EFFECTS OF VERMICOMPOST AND KCL FERTILIZERS ON GROWTH, YIELD, AND QUALITY OF GARLIC (*Allium sativum* L.) IN DEBRE BERHAN, NORTH SHEWA, ETHIOPIA

MSc. Thesis

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EXAMINERS APPROVAL PAGE

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 Horticulture

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APPROVAL SHEET – I

This is to certify that the thesis entitled**: Effects of Vermicompost and KCl Fertilizer on Growth, Yield and Quality of Garlic (*Allium Sativum* L.) In Debre Berhan, North Shewa, Ethiopia** submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in the Graduate Program of the Department of Horticulture, College of Agriculture and Natural Resource Sciences, Debre Berhan University and is a record of original research carried out by Habtu Mamuye Id. No DBU1400518, under my supervision, and no part of the thesis has been submitted for any other degree or diploma. The assistance and help received during this investigation have been duly acknowledged. Therefore, I recommend that it 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 Habtu Mamuye, have read and evaluated his thesis entitled **Effects of Vermicompost and KCl Fertilizer on Growth, Yield and Quality of Garlic (*Allium Sativum* L.) In Debre Berhan, North Shewa, 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.

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DEDICATION

This thesis is dedicated to my beloved brother Mekonn Mamuye for giving me his love that can't be replaced with anything, precious time, energy, money and also for his complete and utter dedication to my success in my life. GOD blesses him throughout his life!

STATEMENT OF THE AUTHOR

I, Habtu Mamuye, hereby declare that this thesis is my genuine work, and that all sources of materials used for this thesis have been thoroughly 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. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the College of Graduate Studies when, in his/her judgment, the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author and advisors of this thesis.

BIOGRAPHICAL SKETCH

The author, Habtu Mamuye, was born to his father, Mr. Mamuye Aleme and his mother, Mrs. Gete Haile Meskel, at Zimamo Got, Menz Mama Wreda, North Shewa Zone, Amhara National Regional State, Ethiopia on December 11, 1992. He attended his elementary education at Astoya Primary School from 2003-2010 and he attended his secondary and preparatory education at Molale Preparatory High School from 2011-2014. Next, he joined Samara University in 2015 after one academic year, transferred to TEL AVIV University of Israel international level competition and after one year, 2016, he returned to Samara University and graduated with a BSC degree in Horticulture in June 2017. Then, he was employed from January 2018 up to February 2022 at Menz Mama Woreda, North Shewa Zone, rural agriculture office in the profession of irrigation. In February 2022, he joined the College of Graduate Studies of Debre Berhan University to pursue his MSc. degree in Horticulture.

ABBREVIATION AND ACRONYMS

ANOVA	Analysis of variance
CACC	Central Agricultural Census Commission
CEC	Cation Exchange Capacity
CIMMYT	International Maize and Wheat Improvement Center
DMC	Dry Matter Content
DMRT	Duncan's Multiple Range Test
EARO	Ethiopian Agricultural Research Organization
ETB	Ethiopian Birr
EthioSIS	Ethiopian Soil information System
FAOSTAT	Food and Agricultural Organization Statistics
FYM	Farm Yard Manure
HCDA	Horticultural Crops Development Authority
KCl	Potassium chloride
MOP	Muriate of potash
MRR	Marginal rate of return
OC	Organic Carbon
OM	Organic Matter
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
TSS	Total Soluble Solid
VC	Vermicompost

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Habtu Mamuye

ABSTRACT

Garlic (Allium sativum L.*) is one of the most important bulb vegetables used as a spice and flavoring agent of food and medicinal plants throughout the globe. It is a cold-weather crop with high water and nutrient requirements, and constrained by several factors. Among these, the inappropriate type and application rate of fertilizer are the major agronomic practices that significantly affect the growth, yield and quality of the crop. Hence, a field experiment was conducted during the 2023/24 main cropping season at Debre Berhan University research site to evaluate the effect of different rates of vermicompost and KCl fertilizer on growth, yield and quality of garlic (Allium sativum* L.*). The treatments consisted of four rates of vermicompost (0, 2.5,5 and 7.5 t/ha) and KCl fertilizer (0, 70,140, and 210 kg /ha). An improved variety 'Tseday' was used as the test crop. The experiment was laid out as a randomized complete block design and replicated three times. The results revealed that vermicompost and KCl rates significantly influenced all growth, yield and quality parameters of garlic. The application of high levels of vermicompost (7.5 t/ha) and KCl (140 kg/ha) resulted in the highest plant height (81.46 cm), leaf length (53.87 cm), mean bulb weight (63.19 g), total bulb yield (20.46 t/ha), and dry matter content (51.43). The application also produced total dry biomass (33.92g), harvest index (84.15%) and TSS (31.19). The combined application of 7.5 kg/ha vermicompost and 140 kg/ha KCl fertilizer resulted in increases of 95.66% in average bulb weight, 62.94% in average clove weight, 56.66% in total bulb yield, 20.62% in total dry biomass, and 33.38% in dry matter content, compared to the control. In addition, the highest net benefit (2710250 birr) with an acceptable marginal rate of return (11492.86) was obtained from the application of 7.5 kg/ha of VC with 140 kg/ha of KCl fertilizer application as compared to other treatments. Hence, it could be concluded that the combined application of VC (7.5t/ha) and (140 kg/ha) KCl fertilizer is acceptable to increase total bulb yield with considerable quality attributes of garlic in the study area and similar agro-ecologies.*

