higher marketable clove size

Table 12. The interaction effect of NPS and zinc fertilizers on marketable clove size of garlic

Treatments		Marketable clove size			
NPS rate (kg ha^{-1})	Zn rate (%)	Very large size weight(g)	Very large size number (No)	Large size weight (g)	Large size number (No)
0	0	35.97^{h}	11.67^{h}	5.84^{h}	2.67^{h}
	0.3	45.21^{g}	13.33^{gh}	14.33^{f}	6.33^{fg}
	0.6	45.89^{fg}	14.33^{f-h}	14.77^{f}	6.67^{fg}
	0.9	42.03^{g}	13.00^{h}	10.20^{g}	4.67^{g}
121	0	50.91^{f}	17.00^{e-g}	15.44^{f}	6.67^{fg}
	0.3	59.54^{e}	17.67^{ef}	17.59^{e-f}	8.00^{d-f}
	0.6	61.01^{e}	18.33^{d-f}	19.87^{de}	9.33^{cde}
	0.9	58.19^{e}	17.33^{ef}	17.01^{ef}	7.67^{ef}
242	0	68.43^{d}	19.00^{de}	20.08^{de}	9.33^{c-e}
	0.3	91.26^{a}	25.67^{b}	32.97^{b}	15.00^{b}
	0.6	92.44^{a}	30.00^{a}	37.56^{a}	18.00^{a}
	0.9	83.77^{b}	22.00^{b-d}	28.33^{c}	13.67^{b}
363	0	75.41^{c}	19.67^{de}	21.45^{d}	10.00^{cd}
	0.3	80.81^{bc}	24.00^{bc}	30.31^{bc}	14.67^{b}
	0.6	80.45^{bc}	22.33^{b-d}	27.13^{c}	13.00^{b}
	0.9	78.82^{bc}	21.00^{c-e}	21.91^{d}	10.67^{c}
Significance level		**	*	**	**
CV (%)		4.93	11.40	11.36	11.69

Means in the table followed by the different letter(s) are significantly different to each other at * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; CV- coefficient of variation.

4.6.3. Acceptably marketable clove size (AMC, 1.5-1.99 g)

The main effect NPS and zinc as well as their interaction significantly affected acceptable marketable clove size (Appendix Table 5). The combined application of 242 kg ha^{-1} of NPS fertilizer with 0.6% of Zn produced the highest proportion of medium-sized marketable cloves both in weight (35.95g) and in number (21). However, the lowest medium size marketable clove both in weight (9.70) and in number (5.67) was obtained from the control treatment (Table 14).

The increase in marketable clove size due to 242 kg ha^{-1} of NPS fertilizer with 0.6% of Zn application could be attributed to the increased photosynthetic area of leaves resulting in higher dry matter accumulation and partitioning of assimilates to the cloves which promote better clove size formation. In agreement, Adekpe *et al*. (2007) indicated that garlic plants which attained higher vegetative growth earlier possibly had developed higher acceptable marketable clove size. Tadesse (2015) also reported that the increased marketable bulb yield of garlic due to the application of the increased fertilizer rate that consequently resulted in higher proportion of medium-sized marketable cloves.

4.6.4. Scarcely marketable clove size (SMC, 1.0-1.49 g)

The main effect NPS significantly ($P \leq 0.001$) influenced scarcely marketable clove size. However, Zn rate and the interaction effect of NPS and Zn rate did not significantly affect this parameter (Appendix Table 6). The highest scarcely marketable clove size both in weight (21g) and in number (17.42) was obtained from the control treatment (Table13). This might be as a result of the lower vegetative growth because of insufficient supply of NPS fertilizer that reduced the physiological activity and metabolic process which caused the development of small cloves and resulted in higher proportion of scarcely marketable clove size both in terms of weight and number. In agreement, Bewket (2021) and Shege (2015) indicated that garlic plants which attained lower vegetative growth due to nil NPS fertilizer application resulted in reduced average bulb weight and that consequently led to higher proportion of scarcely marketable clove size.

Table 13. Effect of NPS and zinc fertilizers on scarcely marketable clove size of garlic

NPS rate (kg ha^{-1})	Scarcely marketable clove size	
	Small size clove weight (g)	Small size clove number (No)
0	21.00^{a}	17.42^{a}
121	16.80^{b}	13.42^{b}
242	12.58^{c}	9.50^{c}
363	13.62^{bc}	11.25^{bc}
Significance level	***	***
CV (%)	29.51	26.83

Means in the table followed by the different letter(s) are significantly different to each other at *** = significant at $P \leq 0.001$, ns = non- significant, CV- coefficient of variation.

4.6.5. Unmarketable clove size (UMC, <1.0 g)

Unmarketable clove size was significantly affected by the main effect NPS and zinc as well as their interaction (Appendix Table 6). The highest unmarketable clove size both in weight (21.13 g) and in number (40.33) was obtained from the control treatment (Table 14). The increment of unmarketable clove size from the control treatment might be due to the insufficient supply of NPS and zinc fertilizers that resulted in lower vegetative growth which possibly had developed small bulbs that might led to the development of small clove weight that in turn resulted in higher proportion of unmarketable clove size. Similarly, Liu *et al*. (2010) indicated that inadequate level of plant nutrient led to weak vegetative growth and poor bulb formation which consequently resulted unmarketable clove size in garlic. Shege (2015) also reported that the increased unmarketable bulb yield of garlic due to reduced fertilizer application that ultimately resulted lower proportion of unmarketable clove size.

Table 14. The interaction effect of NPS and zinc fertilizers on acceptable marketable clove size and unmarketable clove size of garlic

Treatments		Acceptable marketable clove size		Unmarketable clove size	
NPS rate (kg ha^{-1})	Zn rate (%)	Medium size clove weight (g)	Medium size clove number (No)	Very Small size clove weight (g)	Very Small size clove number (No)
0	0	9.70^{i}	5.67^{k}	21.13^{a}	40.33^{a}
	0.3	9.97^{i}	6.33^{jk}	16.16^{b}	31.67^{b}
	0.6	14.25^{gh}	8.33^{h-j}	13.95^{bc}	20.67^{c}
	0.9	12.00^{hi}	7.33^{i-k}	12.00^{cd}	18.00^{cd}
121	0	15.18^{gh}	8.67^{hi}	11.45^{c-e}	16.00^{de}
	0.3	16.11^{fg}	10.00^{f-h}	9.02^{d-h}	12.67^{fg}
	0.6	18.99^{ef}	11.00^{e-g}	9.43^{d-g}	12.00^{f-h}
	0.9	17.21^{fg}	9.00^{g-i}	10.16^{d-f}	13.33^{e-g}
242	0	19.52^{ef}	11.33^{ef}	8.67^{d-h}	15.00^{d-f}
	0.3	21.62^{de}	17.33^{bc}	3.87^{ij}	5.67^{lk}
	0.6	35.95^{a}	21.00^{a}	2.78^{j}	3.67^{l}
	0.9	32.58^{b}	18.67^{b}	6.44^{g-i}	8.67^{i-k}
363	0	20.88^{de}	12.00^{d-f}	8.23^{e-h}	10.33^{g-i}
	0.3	29.85^{bc}	16.00^{c}	5.51^{h-j}	7.00^{jk}
	0.6	27.30^{c}	14.00^{d}	6.90^{f-i}	8.67^{i-k}
	0.9	23.90^{d}	12.67^{de}	7.75^{f-h}	9.00^{h-j}
Significance level		***	***	*	***
CV (%)		9.88	9.86	19.69	12.25

Means in the table followed by the different letter(s) are significantly different to each other at * = significant at $P \leq 0.05$, *** = significant at $P \leq 0.001$, CV- coefficient of variation.

4.7. Results of Correlation Analysis for Growth, Yield Components and Some Quality Parameters of Garlic

Correlation coefficient was calculated for the different response variables which help to show how the growth characters and yield components affected bulb yield and quality of garlic. All growth, yield and quality parameters (except days to emergence) were significantly and positively correlated with each other. Thus, it was observed that total bulb yield was significantly and positively correlated with days to maturity (r=0.58***), plant height (r=0.78***), leaf length (r=0.81***), leaf diameter (r=0.63***), leaf number (r=0.69***), neck diameter (r=0.79***) and shoot dry matter (r=0.81***). This indicated that the vigorous vegetative growth of the plant significantly increased the production of photoassimilates that caused increased yield and quality of garlic. Guesh (2015) and Shege *et al*. (2017) also indicated that total bulb yield in garlic had a positively strong association with growth attributes (plant height, leaf number, leaf length and bulb length). Similarly, Farooqui *et al*. (2009) showed that the adequate supply of nutrient in garlic had a positive association with vigorous vegetative growth that led to higher productivity of the crop.

The correlation analysis further indicated that the total bulb yield of garlic was significantly and positively correlated with bulb length (r=0.86***), bulb diameter (r=0.65***), average bulb weight (r=0.89***), average clove weight(r=0.78***), total dry biomass (r=0.78***), harvest index (r=0.65***), dry mater content (r=0.84***) and total soluble solid (r=0.75***) (Table 15). The increment in bulb yield was a result of increase in yield component of garlic which led to enhanced bulb weight and number that caused increased yield and other quality attribute of garlic. Shege *et al*. (2017) also indicated that the garlic total bulb yield had a positively strong association with bulb length, bulb diameter, bulb weight and marketable bulb yield.