Keywords*: Garlic, organic fertilizer, potassium chloride, quality, vermicompost, yield*

1. INTRODUCTION

Garlic (*Allium sativum* L.) is one of the main and oldest *Allium* vegetable crops known worldwide concerning its production and economic value, which is the second most widely produced *Allium* next to onion (Hamma *et al.*, 2013; Hassan, 2015). It is believed to have originated in central Asia (India, Afghanistan, West China, and Russia), and then it spread to other parts of the world through trade and colonization (Panthee *et al.*, 2006). The value of garlic as a crop has been recognized from very ancient times. Though Egypt has been using garlic since 2000 B.C., China is the world's largest producer and user of garlic, which has been doing so for over 5000 years.

Garlic has both nutritional and functional importance. It is a good source of several nutrients and contains bioactive compounds that contribute to various health benefits, including allicin, a type of antioxidant that may help combat oxidative stress and reduce the risk of chronic diseases (Sunanta *et al*., 2023). Additionally, garlic significantly lowers blood pressure, cholesterol, and platelet aggregation, and has other cardiovascular effects (Lawson, 1998; Banerjee and Maulik, 2002). Beyond its health benefits, garlic is widely used as a spice in various dishes by producers, marketers, and consumers, including curries, fried meals, flavoring dishes, pickles, and sauces (Adane Fentaye and Yigermal Melkamu, 2024). Garlic oil's unique flavor, potent odor, pungency, and volatile sulfur-containing compounds are responsible for its spicy nature. It is an essential ingredient in many dishes from different countries, including Ethiopia (Netsanet Tena and Bizuayehu Desta, 2024). Furthermore, due to its unit price being significantly higher than that of most other vegetables produced, garlic is a major cash crop and a source of income for many smallholder farmers in Ethiopia (Lakew Eshete and Bayih Tegegne, 2022).

Garlic has a wide area of adaptation and cultivation throughout the world. The total world production of garlic was 29,149,437.66 tons (t), from 1,662,384 hectares (ha) of land with an average productivity of 17.53 t/ha (FAOSTAT, 2022). Among the ten top garlic producers, China is the largest producer accounting for nearly 73.39% of world production (21,391,340.27 tons) (FAOSTAT, 2022). Following China, other major producing counties were, India, Banglades, South Korea, Egypt, Spain, Uzbekistan, Ukraine, Maynamar and Russia, respectively. In Africa, the total production of garlic was 948,338.32 tons from 73,390 hectares of land with average productivity of 12.92 t/ha (FAOSTAT, 2022). Ethiopia has placed number 15 in the world ranking, and its total production of garlic was

218,806.97 tons from 29,131 hectares of land with the average productivity of 7.51 t/ha (FAOSTAT 2022).

Amhara region, which produces 70,220.72 tons of garlic annually on 11,206.59 hectares of land with an average productivity of 6.27 t/ha (CSA, 2022), which was very low compared with African and global productivity. According to a report by the North Shoa Zone Agriculture and Development Office, garlic was grown on 2,166.37 hectares of land with a total production of 15,359.56 tons. The average productivity of the garlic was 7.09 t/ha (CSA, 2022), which is lower than the Ethiopian, African, and global productivity rates by 5.92%, 82.23%, and 147.25%, respectively.

This low garlic yields can be attributed by several factors, including lower-producing cultivars Fahimeh, (2019) soil composition Addis Abebaw, (2015) depletion of macro-and micronutrients from the soil Kacjan Marsic *et al*, (2019), the use of chemical fertilizers alone to apply the necessary nutrients might have a detrimental effect on soil health because of excessive levels of chemical residues in the soil, which can result in unsustainable yields Kacjan Marsic *et al*, (2019). Besides, due to their shallow and unbranched root system, the crop is most vulnerable to nutrient stress (Netsanet Tena and Bizuayehu Desta, 2024). Among these, inadequate and unbalanced use of fertilizers is the major constraints that reduce the yield of garlic.

The sound management of fertilization must attempt to ensure both an enhanced and safeguarded environment and for optimum plant growth, nutrients must be available in sufficient and balanced quantities; therefore, a balanced fertilization strategy that combines the use of chemical, organic, or bio fertilizers must be developed and evaluated (Chen, 2006).

Applying fertilizer at the ideal rate is necessary for garlic crops to produce marketable bulb proportions and quality. Therefore, by enhancing soil fertility, the primary attention should be on methods to raise productivity and maximize resource usage at the production site. Application of bio-fertilizers such as vermicomposts (VC) has been recognized as an effective means for improving soil aggregation, structure, and fertility, increasing microbial diversity and populations, improving the moisture-holding capacity of soils, increasing the soil Cation Exchange Capacity (CEC) and increasing crop yields and quality (Hossain and Salam, 2019).

Although most Ethiopian smallholder farmers, especially those in the Debre Birhan District, recognize the importance of fertilizers, they are rarely able to apply them at the recommended amounts due to high costs, credit constraints, supply delays, and low and inconsistent returns. Mineral fertilizers are frequently replaced by organic fertilizers for small scale farmers because of easily available in the garden. However, conventional organic inputs such as crop wastes and animal manures are not able to meet crop nutrition demands over large regions because of their higher quantity requirements, low nutritional content, and labor-intensive processing and application procedures (Ravisankar *et al*., 2021).

To address nutrient deficiencies, farmers in the study area have been using NPS, urea, and NPSB inorganic fertilizers, and animal manures on all garden vegetables, including garlic, to increase crop yields. However, this approach does not take into account soil fertility status and crop requirements. Traditional organic inputs, such as crop residues, cannot meet crop nutrient demands over large areas due to the limited quantities available, the low nutrient content of the materials, and the high labor demands for processing and application (Pratap *et al.*, 2012). On the other hand, excessive application of inorganic fertilizer promotes vegetative growth at the expense of bulb yield, wastes resources, and harms the environment.

This highlights the importance of developing an alternative method to meet plant nutrient demands by blending VC and KCl fertilizers, which contain different macro- and micro-nutrients. As interaction of organic and inorganic is valued, Verma *et al.* (2013) reported that the combined application of organic and inorganic fertilizers provided all the essential nutrients required by plants for their growth and development. Vermicomposting can enhance soil fertility physically, chemically and biologically. Physically, VC-treated soil has better aeration, porosity, bulk density and water retention. Chemical properties such as pH, electrical conductivity and organic matter content are also improved for better crop yield (Lim *et al*., 2015).

One significant characteristic of VC is that many of the nutrients it contains are transformed into forms that plants may absorb more easily, such as nitrate or ammonium nitrate, exchangeable phosphorus (P), and soluble potassium (K), calcium (Ca), and magnesium (Mg), when the earthworms digest the various organic wastes (Suthar and Singh, 2008). During vermicomposting, earthworms eat, grind, and digest organic wastes with the help of aerobic and some anaerobic microflora, converting them into a much finer, humified, and microbial active material (Alemu Degwale, 2016).

As the interaction of organic and inorganic is appreciated, Verma *et al*. (2013) reported that the combined application of organic and inorganic fertilizers provided all the essential nutrients required by plants for their appropriate growth, development and ultimately productivity. Therefore, an integrated nutrient supply approach is the only way to obtain fairly high productivity with substantial fertilizer, leading to sustainable agriculture (Bhagwan *et al*., 2012). In addition to increasing plant growth and production, excessive amounts of inorganic fertilizers are frequently added to soils, which can harm human and animal health and degrade natural resources. An alternative to mineral fertilization is the use of organic fertilizers. One of the more frequently used organic fertilizers is VC, which contains nutrients for plants in readily available forms and is characterized by the slow release of macronutrients and microelements into the soil environment (Paczka¸ *et al*., 2021).

Vermicompost made from earthworms improves the physical characteristics of soil, such as stability, porosity, and water permeability; it also increases the chemical content and water-holding capacity of the soil and improves electrical conductivity. (Lim *et al.*, 2015). Potassium chloride fertilizer plays a role in facilitating photosynthesis, growing plants at the starting level, strengthening the stem and reducing yield decay (Hanan, 2010).