Table 15. Correlation analysis of phenological, growth, yield and quality parameters of garlic as influenced by the application of NPS and zinc fertilizers

PAR	DE	DM	PH	LL	LD	LN	ND	SDW	BL	BD	ABW	ACW	CL	CD	CN	TDB	TBY	HI	PDM	TSS
DE	1																			
DM	-0.78***	1																		
PH	-0.76***	0.68***	1																	
LL	-0.83***	0.68***	0.81***	1																
LD	-0.55***	0.35*	0.69***	0.71***	1															
LN	-0.60***	0.40*	0.64***	0.71***	0.69***	1														
ND	-0.79***	0.65***	0.82***	0.90***	0.63***	0.63***	1													
SDW	-0.79***	0.60***	0.75***	0.85***	0.65***	0.65***	0.81***	1												
BL	-0.73***	0.47**	0.78***	0.79***	0.69***	0.70***	0.77***	0.79***	1											
BD	-0.57***	0.36*	0.52***	0.63***	0.65***	0.66***	0.68***	0.50***	0.62***	1										
ABW	-0.84***	0.66***	0.82***	0.88***	0.59***	0.66***	0.87***	0.85***	0.87***	0.63***	1									
ACW	-0.66***	0.52***	0.76***	0.70***	0.57***	0.61***	0.71***	0.65***	0.74***	0.68***	0.80***	1								
CL	-0.63***	0.44**	0.69***	0.77***	0.56***	0.57***	0.78***	0.75***	0.72***	0.61***	0.79***	0.62***	1							
CD	-0.76***	0.58***	0.76***	0.80***	0.61***	0.68***	0.81***	0.79***	0.87***	0.71***	0.91***	0.75***	0.81***	1						
CN	-0.77***	0.57***	0.77***	0.84***	0.57***	0.57***	0.85***	0.79***	0.79***	0.67***	0.87***	0.77***	0.73***	0.81***	1					
TDB	-0.82***	0.63***	0.81***	0.85***	0.69***	0.70***	0.81***	0.87***	0.81***	0.54***	0.85***	0.69***	0.71***	0.76***	0.79***	1				
TBY	-0.71***	0.58***	0.78***	0.81***	0.63***	0.69***	0.79***	0.81***	0.86***	0.65***	0.89***	0.78***	0.77***	0.91***	0.77***	0.78***	1			
HI	-0.58***	0.37**	0.53***	0.65***	0.63***	0.65***	0.69***	0.50**	0.61***	0.99***	0.63***	0.67***	0.62***	0.71***	0.66***	0.54***	0.65***	1		
PDM	-0.79***	0.71***	0.83***	0.81***	0.58***	0.60***	0.84***	0.71***	0.83***	0.68***	0.90***	0.81***	0.70***	0.89***	0.84***	0.77***	0.84***	0.68***	1	
TSS	-0.59***	0.44***	0.55***	0.67***	0.51**	0.54***	0.59***	0.69***	0.71***	0.61***	0.76***	0.64***	0.66***	0.77***	0.68***	0.66***	0.75***	0.60***	0.63***	1

Where**:** PAR=parameter, DE- days to emergence, DM- days to maturity, PH-plant height, LL- leaf length, LD -leaf diameter, LN-leaf number per plant, ND-neck diameter, SDW-shoot dry weight, BL- bulb length, BD- bulb diameter, ABW-average bulb weight, ACW-average clove weight, CL- clove length, CD- clove diameter, CN- clove number per bulb, TDB- total dry biomass, TBY-total bulb yield, HI- harvest index, PDM- percent dry matter and TSS-total soluble solid. * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$, and *** = significant at $P \leq 0.001$.

4.8. Partial Budget Analysis

The results of the partial budget analysis (Table 16) revealed that applying 242 kg ha^{-1} of NPS and 0.6% of Zn had the highest net benefit (1606330 Birr ha^{-1}) and MRR of 116.61% followed by the combined application of 242 kg ha^{-1} of NPS and 0.3% Zn with a net benefit of 1574030 Birr ha^{-1} and MRR of 1407.22%. Thus, the application of 242 kg ha^{-1} of NPS with 0.6 and 0.3% Zn are recommended as first and second options, respectively, for garlic production in the study area.

Table 16. Summary of partial budget and marginal rate of return analysis for garlic production as influenced by NPS and zinc fertilizer during the irrigation season of 2022/23

Treatments		AvY	AjY	TVC	GFB	NB	MRR
NPS rate (kg ha^{-1})	Zn rate (%)	(t ha^{-1})	(t ha^{-1})	(Eth-birr)	(Eth-birr)	(Eth-birr)	%
0	0	8.15	7.34	0	917500	917500	-
	0.3	8.67	7.8	27700	975000	947300	D
	0.6	9.93	8.94	55400	1117500	1062100	D
	0.9	8.8	7.92	83100	990000	906900	D
121	0	9.65	8.69	6635	1086250	1079615	24433.33
	0.3	10.33	9.3	34335	1162500	1128165	D
	0.6	11.37	10.23	62035	1278750	1216715	D
	0.9	10.85	9.77	89735	1221250	1131515	D
242	0	10.64	9.58	13270	1197500	1184230	1676.71
	0.3	14.36	12.92	40970	1615000	1574030	1407.22
	0.6	14.89	13.4	68670	1675000	1606330	116.61
	0.9	12.69	11.42	96370	1427500	1331130	D
363	0	10.99	9.89	19905	1236250	1216345	799.72
	0.3	13.49	12.14	47605	1517500	1469895	D
	0.6	13.34	12.01	75305	1501250	1425945	D
	0.9	12.35	11.12	103005	1390000	1286995	D

Where: AvY-average yield; AjY- adjustable yield; TVC - total variable cost; GFB - gross field benefit; NB-net benefit; ETB- Ethiopian's birr; D-Dominated; Selling price of garlic at farm gate = 125 Birr kg^{-1}; Purchasing costs of NPS fertilizer= 35 Eth-Birr kg^{-1}; Cost of $ZnSO_4$ =1500 ETB kg^{-1}; Labor cost for fertilizers application = 300 Eth-Birr Man per day.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

Garlic is a highly demanded crop both locally and internationally and also the most paramount economic crop for low-income smallholder farmers in Ethiopia, which is used as spice and flavoring agent for foods and as medicinal plant. However, production and productivity from its yield potential is by far lower compared to other countries. This low yield is mainly due to the depletion of macro and micronutrients from the soil and inadequate and unbalanced use of fertilizer that limit its production. In view of this, the current study is conducted to evaluate the effects of different rates of NPS and Zn fertilizers on growth, yield and quality of garlic (*Allium sativum* L.) during 2022/23 season using irrigation at Debre Berhan University, College of Agriculture and Natural Resource Sciences demonstration and research site. The treatments consisted of four rates of NPS fertilizer (0, 121, 242 and 363 NPS kg ha^{-1}) and four rate of Zn micronutrient (0, 0.3, 0.6 and 0.9%) and laid out in a factorial arrangement using a randomized complete block design with three replications.

The study revealed that the combined application of NPS and zinc at different levels significantly determined most of the parameters evaluated in this experiment. The results showed that the main effect of NPS fertilizer and zinc rate significantly influenced most of growth parameters (except neck diameter) and some yield and quality parameters. However, most of yield and quality parameters were significantly influenced by their interaction. Of all the treatment combinations evaluated, the combined application of 242 kg ha^{-1} of NPS and 0.6% of zinc rate provided the highest and consistent result for different growth, yield and quality parameters of garlic. The widest neck diameter (1.52cm), the highest average bulb weight (44.63g), average clove weight (5.93 g), total bulb yield (14.89 t ha^{-1}), harvest index (87.41%) and percent dry matter content (43.18) were produced from the combined application of 242 kg ha^{-1} of NPS and 0.6% of Zinc.

The increase in total bulb yield due to the combined application of 242 kg ha^{-1} of NPS and 0.6% of zinc was by 39.94 and 82.70% as compared to the application of 242 NPS kg ha^{-1} without zinc and the control treatment, respectively. Similarly, these combined application increased harvest index and percent dry matter by 0.74 and 24.12% as compared to as 242 kg ha^{-1} of NPS without zinc fertilizer application, respectively. In addition, a partial budget analysis also showed that the combined application of 242 kg ha^{-1} of NPS and 0.6% of zinc rate is economically the most feasible in reducing cost of production and increase the profit gained. However, as the experiment was done for only one season and single location it is hardly possible to give a conclusion, while it has to be repeated over seasons and locations to draw sound conclusions and recommendations for optimum garlic.

6. REFERENCES

Abd El-Samad, E. H. A., Khalifa, R. K. M., Lashine, Z. A., & Shafeek, M. R. (2011). Influence of urea fertilization and foliar application of some micronutrients on growth, yield and bulb quality of onion. *Australian Journal of Basic and Applied Sciences*, *5*(5), 96-103.

Abedin, M. J., Alam, M. N., Hossain, M. J., Ara, N. A., & Haque, K. M. F. (2012). Effect of micronutrients on growth and yield of onion under calcareous soil environment. *International Journal of Biosciences (IJB)*, 2(8), 95-101.

Abera Jaleta Berkessa. (2020). growth, yield and yield attributes of garlic (*Allium sativum* L.) as influenced by the interaction of varieties and rates of NPS blended fertilizer in mettu, southwestern Ethiopia. MSc thesis.