Research has not been conducted to elucidate the impact of adding fertilizers, which include KCl and VC, on garlic performance in the study area. If one wants to increase the amount and quality of garlic produced, research on VC and inorganic KCl fertilization is necessary. Hence, the research is very important to recommend the appropriate type and doses of the integrated fertilizers for producers' sustainable and eco-friendly production systems in the study area. Thus, the goal of this research is to find out how garlic bulb yield, productivity, and quality are impacted by VC and KCl.

1.1. Objectives

1.1.1. General objective

- To evaluate the effect of different levels of VC and KCl fertilizers on the growth, yield and quality of garlic.

1.1.2. Specific objectives

- ✔ To evaluate the effect of different rates of VC on the growth, yield and quality of garlic.
- ✔ To evaluate the effect of different rates of KCl on the growth, yield and quality of garlic.
- ✔ To evaluate the interaction effect of different rates of VC and KCl fertilizers on growth, yield and quality of Garlic.
- ✔ To determine the economically feasible rates of VC and KCl fertilizers for garlic production in the study area.

2. LITERATURE REVIEW

2.1. Botany of Garlic

One of the plants in the Allium genus (*Alliaceous*), the biggest genera of monocots with over 900 species spread throughout the northern hemisphere, is *Allium sativum* L. (2n = 16) (Currah and Rabinowitch, 2002) but only seven are widely grown worldwide. Among these are onions *(Allium cepa* L.), shallots *(Allium cepavar*. *ascalonicum* L.), garlic (*Allium sativum* L.) and leeks (*Allium ampeloprasum* L.) are the species that are significant in Ethiopia. Leek is a tetraploid plant with 2n=32 chromosomes, while the first three are diploids with a basic chromosomal number of 2n=16 (Currah and Rabinowitch, 2002).

Garlic is considered sterile and is mostly propagated asexually, but fertile wild garlic has been discovered and collected in its center of origin, in Kazakhstan and Kyrgyzstan (Dhall *et al.*, 2023). It is an herbaceous plant that has an approximately 1 m long fragrant stem divided into 6 to 12 bulb leaves joined by a thin shell, which forms the garlic head. Each bulb consists of four to twenty separate fleshy sections called cloves, each wrapped in a papery skin called the tunic roots that come from the basal section of its disc and can reach a depth of at least 80 cm (Dietz, 2022). Its leaves are long (around 30 cm), narrow, and flat closer to the plant base, but cylindrical and pointy at the tip. Roots reach up to 50 cm depth or a little more. Heads or bulbs are white skinned, divided into sections/cloves (Tadesse Abadi, 2015).

While the entire plant is edible, the most recognizable part of the garlic plant is the bulb. Individual cloves are peeled and eaten raw, dehydrated, or cooked. Growers particularly in tropical climates, can harvest immature garlic as green garlic and use it in the same way as scallions (Petropoulos *et al*., 2018). Raw bulbs have been frequently used in salads since ancient times; it has also been utilized as a spice and medicinal herb (Petropoulos *et al*., 2018).

2.2. Climate and Soil Requirements of the Garlic Crop

Garlic crops can adapt to a wide range of climatic conditions best prefer cool season, grows at high elevations from 900 to 1200 m and grows best within the geographic area having a mean monthly growing temperature ranging from 12^{o}C to 24^{o}C. In most areas elevation from 500 to 2000 m provides suitable growing conditions, particularly during dry periods. It grows best on well drained soils high in organic matter, sandy loam or loam soils (Muluneh Bekele, 2018). It is better to plant on flat beds; but on heavy soils, which are poorly drained during the rains; it is advisable to plant on the ridges (Tadesse Abadi, 2015). Drought or excessively wet conditions will reduce yields and marketable bulbs. Garlic production requires a growing period of 4.5-6 months and the amount of rainfall ranges between 600 mm to 700 mm during its production season (Tadesse Abadi, 2015).

Garlic is a high-value crop, which requires rich soil, good drainage, friable soil-preferably with high organic matter content, and water should not be deficient during bulb formation until two weeks before harvesting time. Excess supply of water two weeks before harvesting time affects the storage quality and the crop prefers a soil with a pH of 6.5-7.5 as it is sensitive to higher acidity (Bachmann, 2001; Potgieter, 2006). The most suitable soil types for garlic crop growth are sandy loam to sandy clay loam, and very fine sandy loam (silts) soils, deep mineral topsoil, well-drained muck soils and relatively high (greater than 2%) in organic matter are ideally suited for growing of garlic bulbs.