Abiti Getaneh Gebremeskel. (2011). Ethiopian Water Resource Potential and Development. Ministry of Water and Energy.

Abraham, A. D., Kidanemariam, D. B., & Holton, T. A. (2019). Molecular identification, incidence and phylogenetic analysis of seven viruses infecting garlic in Ethiopia. *European Journal of Plant Pathology*, *155*, 181-191.

Abreham Mulatu, Bizuayehu Tesfaye and Essubalew Getachew. (2014). Growth and bulb yield garlic varieties affected by nitrogen and phosphorus application at Mesqan districts, South Central Ethiopia. *Journal of Agricultural Research* Vol. 3 Pp. 249 – 255.

Acharya, U., Venkatesan, K., Saraswathi, T., & Subramanian, K. S. (2015). Effect of zinc and boron application on growth and yield parameters of multiplier onion (*Allium cepa* L. var aggregatum Don.) var. CO (On) 5. *International Journal of Research*, *2*(1), 757-765.

Achieng, J. O., Ouma, G., Odhiambo, G., & Muyekho, F. (2010). Effect of farmyard manure and inorganic fertilizers on maize production on Alfisols and Ultisols in Kakamega, western Kenya. *Agriculture and Biology Journal of North America*, *1*(4), 430-439.

Adekpe, D. I., Shebayan, J. A. Y., Chiezey, U. F., & Miko, S. (2007). Yield responses of garlic (*Allium sativum* L.) to oxadiazon, date of planting and intra-row spacing under irrigation at Kadawa, Nigeria. *Crop protection*, *26*(12), 1785-1789.

Akuamoah-Boateng, M. (2016). Effect of poultry manure and NPK fertilizer on the growth, yield and mineral composition of onion (*Allium cepa* L.) grown in acid soil. PhD dis., University of Ghan.

Alam M N, Abedin M J and Azad M.A. K. (2010). Effect of micronutrients on growth and yield of onion under calcareous soil environment. *International Research Journal of Plant Science*,1, 56-61.

Alam, S. M., Mahmood, I. A., Ullah, M. A., Naseeb, T., Nawab, N. N., Haider, S. I., & Aamir, S. S. (2019). Growth and yield of garlic (*Allium Sativum*) influenced by Zn and Fe application. *Food Biology*, *8*, 13-15.

Alemayehu, M., Tesfa, F., Bizuayehu, S., & Ayele, B. (2015). Amhara Region Horticultural Development Strategy 2015–2020. *AgroBIG and ANRS BoA*, *Bahir Dar, Ethiopia*, *127*.

Alemu Degwale, Nigussie Dechassa and Fikreyohannes Gedamu. (2016). Effect of vermicompost on growth, yield and quality of garlic (*Allium sativum* L.) in Enebse Sar Midir District, Northwestern Ethiopia. Journal of Natural Sciences Researc, 6(3) ISSN2224-3186 (Paper) ISSN 2225-0921 (Online).

Alemu Degwale. (2014). Effect of Vermicompost and Inorganic NP Fertilizers on Growth, Yield and Quality of Garlic (*Allium Sativum* L.) in Enebse Sar Midir District, Northwestern Ethiopia. MSc thesis submitted to Haramaya University, Haramaya, Ethiopia.

Ali, S.M.D. (2013). Effects of micronutrients on growth, yield and quality of three varieties of summer onion. MSc (Agri) thesis submitted to Bangladesh Agriculture University, Mymensing.

Allen, J. (2009). Garlic production. Factsheet, Garlic production, order number 97-007. www.omafra.gov.on.ca/english/crops/facts/09-011w.htm.

Alloway, B.J. (2008). Zinc in soils and crop nutrition. 2nd ed. International Zinc Association and International Fertilizer Industry. Brussels. Belgium. 5.

Amin M.M.U., Rahim M.A., and Hashem M.A. (1995). Influences of planting time and nitrogen on the growth and yield of onion. *Bangladesh Journal*. *Scientific and Indust*. Res. 30:2-3.

Amin, Ababiya. (2018). Integrated use of NPS blended fertilizer and cattle manure on growth, yield and quality of potato (*Solanum tuberosum* L.) under Dabo Ghibe Kebele, Seka Werada of Jimma Zone, Southwest Ethiopia (Doctoral dissertation, Jimma University).

Amin, M. R., Hasan, M. K., Naher, Q., Hossain, M. A., & Noor, Z. U. (2007). Response of onion to NPKS fertilizers in low ganges river flood plain soil. Int. J. Sustain. Crop Prod, 2(1), 11-14.

Amin, M., Tadele, S., & Selvaraj, T. (2014). White rot (*Sclerotium cepivorum-Berk*) an aggressive pest of onion and garlic in Ethiopia: An overview. *Journal of Agricultural Biotechnology and Sustainable Development*, 6(1), 6-15.

Arif, U., Hussain, S., Shah, S. Z. A., Hamid, A., Yaqoob, A., Arif, A. A & Muneer, N. (2016). Interactive effect of phosphorus and zinc on the growth, yield and nutrient uptake of garlic (*Allium sativum* L.) variety Gulabi. *Asian Journal of Agriculture and Food Sciences*, *4*(5).

Asfaw. Zeleke and Eshetu Derso. (2015). Production and Management of Major Vegetable Crops in Ethiopia, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia. Volume I, page 149.

Ashebre, K. M. (2015). On Opportunities and Potential in Ethiopia for Production of Fruits and Vegetable. *International Journal of African and Asian Studies*, 15.

ATA (Agricultural Transformation Agency). (2016). Transforming the use of fertilizer in Ethiopia: Launching the national fertilizer blending program; February 12, 2013.

Babaleshwar, S. B., Koppad, S. R., Dharmatti, P. R., & Math, K. K. (2017). Impact of micronutrients on growth, yield and quality of onion (*Allium cepa* L). *International Journal of Pure & Applied Bioscience, 5*, 1205-1209.

Bachmann, J. (2001). Organic Garlic Production. National sustainable agriculture information service. Davis, California, USA. (http://attra.ncat.org/attra- Pub/PDF/garlic.pdf.

Ballabh, K., & Rana, D. K. (2012). Response of micronutrients on qualitative and quantitative parameters of onion (*Allium cepa* L.). *Progressive Horticulture*, *44*(1), 40-46.

Ballabh, K., Rana, D.K. and Rawat, S.S. (2013). Effects of foliar application of micronutrients on growth, yield and quality of onion. *Indian Journal of Horticulture*. 70(2): 260-265.

Barman, H., Das, S.K.& Roy, A. (2018). Zn in soil environment for plant health and management strategy. *Universal Journal of Agricultural Research,* 6 (5),149- 154.

Bashour, I. I., & Sayegh, A. H. (2007). Methods of analysis for soils of arid and semi-arid regions. Food and agriculture organization of the United Nations. Rome, 119 p.

Batal, K., Bondari, K., Granberry, D. and Mulinix, B. (1994). Effects of source, rate and frequency of N application on yield, marketable grades and rot incidence of sweet onion (*Allium cepa* L.) Granex 33. *Journal of Horticultural Science*. 69(6): 1043-1051.

Begum, R. A. B. I. A., Jahiruddin, M., Kader, M. A., Haque, M. A., & Hoque, A. B. M. A. (2015). Effects of zinc and boron application on onion and their residual effects on Mungbean. *Progressive Agriculture*, *26*(2), 90-96.

Belay Y (2015). Integrated soil fertility management for better crop production in Ethiopia. *International Journal of Soil Science* 10:1-16.

Bewket, Gashaw. (2021). Evaluation of different rates of NPS on growth and yield performances of garlic (Allium sativum L.) in Cheha District, Gurage Zone, Ethiopia. *International Journal of Agronomy, 2021*, 1-5.

Bhagwan, S. C., Soni, A. K., & Khaswan, S. L. (2012). Growth, yield and quality of garlic (*Allium sativum* L.) as influenced by different nutrient management practices. *Asian Jornual. Agriculture. Research*, *8*, 211-217.

Bhandari, S. A., Patel, K. S., & Nehete, D. S. (2012). Effect of integrated nutrient management on growth, yield and quality of garlic (*Allium sativum* L.) cv. Gujrat Garlic-3. *Asian Journal of Horticulture*, 7(1), 48-51.

Bhat, T. A., Chattoo, M. A., Mushtaq, F., Akhter, F., Mir, S. A., Zargar, M. Y., ... & Parry, E. A. (2018). Effect of zinc and boron on growth and yield of onion under temperate conditions. *Int. J. Curr. Microbiol. App. Sci*, *7*(4), 3776-3783.

Bhat, T. A., Chattoo, M. A., Parray, E. A., Mushtaq, F., Rather, A. M., Zehra, S. B., ... & Shah, M. D. (2018). Influence of varying levels of Zn on quality attributes and shelf life of onion in Kashmir. *The Parma Innovation Journal*, *7*(7), 342-345.

Bizuayehu Desta, Kebede, Woldetsadik & Wassu Mohammed. (2021). Effect of harvesting time, curing and storage methods on storability of garlic bulbs. *The Open Biotechnology Journal*, *15*(1).

Bizuayehu, Desta., Netsanet, Tena., & Getachew, Amare. (2021). Growth and bulb yield of garlic as influenced by clove size", *Hindawi. The Scientific World Journal*, 1, 7.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils 1. *Agronomy journal*, 54(5), 464-465.

Brewster, J. (1994). Onions and other vegetable alliums. Horticultural research international, Wellesbourne, Warwick, UK University press, Cambridge, 3: 83-125.

Broadbent F.E. (1953). The soil organic fraction. Advanced. Agronomy, 5: 153-183.

Cantwell, M., Voss, R., Hanson, B., May, D., & Rice, B. (2006). Water and Fertilizer management for Garlic: Productivity, Nutrient and Water Use Efficiency, and Post-Harvest Quality. *Report of a FREP Contact*, (97-0207).

Chala Kitila, Abdisa Abraham and Soressa Shuma. (2022). Growth and bulb yield of some onion (*Allium cepa* L.) varieties as influenced by NPS fertilizer at Dambi Dollo University Research site, Western Ethiopia. *Cogent Food & Agriculture*, *8*(1), 2097606.

Chanchan, M., Hore, J. K., & Ghanti, S. (2013). Response of garlic to foliar application of some micronutrients. *Journal of Crop and Weed*, *9*(2), 138-141.

Chandra, N. and N. Pandey. (2013). Effect of sulfur on the growth, dry matter, tissue sulfur and carbohydrate concentration of *Allium sativum* L. and *Allium cepa* L. Indian J. Agr. Biochem. 26:182–186.

Cheng, B., H.F. Lian, S.Q. Liu, H.P. Guo, and Y.L. Sun. (2015). Effects of sulfur and selenium combination fertilizing on the growth, quality and antioxidant ability of allium sativum during senescence. *Plant Physiol. Journal.* 51:44–50.

Chesinin, L, and Yien, C.H. (1951). Turbid metric determination of available sulfur. Process of soil Science, 15:149- 151.

Chintala, R., McDonald, L. M., & Bryan, W. B. (2012). Effect of soil water and nutrients on productivity of Kentucky bluegrass system in acidic soils. *Journal of Plant Nutrition*, 35(2), 288-303.

Choudhary, M. K., Kavita, A., Maurya, I. B., Singh, B., Sharma, M. K., & Hatwal, P. K. (2014). Effect of biofertilizers and micronutrients on growth andyield of garlic (*Allium sativum* L.) var. 'G-282'. *Progressive Horticulture*, 46(2), 367-371.

Choyal, P., Garhwal, O. P., Choudhary, M. R., & Mahala, K. (2022). Effect of Sulphur and Micronutrients on the Yield and Quality of Garlic (*Allium sativum* L). *International Journal of Environment and Climate Change*, *12*(3), 15–22.

CIMMYT Economics Program. (1988). From agronomic data to farmer recommendations: an economics training manual (No. 27). CIMMYT.

Cottenie I. (1980). Soil and plant testing as a base for fertilizer recommendation. FAO soils bulletin No.38/2, FAO, and Rome Italy/.

Cottenie, A., Verloo, M., Kickens, L., Velghe, G and Camerlynck, R. (1982). Chemical analysis of plants and soils, laboratory of analytical and Agro chemistry. State university, Ghent Belgium. Pp63.

CSA (Central Statistical Agency). (2022). Report on Farm Management Practices report on area and production of major crops (private peasant holdings, meher season) volume I, part III Ethiopian statistics service agricultural sample survey (2021/22). Federal Democratic Republic of Ethiopia, Central Statistical Authority, Addis Ababa. Statistical Bulletin 593. Pp. 19-31.

Currah, L and Rabinowitch HD. (2002). Allium Crop Science: Recent Advances, CABI publishing. Pp. 329–515.

Dayi, R.U. (2008). Effects of NPK Fertilizer and Intra – row Spacing on the Growth and Yield of Garlic (*Allium sativum* L.). Paper Presented during the Second National Conference of the Joint CST of Hassan Usman Katsina Polytechnic 27 –30thNovember, 2008.

DBARC (Debre Berhan Agricultural Research Center). (2021). Registration of "Qundi" Garlic variety.

Diriba Shiferaw. (2014). Response of Garlic (*Allium sativum* L.) to Fertilizer Management in Ada'a District, Central Highland of Ethiopia. PhD. Dissertation. Haramaya University, Haramaya, Ethiopia.

Diriba-Shiferaw, G. (2016). Review of management strategies of constraints in garlic (*Allium sativum* L.) production. *Journal of Agriculture Science*. 11(3):186–207.

Diriba-Shiferaw, G., Nigussie-Dechassa, R., Kebede, W., Getachew, T., & Sharma, J. J. (2013). Growth and nutrients content and uptake of garlic (*Allium sativum* L.) as influenced by different types of fertilizers and soils. *Science, Technology and Arts Research Journal*, *2*(3), 35-50.

Diriba-Shiferaw, G., Nigussie-Dechassa, R., Woldetsadik, K., Tabor, G., & Sharma, J. J. (2015). Effect of nitrogen, phosphorus, and sulphur fertilizers on growth yield, and economic returns of garlic (*Allium sativum* L.). *Science, Technology and Arts Research Journal*, *4*(2), 10-22.

Dufoo-Hurtado, M.D., Huerta-Ocampo, J.A., Barrera-Pacheco, A., Barba de la Rosa, A.P. and Mercado-Silva, E.M. (2015). Low temperature conditioning of garlic (*Allium sativum* L.) "seed" cloves induces alterations in sprouts proteome. Frontiers in Plant Science. 6:332.

DZARC (Debre Zeit Agricultural Research Center). (2003). Annual Research Report.2002/03.6 7.

EHPEA (Ethiopia Horticulture Producers and Exporters Association). (2013). Ethiopian Investment Commission database of licensed projects; Embassy of Ethiopia in China; All Africa.

EIA (Ethiopia Investment Agency). (2012). Investment Opportunity Profile for the production of Fruits and Vegetables in Ethiopia, Addis Ababa; 2012.

Elhifny, I. (2010). Response of Garlic (Allium Sativum L.) to Some Sources of Organic Fertilizers under North Sinai Conditions. *Research Journal of Agriculture and Biological Sciences*, 6 (6): 928-936.

Elosta, A., Slevin, M., Rahman, K., & Ahmed, N. (2017). Aged garlic has more potent antiglycation and antioxidant properties compared to fresh garlic extract in vitro. *Scientific reports*, *7*(1), 39613.

El-Shafie, F. S., & El-Gamaily, E. (2002). Effect of organic manure, sulphur and microelements on growth, bulb yield, storability and chemical composition of onion plants. *Minufiya Journal of Agricultural Research*, *27*(2), 407-424.

FAO (1984). Highland reclamation study Ethiopia. Final report volume 1 and 2 Rome.

FAO (Food and Agriculture Organization). (2006). Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant Nutrition Bulletin 16, Rome.

FAOSTAT (Food and Agriculture Organization Statistics). (2022). Food and agriculture data access our website: https://www.fao.org/faostat/en/#home. Accessed December 27, 2023.

FAOSTAT (Food and Agriculture Organization Statistics). (2022). List of countries by garlic production, Retrieved 9 June 2022.

Farooqui M., Naruka I., Rathore S., Singh P. and Shaktawat R. (2009). Effect of nitrogen and sulphur levels on growth and yield of garlic (*Allium sativum* L.). Asian Journal of Food and Agro-Industry, 19-23.

Fikreyohanne, Gedamu. (2005). Effect of Clove Size and Plant Density on the Bulb Yield and Yield Components of Garlic (*Allium sativum* L.) in Awabel Woreda, Eastern Gojjam Zone. M.Sc. Thesis Submitted to School of Graduate Studies of Alemaya University, Ethiopia. Pp 19-41.

Fouda K F. (2017). Response of Onion Yield and Its Chemical Content to NPK Fertilization and Foliar Application of Some Micronutrients. Egypt. J. Soil Sci. pp.1-12.

Gao, X. P., Zhang, F. S., &Hoffland, E. (2009). Malate exudation by six aerobic rice genotypes varying in Zn uptake efficiency. Journal of Environmentalquality,38(6), 2315–2321.

Gebrehaweria Teklemariam and Nigussie Dechassa. (2007). Effects of mulching, nitrogen and phosphorus on yield and yield components of garlic (*Allium sativum* L.) at Alshaday, Eastern Zone of Tigray, Northern Ethiopia. M.Sc. Thesis. Haramaya Univesrity, Ethiopia.

Gebremedhin Woldewahid, Berhanu Gebremedhin, Kahsay Berhe, and Dirk Hoekstra. (2010). Improving Livelihood of Small-scale Farmers through Market Led Irrigated Crops: Case Study from Tigray, Northern Ethiopia. Conference on International Research on Food Security, Pp-1-4.

Geleta D.S. (2014). Response of Garlic (Allium sativum L.) to Fertilizer Management in Ada'a District, Central Highland of Ethiopia. Dissertation submitted to Haramaya University, Haramaya, Ethiopia.

Getachew Alemayehu and Asefa Abate. (2021). Influence of integrated soil fertilization on the productivity and economic return of garlic (*Allium sativum* L.) and soil fertility in northwest Ethiopian highlands. *Open Agriculture*, *6*(1), 714-727.

Getachew Amare & Temesgen, Mamo, (2020). Effects of nitrogen and NPS fertilizer rates on fresh yield of garlic (*Allium sativum* L.) at Debre Berhan, Ethiopia. *Journal of Agriculture and Crops*, 68(68), 113–118.