2.3. Use and Importance of Garlic

Garlic is one of the most important and widely cultivated spice crops used for food as well as medicinal purposes. Compared to other *Allium* species, it has a higher concentration of sulfur compounds, which gives garlic its strong smell and many of its therapeutic properties (Choudhary *et al.,* 2022). It is primarily used for home consumption in various forms for cooking as either a spice or condiment as a seasoning in many foods worldwide; without garlic, many of our popular dishes would lack the flavor and character that make them favorites (Kim *et al*., 2020).

According to clinical studies, garlic significantly lowers blood pressure, cholesterol, and platelet aggregation, and has other cardiovascular effects (Lawson, 1998 and Banerjee and Maulik, 2002). It is rich in beneficial substances like allicin and ajoene, and offers numerous health benefits, including antibacterial, antithrombotic, antioxidant, hypoglycemic, anti-hypertensive, hypo-lipidemic, anti-atherogenic, anti-carcinogenic, antitumor, fibrinolytic, immune-modulatory, and anti-anemic effects (Nainwal *et al.,* 2015). It is also used to cure a variety of heart conditions, stomach disorders, sore eyes, and earaches because it has anti-carcinogenic, antimicrobial, and insecticidal qualities (Espinoza *et al*., 2020).

Economically, garlic is becoming more and more popular among farmers around the nation because of its high yields and easily accessible local market (Gichaba, 2019). It is an important cash crop for smallholder; farmers in Ethiopia as its unit price are much higher than most of the other vegetables produced (Emana *et al.,* 2015).

2.4. Potentials and Constraints of Garlic Production in Ethiopia

Because of its altitudinal alterations, Ethiopia has a range of agro-ecologies that enable it to grow temperate, tropical, and subtropical crops, including garlic, throughout the year (Getachew Tabor and Asfaw Zelleke, 2000). The nation, including the Amhara region, has surface and subsurface water resources that can be utilized for horticulture crop production (Muluneh Nigatu, 2016). The increasing demand in the export market can also be considered as an important opportunity for farmers to produce garlic having export quality, since the country is close to the world market compared to other exporters (Fekadu Mariame and Dandena Gelmesa, 2006).

Furthermore, as stated in its second Growth and Transformation Plan 2010–2015, the Ethiopian government is dedicated to expanding the horticulture industry by creating irrigation systems that allow farmers to grow vegetables, including garlic, all year round (MoFED, 2010). The production and productivity of horticultural crops, including garlic, are extremely low in Ethiopia in general and the Amhara Region in particular, despite their importance, great production potential, and high market demand.

Major production constraints include inadequate agronomic techniques, poor pest and disease management strategies, reduced soil fertility status in various soil types, and improper planting materials (enhanced varietals) (Getachew Tabor and Asfaw Zelleke, 2000). Biological factors, such as fungal disease and soil nutrient deficiencies, pose significant challenges to vegetable crops, particularly garlic (Anum *et al*., 2024). Fungal disease is the most destructive pathogen, making it difficult to manage and permanently affecting garlic production (Fuad Abba, 2019). In Ethiopia, soils are rapidly depleted, affecting crop growth, yield, and quality. Traditional farming systems also contribute to low productivity (Melkamu Alemayehu *et al.*, 2015).

The low productivity of garlic is also associated with improper agronomic practices, lack of improved and high-yielding varieties, low level of fertilizer use, high incidence of diseases and insect pests and unavailability of pesticides. Moreover, the production of garlic is constrained with limitations of irrigable land and shortage of irrigation water and lack of finance for input purchase, which contributes to the low yield of garlic (Shege Getu *et al.*, 2021)

2.5. Roles of Organic Fertilizers in Garlic Crop

Nutrient management is crucial for good growth, yield, and quality in garlic crops (Diriba Shiferaw, 2016c). Organic fertilizers release macro, micro nutrients and plant growth regulators during mineralization, increasing fertilizer use efficiency (Yadav *et al.*, 2017). Organic manure, such as VC and FYM, is eco-friendly and economically viable. Well-composted manure applied and incorporated at a rate of 20 tons to 30 tons per acre is ideal as a soil amendment, especially on low organic matter soils, (Roper *et al.*, 2012). In addition to increasing the amount of humic acid and lowering the C:N ratio, organic manure gives plants access to minerals like nitrate, exchangeable phosphorus, soluble potassium, calcium, and magnesium (Yadav *et al*., 2017).

Apart from achieving higher yields and maximum plant growth, excessive amounts of inorganic fertilisers are often applied to soils, affecting human and animal health and leading to the degradation of environmental resources. The use of organic fertilisers is proposed as an alternative to mineral fertilisation. One of the more frequently used organic fertilisers is VC, which contains nutrients for plants in readily available forms and is characterised by the slow release of macronutrients and microelements into the soil environment (Paczka¸ *et al*., 2021).