Getachew Tabor and Asfaw Zelleke. (2000). Research achievements in garlic and shallot. Research Report. No. 36. Ethiopian Agricultural Research Organization, Addis Ababa. Ethiopia. Pp 43.

Gledhill, D. (2008). The names of plants. Cambridge University Press.

Gomez, K.A., and A.A. Gomez. (1984). Statistical Procedures for Agricultural Research. John Willey and Sons, New York. 390 p.

Goronski, J., Beer U., Johnson, M. and Jocelyn, C. (2010). Improving and preparing soil for growing garlic in Gloucester and surrounding areas. *The Gloucester Project Inc*, (1): 2- 12.

Govind, Maji, S., Kumawat, R., Pal, A., Kumar, S. and Saha, S. (2015). Improvement of growth, yield and quality of garlic (*Allium sativum* L.) cv. G-282 through a novel approach. The Bioscan. 10(1): 23-27.

Gubb, I., R. and Tavis, M., S., H. (2002). Onion pre harvest and post-harvest considerations. In: H.D. Rabinowitch and L. Currah (eds.). Allium Crop Science, CABI. pp. 237-250.

Guesh Tekle. (2015). Growth, yield, and quality of onion (*Allium cepa* L.) as influenced by intra-row spacing and nitrogen fertilizer levels in central zone of Tigray, Northern Ethiopia. MSc. Thesis, Haramaya University, Haramaya, Ethiopia.

Gurmani, A.R., J.U. Din, S.U. Khan, R. Andaleep, K. Waseem, A. Khan and Hadyat-Ullah, (2012). Soil Application of zinc improves growth and yield of tomato. *International Journal of Agriculture & Biolog*., 14(1): 91–96.

Hafeez, B. M. K. Y., Khanif, Y. M., & Saleem, M. (2013). Role of zinc in plant nutrition-a review. *American journal of experimental Agriculture*, *3*(2), 374-391.

Hamma IL, Ibrahim U, Mohammed AB. (2013). Growth, yield and economic performance of garlic (*Allium sativum* L.) as influenced by farm yard manure and spacing in Zaria, Nigeria. Journal of Agricultural Economics and Development 2(1):001-005.

Hassan, A. (2015). Improving growth and productivity of two garlic cultivars (Allium sativum L.) grown under sandy soil conditions. *Middle East Journal of Agriculture Research* 04(02):332-346.

Hazelton, P. and Murphy, B. (2007). Interpreting soil test results: what do all the numbers mean 2nd(ed). Department of natural resources. CSIRO publishing. Australia. Pp. 77-79.

Hector, S., Espino F. San J. H., Olivio H. H. (2012). Agronomic and Biotechnological Strategies for Breeding Cultivated Garlic in Mexico, Prof. Mahmut Caliskan (Ed.), Genetic Diversity in Plants, ISBN: 978-953-51-0185-7.

Hore J.K., Granit S. and Chanchan M. (2014). Influence of Nitrogen and Sulphur Nutrition on Growth and Yield of Garlic (*Allium sativum* L.) *Journal of Crop and Weed* 10(2):14-18.

Hussena S, Medhinbs F, Tadesse A (2014). Effect of intra-row spacing on growth performance of garlic (*Allium sativum* L) at the experimental site of Wollo University, South Wollo, Ethiopia. European Journal of Agriculture and Forestory Research 2(4):54-61

Ipek M., Ipek A. Almquist S.G. and Simon P.W. (2005). Demonstration of linkage and development of the first low-density genetic map of garlic, based on AFLP markers. Theor. Appl. Genet. 110:228-236.

Jafar, M., Degefa, G., Wakgari, G., & Benti, G. (2021). Adaptation trail of garlic (Allium sativum L.) varieties in the high land of eastern hararghe zone, Oromia, Ethiopia. *American Journal of Life Sciences*, *9*(1), 7-10.

Jaggi, R.C., & Raina, S.K. (2008). Direct, residual and direct + residual effects of sulphur in garlic (*Allium sativum* L) – maize (Zea mays) cropping sequence. *Journal of Environmental Biology*. 29(1), 85-88.

Jamali, G., Enteshari, S.H., Hosseini, S.M. (2011). Study Effect Adjustment drought stress application Potassium and zinc in corn. Iranian Journal of crop ecophysiology. 3(3):216-222.

Jenkins P. and Ali H. (1999). Growth of Potato Cultivars in Response to Application of Phosphate Fertilizer. *Annals of Applied Biology*, 135(12):431-438,

Johnson, G.V. and P.E. Fixen. (1990). Testing Soils for Sulfur, Boron, Molybedenum and Cholorine. In: Soil Testing and Plant Analysis, Westermann, R.L. (ED.). 3rd Edn., *Soil Science Society of America, Madison*, USA., pp: 265-273.

Jones B. (2003). Agronomic Handbook: Management of Crops, Soils, and Their Fertility. CRC Press LLC, Boca Raton, FL, USA. 482p.

Jones C, Kathrin OR, Courtney PD. (2011). Nutrient uptake timing by crops to assist with fertilizing decisions. Department of Land Resources and Environmental Science. Montana State University, Bozeman. http://msuextension.org/publications/AgandNaturalResources/EB0191.pdf.

Kakar, A., Abdullahzai, M., Saleem, M. and Shah, S. (2002). Effect of Nitrogenous Fertilizer on Growth and Yield of Garlic. *Asian Journal of Plant Sciences*. 1(5): 544-545.

Kamenetsky, R. and H. Rabinowitch. (2001). Floral development in bolting garlic. Sex and Plant Reproduction, 4: 235-241.

Kelem,Muluneh., Tiru Tesfa., and Bizuayehu Desta. (2024). Effect of NPS and Zinc Fertilizer Rates on Growth and Yield of Onion (Allium cepa L.) at Shewa Robit, North Shewa, Ethiopia. *Applied and Environmental Soil Science, 2024(9).*

Khan, A. A., Zubair, M., Bari, A., & Maula, F. (2007). Response of onion (*Allium cepa* L) growth and yield to different levels of nitrogen and zinc in swat valley. *Sarhad Journal of Agriculture*, *23*(4), 933.

Kilgori M J, Magaji M D & Yakubu A I. (2007). Productivity of two garlic (*Allium sativum* L.) cultivars as affected by different levels of nitrogenous and phosphorus fertilizers in Sokota, Nigeria. Am-Eur. *Journal of Agriculture. Environment*. Sci. 2: 158–162.

Kolota, E and Osinska M. (2001). Efficiency of foliar nutrition of field vegetables grown at different nitrogen rates. *Acta Horticulture*, 563: 87-91.

Kulthe, S. D., Pawar, G. S., & Pawar, P. T. D. V. (2022). Effects of micronutrients on growth, yield & storage of garlic (*Allium sativum* L.). The Pharma Innovation Journal; 11(12): 2045-2048.

Kumar, P., Kamboj, D., Sharma, R. R., & Thind, V. (2019). Effect of integrated nutrient management on growth and yield of garlic (*Allium sativum* L.). *Journal of Pharmacognosy and Phytochemistry*, *8*(3), 2569-2572.

Landon, J. R. (1991). Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evolution in the tropics and subtropics. Longman Scientific and Technical. Essex, New York. 474p.

Lawrence, R. and Lawrence, K. (2011). Antioxidant activity of garlic essential oil (*Allium sativum* L) grown in north Indian plains. *Asian Pacific Journal of Tropical Biomedicine*,1, 51-54.

Lemma Dessalegn and Hearth, E. (1994). Agronomic studies on allium. In: Horticulture research and development in Ethiopia; Proceedings of the p. 139-152, 1994 (Eds.). National Horticultural Workshop of Ethiopia, 2nd, Dec 1-3, 1992. Institute of Agricultural Research, Addis Ababa, Ethiopia. Pp. 152-162.

Lindsay WL; Norvell WA. (1978). Development of DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am. J., 42:421–428.

Liu, Z., Liu, S., & Zhang, Z. (2010). Effects of sulfur on physiological characteristics and main mineral elements absorption in garlic. *China Vegetables*, (10), 46-50.

Losak, T., and Wisniowska-Kieliam, B. (2006). Fertilization of garlic (*Allium sativum* L.) with nitrogen and Sulphur. Annals Universities Mariae Curie Skodowska Section-E. Agricultura., 61, 45-50.

Lourenco Jr V, Vieira BS, Lopes EA, Villalta ON. (2018). Etiology, epidemiology, and management of white rot on onion and garlic: current knowledge and future directions for Brazil. Cientıfica. 46(3):241–256.

Lujiu, B. L., Xisheng, G., Qingsong, Z., Hongmin, X., and Lin, Z. (2004). "Balanced fertilization increases garlic yield in Anhui." Better Crops, vol. 88, pp. 4-6.

Manna, D. (2013). Growth, yield and bulb quality of onion (*Allium cepa* L.) in response to foliar application of boron and zinc. *SAARC Journal of Agriculture*, *11*(1), 149-153.

Manna, D., Maity, T. K., & Ghosal, A. (2014). Influence of foliar application of boron and zinc on growth, yield and bulb quality of onion (*Allium cepa* L.). *Journal of Crop and Weed*, *10*(1), 53-55.