2.5.1. Roles of Vermicompost

Vermicompost is an organic amendment that is rich in nutrients and microorganisms that is produced when earthworms and microorganisms combine to break down organic materials (Chatterjee *et al*., 2020). The final product of vermicomposting is stable and homogeneous; having desirable aesthetics such as reduced levels of contaminants, and this converted product can be used as a fertilizer or as a source of nitrogen for microbial populations which can be beneficial to plant growth. Ahirwar and Hussain (2015) reported that VC can meet the nutrient demand of greenhouse and field crops and significantly reduce the use of fertilizers. Adrian *et al.,* (2016) also found that VC can meet nutrient demands for greenhouse and field crops, reducing fertilizer use. They increase soil fertility without polluting, and improve plant growth under water deficit conditions.

Vermicompost is a suitable source for garlic quality due to its high porosity, aeration, drainage, water-holding capacity, enhanced cation exchange capacity, and large surface area (Nada *et al.,* 2011). Its organic carbon allows plants to absorb available nutrients (Ansari *et al.,* 2016). Farmers value low cost agricultural output using ideal concentrations of VC (Singh *et al*., 2022). Earthworms consume, grind, and digest organic waste during vermicomposting, resulting in a finer, humified, and microbially active material. It improves root aeration, increases water availability, and stimulates exchange of nutrients (Gichaba, 2019). It increases bulb dry weight and fructan precursor metabolism, leading to higher quantity, quality, and yield at harvest. The treatment also promotes reserve substance building (Gashaw Bewuket and Woldetsadik Kebede, 2020).

Vermicompost impacts garlic crop growth, including days to emergence, maturity, leaf number, leaf area index, clove weight, bulb weight, fresh biomass yield, total bulb yield, dry matter percentage, and total soluble solids (Fikru Tamiru and Fikreyonnes Gedamu, 2020).

2.6. Inorganic Fertilizers in Garlic Crop

Chemical fertilizers have a potential role on the growth and development of vegetables including garlic by improving soil fertility. The use of balanced sources of nutrients to obtain high yield and good quality garlic bulbs is an important practice in today's garlic production. Farmers strive to produce high yield and good quality garlic both for consumption and economic value but soil fertility depletion is among the major obstructions to sustained garlic production, especially in the less developed countries, because of limited application of suitable rate, type and sources of fertilizers (Diriba Shiferaw *et al.*, 2013).

The availability of inorganic nutrients especially, nitrogen, phosphorus and potassium are critical for plant growth since they are necessary sources of protein and nucleic acid molecules. These are an integral part of chlorophyll molecules, which are responsible for photosynthesis. Based on the findings obtained, application of 130 kg N, 20 kg P, 21 kg S and 15 kg Zn fertilizers per hectare in combination is recommended; which is yielding of 4760, 4388, 4240 and 3451 kg/ha, respectively (Abraha Gebrekiros *et al.,* 2015). The study in Debre Berhan district found that the highest growth parameters were achieved from the highest amounts of nitrogen fertilizer (Netsanet Tena and Bizuayehu Desta, 2024).

2.6.1. Roles of KCl

Potassium chloride (KCl) is a widely used potassium fertilizer, providing essential nutrients for plants and animals (Yahaya *et al*., 2023). Potassium is the third most important macronutrient required for plant growth, after nitrogen and phosphorus (Rawat *et al.*, 2016). It enhances crop yield production and quality determination, assimilates transport and storage, and maintains tissue water relationships

(Ahmad and Maathuis, 2014). However, excessive application can decrease food quality and yields, leading to economic losses and food safety issues (Allison *et al*., 2001). Since chlorine activates over 60 enzymes, influences plant water relations, and promote crop cell growth and development, which is crucial for crop nutrition when present in the lithosphere (Eshetu Betewulign, 2014; Hasanuzzaman *et al*., 2018).

KCl fertilization enhances garlic's biomass and vegetation index, promoting the transfer of nitrogen, phosphorus, and potassium nutrients from the stem and leaf to the bulb (Wang *et al*., 2022). It also improves nutritional quality, reduces nitrate accumulation, and enhances root growth and bulb weight (Behairy *et al*., 2015). Garlic fertilization and manuring are similar to onions (Mahmoud *et al.,* 2000), and applying 140 kg/ha KCl fertilizer can enhance garlic crop productivity and farmer income (Diriba Shiferaw, 2016c).

The addition of potassium fertilizer also increase K available in the soil so that it can be absorbed by plants which play a role in photosynthesis process, translocation and storage of assimilates, increasing the size, number and yield of bulb per plant, increasing bulb density and reducing the rate of rotting yield (Hayati *et al.*, 2021). Based on several studies that have been conducted at dry lands showed that the application of potassium as KCl 180 kg/ha is a dosage that is sufficient for plants and the application of K fertilizer in the form of potassium sulfate with dosage of K_2O 144 kg/ha K_2O can increase plant growth, quality and bulb yield of shallot (Hanan, 2010).

2.7. Roles of Integrated Nutrient Management

Fertilizers are often applied based on general guidelines without considering soil fertility levels, leading to unprofitable application (Getnet Bitew *et al.,* 2022). Chemical fertilizers alone harm the ecosystem by damaging soil microflora and microfauna, prompting the recommendation of synthetic and organic alternatives (Prashar and Shah, 2016).

The integrated nutrient delivery strategy promotes sustainable agriculture by achieving high productivity with substantial fertilizer use. It maintains soil health, productivity, and fertility, offering agronomical and environmental benefits. This approach increases yield potential, quality, and profit margins for garlic crop growers (Yadav *et al*., 2017, Petropoulos *et al.*, 2018 and Shah and Wu, 2019).

Garlic growth, nutrient concentration and uptake by the crop quality were significantly increased with integrated fertilization of the crop using different nutrients/elements (Diriba Shiferaw, 2016c). As

(Petropoulos *et al*., 2018) reported that integrated application of organic and inorganic fertilizers provide plants with all essential elements required for growth and development. It was found that also the combination of VC and mineral nitrogen fertilizer generated the greatest results for the research crop (Kumrawat *et al.,* 2020). Combined application of 50 kg N/ha and 10 t/ha manure per hectare increased total bulb yield of garlic crops (Bewuket Gashaw and Kebede Woldetsadik 2020).

2.7.1. Effects of Vermicompost and KCl Fertilizers on Garlic Crop

Traditional organic inputs, such as crop residues and animal manures, cannot meet crop nutrient demand over large areas because they require higher amounts, have low nutrient content, and entail high labor demands for processing and application (Timsina, 2018). Therefore, the combination of VC and mineral KCl fertilizer is crucial to increase the productivity of plants with reduced pollution of the environment. Vermicomposting has been an easy technology, environmentally friendly process used to treat organic waste. This organic fertilizer is therefore increasingly considered in agriculture and horticulture as a promising alternative to chemical fertilizers. However, the effects of VC on garlic were not yet fully understood in Ethiopian conditions (Wilson, 2021). Therefore, the present research focused on studying the effect of VC in combination with chemical fertilizers KCl on the yield and quality of garlic. Garmame Galgaye, (2022) recommended that the application of 5 t/ha VC led to the maximum growth, yield, and quality of the garlic crop. Whereas (Purba, 2014) reported that 100 kg of KCl for shallot increases productivity.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted during the summer season, from June to November 2023 G.C., on the research farm of Debre Berhan University. The area is located in Amhara Regional State, North Shewa Zone, which is 130 kilometers northeast of Addis Ababa, the capital city of Ethiopia. The study site is located between 9°41' N latitude and 39°32′ E longitude at an elevation of 2,840 meters above sea level (m.a.s.l). The area receives a mean annual rainfall of 927.1 mm and is characterized by a bimodal rainfall pattern with maximum (293.02 mm) and minimum (4.72 mm) peaks in June-September and February-April, respectively. The average monthly minimum and maximum temperatures range from 2.4 to 8.9 ^{0}C and from 18.3 ^{0}C to 21.8 ^{0}C, respectively. Major crops grown in the study area include wheat, barley, peas, fava beans, faba beans, potatoes, carrots, and garlic, with a mixed crop livestock farming system. According to the FAO soil classification system, the most dominant soil in the area is vertisol. In general, the areas fall under the Highland (*Dega*) agroecological zone, with frost incidence from December to January.

3.2. Experimental Materials

Tsedey 92, as improved variety released by Debre Zeit Agricultural Research Center, during 1999/2000 E.C. Tsedey 92 has purple white bulbs, green leaves and takes about 110-130 days for its maturity and yields 7.5 to 8.13 t/ha with an average bulb weight of 41.59 g (Mulu Teshale, 2021). The variety grows in the altitude ranges from 1800 to 3200 m.a.s.l. with 760-1010 mm rainfall (Hisako *et al.,* 2019).

3.3. Treatment and Experimental Design

The treatments consisted of four rates of (VC) (0, 2.5, 5.0, and 7.5 t/ha), and four KCl fertilizer rates (0, 70, 140 kg, and 210 kg KCl/ha). Thus, the total treatments were 16. The experiment was laid out in randomized complete block design (RCBD) with three replications in a factorial combination.