Mansoub NH. (2011). Comparative effects of using garlic as probiotic on performance and serum composition of broiler chickens. Ann Biol Res 2:486 –490.

Maritu, Asefa. (2019). Effects of liming and NPS fertilizer rates on yield and yield components of onion (*Allium cepa* L.) at koga irrigation scheme, mecha district of north west Ethiopia (Doctoral dissertation).

Marschner, H. (1995). Mineral nutrition of higher plants. 2nd edition, Academic Press, London. 889.

Meena, D., Ram, R. B., Verma, R. S., & Shivran, B. C. (2019). Effect of phosphorus levels and bio-fertilizers on yield and quality parameters of garlic (*Allium sativum* L.) cv. G-282. *Pharma Innov J*, *8*, 681-683.

Mekides Mekashaw, Melkamu Alemayehu, Getachew Shumye and Amare Haileslassie (2020). Effects of blended NPS fertilizer rates on yield and yield components of potato (*Solanum tuberosum* L.) varieties at Dessie Zuria district, Northeast Ethiopia. *Cogent Food & Agriculture*, *6*(1), 1779478.

Melkamu Alemayehu and Minwyelet Jemberie. (2018). Optimum rates of NPS fertilizer application for economically profitable production of potato varieties at Koga Irrigation Scheme, Northwestern Ethiopia. *Cogent Food and Agriculture* 4: 1439663.

Meredith, T. J., & Drucker, A. (2014). Growing Garlic from True Seed. *Blogspot: Garlic Analecta*, *47*, 125-132.

Merga Afeta, B. (2022). Effects of intra-row spacing and rates of NPS fertilizer on bulb yield and yield related traits of shallot (*Allium cepa* L. var. ascalonicum backer) in chiro district, west harerghe, Ethiopia (Doctoral dissertation, Haramaya University).

Minwyelet Jemberie. (2017). Effects of NPS fertilizer rate and irrigation frequency determination method on the growth and tuber yield of potato (*Solanum tuberosum* L) in Koga Irrigation Scheme, Northwestern Ethiopia (M.Sc. thesis). Bahir Dar University, Ethiopia.

Mishra, T. D., & Vikram, B. (2017). Evaluation of Garlic (*Allium sativum* L.) germplasms for yield potential and quality characters under Allahabad agro-climatic conditions. *Journal of Pharmacognosy and Phytochemistry*, *6*(6), 433-436.

Mohamed Adem, C., & Wagi, F. G. P. L. (2021). Effects of blended NPS and vermicompost on bulb yield and storability of onion *(Allium cepa L.)* at haramaya, eastern Ethiopia (Doctoral dissertation, Haramaya university).

Muluneh Nigatu, Melkamu Alemayheu and Amare H/Sillassie. (2018). Optimum rate of NPS fertilizer for economical production of irrigated onion (*Allium cepa* L) in Dembyia District of Amhara Region, Ethiopia. *Ethiopian Journal of Science and Technology*, 11(2): 113-127.

Muneer N., Hussain M., Ahmad M.J., Khan N., Hussain N. and Hussain B. (2016). Effect of Planting Density on Growth, Yield and Quality of Garlic at Rawalakot, Azad Kashmir. International Journal of Agronomy and Agricultural Research 10(1):42-51.

Nagaich, H.N., Trivedi, S.K., & Lekgi, R. (2003). Effect of sulphur and potash on growth, yield and quality of garlic (Allium sativa Linn.). *Scientific Horticulture*, 8, 143-147.

Nai-hua Y, Dingguo Z., and Wang J. (1998). Phosphorus and Potassium Nutrient Management for Vegetable Soils in Shanghai and Guangdong. In: Donald L. Armstrong (Ed.), Better Crops International. 12(1):1.

Nardos, M. W. (2021). Effect of NPS fertilizer rates on yield and yield components of tomato (*lycopersicon esculentum* mill) varieties at ginchi, central high land of west shoa zone of Oromia, Ethiopia (Doctoral dissertation, Ambo University).

Nasereen S., Hap S. and Hossain M. (2003). Sulfur Effects on Growth Responses and Yield of Onion. *Asian J. Plant Sci.* 2(7):897-902.

Nicastro, H. L., Ross, S. A., & Milner, J. A. (2015). Garlic and Onions: Their Cancer Prevention Properties Garlic and Onions: Their Cancer Prevention Properties. *Cancer prevention research*, *8*(3), 181-189.

Olsen, S., Cole, F., Watanabe, D. and Dean, A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. Agric. Circ.939, 19 USA.

Omesh, Thakur and Vijay, Kumar. (2021). Review on Impact of Micronutrients (Zinc and Boron) in Relation to Growth, Yield and Quality of Onion. *International Journal of Current Microbiology and Applied Sciences*, 10(03): 1733-1740.

Ovesná, J., Ladislav Kucera, L., Hornícková, J., Svobodová, L., Stavelíková, H., Velísek, J. and Milella, L. (2011). Diversity of S-alk(en)yl cysteine sulphoxide content within a collection of garlic (*Allium sativum* L.) and its association with the morphological and genetic background assessed by AFLP. *Science Horticulture*. 129: 541-547.

Pandav, A. K., Nalla, M. K., Aslam, T., Rana, M. K., & Bommesh, J. C. (2016). Effect of foliar application of micronutrients on growth and yield parameters in Eggplant cv HLB 12. *significance*, *1*(1.63), 1-55.

Pankaj, P., Kujur, P. K., & Saravanan, S. (2018). Effect of different micronutrient on plant quality of broccoli (*Brassica oleracea* var. italica) CV green magic. *Journal of Pharmacognosy and Phytochemistry*, *7*(1S), 2825-2828.

Panthee, D., Bhattarai, R. and Dhakal, R. (2006). Diversity Analysis of Garlic (*Allium sativum* L.). Germplasms available in Nepal based morphological characters. *Genetical Resource of Crop Evolution*, 53, 205-212.

Potgieter, J. (2006). Verbal communication on macro-elements application time. Researcher, Limpopo Department of Agriculture. April 2006.

Pribyl, D.W., 2010. A critical review of the conventional SOC to SOM conversion factor. Geoderma 156 (3–4), 75–83.

Rafie, M. R., Khoshgoftarmanesh, A. H., Shariatmadari, H., Darabi, A., & Dalir, N. (2017). Influence of foliar-applied zinc in the form of mineral and complexed with amino acids on yield and nutritional quality of onion under field conditions. *Scientia Horticulturae*, *216*, 160-168.

Rao, M.R., Kwesiga, N.A., Duguma, F.B., Frazel, S., Jama, B., & Buresh, R. (1998). Soil fertility Replenishment in Sub-Saharan Africa. In: Agro forestry today (Debra London Ed.) *International Center for Research in Agro forestry* (ICRAF) UK. 10(2), 2 –5.

Robert, L. and Bradley, R. (2010). Moisture and Total Solids Analysis. Food Analysis. 85-104.

Rohidas, S.B., Bharadiya, P.S., Jature, S.D. and Ghate, K.B. (2010). Effect of micronutrient on growth and yield of garlic (*Allium satvium* L.) var. G-41, Asian J. Hort., 5 (2); 517-519.

Roohani, N., R. Hurrell, R. Kelishadi and Schulin, R. (2013). Zinc and its importance for human health: An integrative review. Journal of Research in Medical Sciences. 18(2): 144– 157**.**

Rubatzky, V.E., and Yamaguchi, M. (1997). World Vegetables, Principles, Production and Nutritive Values. Second edition. Chapman and Hall. International Thomson publishing, New York, USA. Pp 843.

Ryan, J. (2008). A Perspective on balanced fertilization in the Mediterranean Region. Turkish *Journal of Agriculture and Forestry*. 32, 79-89.

Ryan, J., Estefan, G., & Rashid, A. (2001). Soil and plant analysis laboratory manual. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, Manual, p: 172.

Salomon, R. (2002). Virus diseases in garlic and the propagation of virus free planting. In: Rabinwitch, H.D. and L. Currah (Eds.). *Allium crop sciences: Recent advance*s. CAB International, Wallingford, UK. Pp. 311-327.

Schollenberger C; Simon R. (1945). Determination of exchange capacity and exchangeable bases in soil-ammonium acetate method. Soil Science, 59:13–24.

Selvaraj T, Tadele S, Amin M. (2014). White rot (*Sclerotium cepivorum* Berk)-an aggressive pest of onion and garlic in Ethiopia: An overview. *Journal Agriculture Biotechnology;*30;6(1):6-15.

Sharma U and Kumar P. (2016). Extent of deficiency, crop responses and future challenges. *International Journal of Advanced Research*. 4(4):1402-1406**.**

Sharma, A., Patni, B., Shankhdhar, D., &Shankhdhar, S. C. (2013). Zinc - An Indispensable Micronutrient. *In Physiology and Molecular Biology of Plant*,19(1),11–20.

Sharma, M., & Singh, Y. (2018). Effect of Foliar Application of Zinc Sulphate on Onion. *Journal of Krishi Vigyan*, *6*(2), 43-45.

Shege Getu, Melkamu Alemayehu, Amare Haileslassie and Yigzaw Dessaleg. (2021). Assessment of small holder farmer's garlic (*Allium sativum* L.) production practices under irrigated farming system in the Highlands of Ethiopia. *African Journal of Agricultural Research*, *17*(9), 1172-1179.

Shege, G., Melkamu, A., Amare, H., & Yigzaw, D. (2017). Economic and agronomic optimum rates of NPS fertilizer for irrigated garlic (*Allium sativum* L) production in the highlands of Ethiopia. *Cogent Food & Agriculture*, *3*(1), 1333666.

Shege, Getu. (2015). Assessment of garlic production practices and effects of different rates of NPS fertilizer on yield and yield components of Garlic (*Allium Sativum* L) under irrigated farming system in Yilmana Densa district, Amhara Region, Ethiopia MSc Thesis. *Bahir Dar University*.

Shukla, Y. R., Kaushal, M., & Shilpa, V. I. J. (2018). Studies on the Effect of Macro and Micro Nutrients on Growth and Yield of Garlic (*Allium sativum* L.). *Int. J. Curr. Microbiol. App. Sci*, *7*(8), 4787-4791.

Shura, G., Beshir, H. M., & Haile, A. (2022). Improving onion productivity through optimum and economical use of soil macronutrients in Central Rift Valley of Ethiopia. *Journal of Agriculture and Food Research*, *9*, 100321.

Singh, D.P. and Tiwari. R.S. (1996). Effect of micro-nutrients on yield and quality of Onion (Allium cepa L) variety Pusa Red. *Recent Horticulture* 3:111-117.

Singh, G. and Singh, S. (2017). Effect of bio fertilizers and NPK on yield of garlic and nutrient availability of soil. *Agriways*, 5 (2): 91-96.

Solanki, V. P. S., Singh, J. P., & Singh, V. I. N. A. Y. (2018). Effect of zinc and boron nutrition on productivity and uptake of nutrients in onion (*Allium cepa* L). *Annals of Plant and Soil Research*, *20*(2), 214-217.

Srivastava, R., Agarwal, A., Tiwari, R. S., & Kumar, S. (2005). Effect of micronutrients, zinc and boron on yield, quality and storability of garlic (*Allium sativum* L). *The Indian Journal of Agricultural Sciences*, *75*(3).

Stone, D. A., D. J. Greenwood and T. V. Karpinets. (2001). Dynamic model for the effects of soil P and fertilizer P on crop growth, P uptake and soil P in arable cropping. Ann. Bot. 88: 293-306.

Stork, P., Potgieter, J., Van den Heever, E. and Niederwieser., G. (2004). Garlic Production, Guide to Garlic Production in South Africa, Agricultural Research Council-Vegetable and Ornamental Plant Institute, Roodeplaat, Pretoria.

Sumner, M.E. (2000). Handbook of Soil Science, CRC Press, Boca Raton, FL.

Sung, S.Y., L.T. Sin, T.T. Tee, S.T. Bee, and W.A.W.A. Rahman. (2014). Control of bacteria growth on ready-to-eat beef loaves by antimicrobial plastic packaging incorporated with garlic oil. Food Control 39:214–221.

Surendra, S. (2008). Effect of sulphur on yields and S uptake by onion and garlic grown in acid alfisol of Ranchi. Agricultural Science Digest. 28(3), 189-191.

Tadesse Abadi. 2015. Growth and yield response of garlic (*Allium sativum* L.) varieties to N fertilizer rates at Gantaafeshum, Northern Ethiopia. Msc. Thesis, Haramaya University, Haramaya, Ethiopia.

Takkar, P. N., & Randhawa, N. S. (1980). Zinc deficiency in Indian soils and plants. In *Proceedings of Seminar on Zinc Wastes and their Utilization* (pp. 15-16).

Tantawy E. and Beik E. (2009). Relationship between Growth, Yield and Storability of Onion with Fertilization of Nitrogen, Sulphur and Copper under Calcareous Soil Conditions. *Res.J.Agri. biological.* 5(6):361-371.

Tekalign Taddese. (1991). Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia.

Teklu E., Karl S., Getachew T. (2004.) Integration of Organic and Inorganic Fertilizers: Effect on Vegetable Productivity. www.tropentag.de 200 abstracts full 20.pdf. pp. 1-9.

Tibebu S., Melese T., Abrham S. and Samuel U., (2014). The effect of variety, nitrogen and phousphorous fertilization on growth and bulb yield of onion (*Allium Cepa* L.) at Wolaita, Southern Ethiopia. Journal of Biology, Agriculture and Healthcare, 4(11): 2224-3208.

Tisdale, S. L., Nelson, W. L. and Beaten, J. D. (1985). Micronutrients and other beneficial elements in soils and fertilizers. In: Soil Fertility and Fertilizers, Zinc. Macmillan Publishing Company, New York. pp.387-388.

Tisdale, S., Nelson, W., Beaton J. and Halvin, J. (1995). Soil Fertility and Fertilizers 5th Edition. Macmillan Publishing Co., Inc. New York. pp. 109-229.

Tripathi, D. K., Singh, S., Singh, S., Mishra, S., Chauhan, D. K., and Dubey, N. K. (2015). Micronutrients and their diverse role in agricultural crops: advances and future prospective. *Acta Physiologiae Plantarum*, *37(7)*, 1-14.83.

USSLS (United States Salinity Laboratory Staff). (1954). Diagnosis and improvement of saline and alkali soils. USDA Agri. Handbook. No. 60. 160 p.

Veer, D. R., Jagtap, V. S., Wankhede, S. S., Kharade, M. R., and Chavan, S. S. (2021). Effect of sources and levels of sulphur on growth and yield of garlic (*Allium sativum* L.). *The Pharma Innov. J*, *10*(10), 754-757.

Walkley, A. and Black, I. (1934). An examination of the Degtjareff method for determining soil organic matter and proposed modification of the titration method, Soil Science, 37: 29– 38.

Wiersinga, R. C., & de Jager, A. (2009). Business opportunities in the Ethiopian fruit and vegetable sector. Ministry of Agriculture, Nature and Food Quality.

Workat Sebnie, Merse Mengesha, Gebrehana Girmay and Tesfaye Feyisa. (2018). Response of garlic (*Allium sativum* L.) to nitrogen and phosphorus under irrigation in Lasta district of Amhara Region, Ethiopia. *Cogent Food & Agriculture*, *4*(1), 1532862.

Wu, B. M., Davis, M., & Turini, T. (2010). Developing New Integrated Strategies for Controlling White Rot in Garlic. In Third Annual Symposium Spotlights Research Spring. California Garlic & Onion Research Advisory Board.

Yadav P.K. (2003). Effect of nitrogen and potassium on growth and yield of garlic (Allium sativum L.) in western Rajasthan. *Haryana J. Hort*. Sci., 32: 290-91.

Yadav, L. M., Singh, Y. P., Kumar, J., Prasad, S. S., and Mishra, A. K. (2018). Response of zinc and boron application on yield, yield parameters and storage quality of garlic (*Allium sativum* L.) var. G-282. *Journal of Pharmacognosy and Phytochemistry*, *7*(1), 1768-1770.

Yohannes, U. (1994). The effect of nitrogen, phosphorous, potassium, and sulphur on the yield and yield components of Enset (*Ensete ventricosum* W.) in southeast Ethiopia. Doctoral dissertation. Institute of Plant nutrition, Faculty of Agriculture. Justus Liebig University, Giessen, Germany.

Yousuf, M.N., Hasan, M.M., Brahma, S., Sultana, D. and Kabir, A.F. (2016). Responses of garlic to zinc, copper, boron and molybdenum Application in grey terrace soil of amnura soil series. *Bangladesh Journal of Agricultural Research*, *41*(1), pp.85-90.

Zaman M.S., Hashem M.A., Jahiruddin M., Rahim M.A. (2011). Effect of Nitrogen for Yield Maximization of Garlic in Old Brahmaputra Flood Plain Soil. Bangladesh Journal of Agricultural Research 36(2): 357-367.

Zhimomi, L. K. (2022). Effect of micronutrients on growth, yield and quality of garlic (*Allium sativum* L.). *The Pharma Innovation Journal*, 11(1): 249-251.

7. APPENDICES

Appendix Table 1. Mean square from analysis of variance (ANOVA) for days to emergence and maturity, plant height, leaf length, leaf diameter, leaf number, neck diameter and shoot dry weight of garlic as influenced by NPS and Zn fertilizer.

Source of variation	DF	DE	DM	PH	LL	LD	LN	ND	SDW
Rep	2	0.81 *	13.15 ns	25.98 ns	2.81 ns	0.05 ns	3.33 *	0.001 ns	4.50 **
NPS	3	31.58 ***	466.97 ***	498.97 ***	193.69 ***	0.32 ***	6.27 ***	0.22 ***	32.42 ***
Zinc	3	0.08 ns	23.58 ns	144.54 ***	25.49 ***	0.40 ***	3.27 **	0.02*	4.50 ***
NPS x Zn	9	0.28 ns	3.29 ns	1.87 ns	3.51 ns	0.05 ns	0.22 ns	0.01 ***	0.47 ns
Error	30	0.21	12.61	10.62	1.99	0.03	0.41	0.001	0.41
CV (%)		3.00	2.42	5.45	3.45	6.81	6.91	2.66	8.22

Where**:** - DF - degree of freedom, DE - days to emergence, DM - days to maturity, PH - plant height, LL - leaf length, LD – leaf diameter, LN - leaf number, ND – neck diameter, SDW – shoot dry weight.

Appendix Table 2. Mean square from analysis of variance (ANOVA) for bulb length, bulb diameter, clove length, clove diameter and clove number per bulb of garlic as influenced by NPS and Zn fertilizer.

Source of variation	DF	BL	BD	CL	CD	CN
Rep	2	0.13 ns	1.68 ***	0.0002 ns	0.009 *	0.98 ns
NPS	3	3.69 ***	1.45 ***	0.19 ***	0.29 ***	84.07 ***
Zinc	3	1.21 ***	0.70 ***	0.036 ***	0.05 ***	20.63 ***
NPS x Zn	9	0.15 *	0.15 *	0.003 **	0.01 ***	1.42 ns
Error	30	0.06	0.05	0.0006	0.002	0.83
CV (%)		6.27	6.00	1.04	3.20	6.83

Where**: -** DF – degree of freedom, Rep.-replication, BL-bulb length, BD - bulb diameter, CL - clove length, CD - clove diameter, CNB – clove number per bulb.

Appendix Table 3**.** Mean square from analysis of variance (ANOVA) for total dry biomass, average bulb weight, average clove weight, total bulb yield and harvest index of garlic as influenced by NPS and Zn fertilizer.

Source of variation	DF	TDB	ABW	ACW	TBY	HI
Rep	2	12.00 ns	1.01 ns	2.70 ***	0.33 ns	1.63 ***
NPS rate	3	509.64 ***	654.11 ***	11.40 ***	45.31 ***	1.31 ***
Zinc rate	3	135.11 ***	79.27 ***	3.93 ***	13.78 ***	0.60 **
NPS x Zn	9	4.57 ns	3.57 *	0.62 *	1.52 *	0.17 *
Error	30	5.45	1.32	0.15	0.62	0.04
CV (%)		5.92	3.21	9.10	7.00	0.22

Where: - DF – degree of freedom, Rep.-replication, TDB - total dry biomass, ABW - average bulb weight, ACW - average clove weight, TBY - total bulb yield, HI - harvest index.

Appendix Table 4**.** Mean square from analysis of variance (ANOVA) for percent dry matter and total soluble solid of garlic as influenced by NPS and Zn fertilizer.

Source of variation	DF	PDMC	TSS
Rep	2	23.69 **	3.57 **
NPS rate	3	350.64 ***	11.02 ***
Zinc rate	3	58.01 ***	5.26 ***
NPS x Zn	9	7.43 *	0.25 ns
Error	30	2.77	0.37
CV (%)		4.68	4.19

Where: - DF – degree of freedom, Rep.-replication, PDMC - percent dry matter content, TSS - total soluble solid.

Appendix Table 5. Mean square from analysis of variance (ANOVA) for marketable clove size and acceptably marketable clove size of garlic as influenced by NPS and Zn fertilizer.

Source of variation	DF	MC			AMC		
		Very large size weight	Very large size number	Large size weight	Large size number	Medium size Weight	Medium size Number
Rep	2	9.90 Ns	8.58 ns	147.02 ***	30.08 ***	187.76 ***	60.58 ***
NPS rate	3	4499.63 ***	284.74 ***	803.04 ***	194.58 ***	668.27 ***	239.17 ***
Zinc rate	3	378.37 ***	45.91 *	213.0 ***	50.30 ***	130.22 ***	37.00 ***
NPS x Zn	9	42.64 *	12.22 *	23.66 *	5.39 *	44.25 ***	10.24 ***
Error	30	10.49	4.76	5.65	1.31	4.03	1.36
CV (%)		4.93	11.40	11.36	11.69	9.88	9.86

Where: - DF – degree of freedom, Rep.-replication, MC- marketable clove size, AMC- acceptably marketable clove size.

Appendix Table 6. Mean square from analysis of variance (ANOVA) for scarcely marketable clove size and unmarketable clove size of garlic as influenced by NPS and Zn fertilizer.

Source of variation	DF	SMC		UMC	
		Weight	Number	Weight	Number
Rep	2	174.54 *	110.40 **	74.45 ***	6.77 ns
NPS rate	3	172.05 ***	139.80 ***	249.27 ***	985.92 ***
Zinc rate	3	32.84 ns	19.19 ns	42.56 *	202.75 ***
NPS x Zn	9	3.79 ns	3.06 ns	10.81 *	68.14 ***
Error	30	22.29	11.97	3.56	3.17
CV (%)		29.51	26.83	19.69	12.25

Where: - DF – degree of freedom, Rep.-replication, SMC – scarcely marketable clove size, UMC – unmarketable clove size.

Appendix Table 7. Effect of NPS and Zn fertilizers on neck diameter, bulb length, bulb diameter, clove length and clove diameter of garlic

NPS rate (kg ha^{-1})	ND	BL	BD	CL	CD
0	1.18c	3.22^{c}	3.29^{c}	2.25^{d}	1.09^{d}
121	1.38^{b}	3.84^{b}	3.82^{b}	2.35^{c}	1.22^{c}
242	1.47^{a}	4.41a	4.12^{a}	2.52^{a}	1.43^{a}
363	1.45^{a}	4.36^{a}	3.88^{b}	2.49^{b}	1.38^{b}
Significance level	***	***	***	***	***
Zn rate (%)					
0	1.31^{b}	3.52^{c}	3.44^{b}	2.34^{c}	1.20^{c}
0.3	1.37^{a}	4.06^{ab}	3.86^{a}	2.45^{a}	1.31^{a}
0.6	1.41^{a}	4.27^{a}	4.01^{a}	2.46^{a}	1.35^{a}
0.9	1.39^{a}	3.98^{b}	3.79^{a}	2.38^{b}	1.25^{b}
Significance level	**	***	***	***	**
CV(%)	2.66	6.27	6.00	1.04	3.20

Where: - ND-neck diameter, BL-bulb length, BD- bulb diameter, CL- clove length, CD-clove diameter

Appendix Table 8. Effect of NPS and Zn fertilizers on average bulb weight, average clove weight, total bulb yield, harvest index and percent dry matter of garlic.

NPS rate (kg ha^{-1})	ABW	ACW	TBY	HI	PDM
0	26.19^{c}	3.06^{d}	8.89^{c}	86.33^{c}	28.63^{c}
121	34.10^{b}	3.95^{c}	10.55^{b}	86.82^{b}	34.13^{b}
242	42.17^{a}	5.26^{a}	13.15^{a}	87.10^{a}	39.13^{a}
363	41.05^{a}	4.82^{b}	12.54^{a}	86.91^{ab}	40.54^{a}
Significance level	***	***	***	***	***
Zn rate (%)					
0	32.72^{d}	3.46^{c}	9.86^{c}	86.48^{b}	33.16^{b}
0.3	37.12^{b}	4.52^{ab}	11.71^{ab}	86.85^{b}	36.80^{a}
0.6	38.64^{a}	4.78^{a}	12.39^{a}	87.00^{a}	38.01^{a}
0.9	35.03^{c}	4.33^{b}	11.17^{b}	86.82^{a}	34.47^{b}
Significance level	***	***	***	**	***
CV(%)	3.21	9.10	7.00	0.22	4.68

Where: - ABW – average bulb weight, ACW- average clove weight, TBY- total bulb yield, HI- harvest index, PDM – percent dry matter.

Appendix Table 9. Effect of NPS and Zn fertilizers on marketable clove size, acceptably marketable clove size and unmarketable clove size.

	MC				AMC		UMC	
NPS rate (kg ha^{-1})	Vlsw	Vlsn	Lsw	Lsn	Msw	Msn	Vsscw	Vsscn
0	42.28^{d}	13.08^{d}	11.28^{d}	5.08^{d}	11.48^{c}	6.92^{d}	15.81^{a}	27.67^{a}
121	57.41^{c}	17.58^{c}	17.48^{c}	7.92^{c}	16.87^{b}	9.66^{c}	10.01^{b}	13.50^{b}
242	83.98^{a}	24.17^{a}	29.74^{a}	14.00^{a}	27.42^{a}	17.08^{a}	5.44^{c}	8.75^{c}
363	78.87^{b}	21.75^{b}	25.20^{b}	12.08^{b}	25.48^{a}	13.67^{b}	7.10^{c}	8.25^{c}
Significance level	***	***	***	***	***	***	***	***
Zn rate (%)								
0	57.68^{c}	16.83^{c}	15.70^{c}	7.17^{c}	16.32^{c}	9.42^{c}	12.37^{a}	20.41^{a}
0.3	65.70^{b}	20.17^{ab}	23.80^{a}	11.00^{a}	19.39^{b}	12.42^{ab}	8.64^{b}	14.25^{b}
0.6	69.95^{a}	21.25^{a}	24.83^{a}	11.75^{a}	24.12^{a}	13.58^{a}	8.26^{b}	11.25^{b}
0.9	69.21^{a}	18.33^{bc}	19.36^{b}	9.17^{b}	21.42^{ab}	11.92^{ab}	9.09^{b}	12.25^{b}
Significance level	***	**	***	***	***	***	**	***
CV(%)	4.93	11.40	11.36	11.69	9.88	9.86	19.69	12.25

Where: - MC – marketable clove size, Vlsw- very large size weight, Vlsn-Very large size number, Lsw- large size weight, Lsn- Large size number, AMC – acceptably marketable clove size, Msw-medium size weight, Msn-medium size number, UMC – unmarketable clove size, Vsscw- very small size clove weight, Vsscn- very small clove number