3.4. Experimental Procedures

Vermicompost was prepared from locally available organic input materials in the Deneba's young organization of vermicomposting sheds.

The experimental field was plowed and harrowed with a tractor and then leveled the land, and 20 cm raised beds were made by human labor. Each plot size was 1.6 m x 1.8 m (2.88 m^2) and there have been left 1m and 0.5 m space between blocks and plots, respectively. Each plot consists of 6 rows of which each containing 16 plants per row and a total experimental area of 244.94 m^2 (33.1 m x 7.4 m). Each treatment has been assigned randomly to the plots within a block. The outermost row from each side of the plots and one plant on both ends of each row are considered as borders.

Healthy and uniform large-sized cloves of 2-2.5 g (Netsanet Tena and Bizuayehu Desta, 2024) were selected and planted on 29 June 2023 at a depth of 3-4 cm. Cloves are planted at a spacing of 30 cm between rows and 10 cm between plants. Vermicomppost was applied one month before planting and mixed into the soil. KCl fertilizer as per the treatment applied at planting. Supplemental irrigation of water was applied twice a week after the rain ceased in September to October and other recommended practices were undertaken uniformly to the plots (Getachew Tabor and Asfaw Zelleke, 2000). Garlic bulbs were harvested on 5 December 2023 and the bulbs were cured for ten days in ambient environmental condition in lab house room.

3.5. Vermicompost and Soil Sample Physicochemical Analysis

Soil samples were taken with an auger from the experimental field at a depth of 20 cm in a zigzag (W-shaped) pattern. A composite sample weighing one kilogram was made from this mixture and placed inside a plastic bag. The soil sample that had been dehydrated in the shade was analyzed by the Debre Berhan Agricultural Research Center for several important physicochemical properties, such as pH, texture, organic carbon, total N, accessible P, S, and K, and soil cation exchange capacity (CEC). The Bouyocous hydrometer method (Moodie *et al.,* 1954) was used to determine the texture of the soil.

The soil pH was estimated in 1:2.5 soil-water suspensions using a glass electrode pH meter. The textural class was determined by using the hydrometer method of (Bouyoucos, 1962) and the organic carbon content was analyzed as described by (Walkley and Black, 1934). Cation exchange capacity and available K content of the soil were determined by the ammonium acetate method. The total N content was determined by the micro-Kjeldahl method and the available phosphorus was determined using the Olsen method as described by Olsen *et al*. (1954). The chemical content of the VC was determined using similar procedures used for the soil.

3.6. Data Collected

3.6.1. Phenological parameters

Days to emergence: Days to 50 % emergence was recorded when cloves sprout and emerge from the soil in each plot. The average of days to emergence on each plot for all replications has been taken as the actual number of days to emergence.

Days to harvest maturity: Physiological maturity was recorded when 75 % of the leaves of the plants in each plot became yellow, dry, and showed senescence.

3.6.2. Growth parameters

Plant height (cm): Ten randomly selected plants from the center four rows of each plot were measured in ruler from the soil surface to the tip at physiological maturity. The average of these measurements was then computed for statistical analysis.

Leaf length (cm): The average length of the longest leaf, at physiological maturity was measured from the ten randomly selected plants.

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

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

Number of leaves per plant (No.): The number of leaves on randomly selected ten plants per plot was counted at physiological maturity, and the mean values were computed.

Shoot dry weight (g): The shoot fresh mass was oven-dried until a constant weight was achieved and its dry matter yield was determined.

3.6.3. Yield and yield components

Average bulb weight (g): The average mature bulb weight per plant was registered after the weighing of cured bulbs produced in the four central rows and divided by the number of bulbs.

Clove length (cm): The average clove length of ten randomly taken bulbs was measured from the base to the tip of the clove using a caliper.

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

Average clove weight (g): The clove weight of ten randomly selected plants from the four central rows was measured after curing and divided by the number of cloves.

Clove number per bulb: The number of cloves produced from ten randomly selected plants was counted and divided by the number of bulbs.

Bulb length (cm): Ten bulbs were randomly taken from each treatment and measured from the bottom to the top using a caliper.

Bulb diameter (cm): Ten bulbs were randomly taken and measured in the middle using a caliper.

Total dry biomass (g): This was determined by taking the total biomass weight, which included dried bulbs, leaves, stems, and roots, after drying in an oven until a constant weight was achieved.

Total bulb yield per hectare (t/ha): The total bulb yield harvested from the four central rows of harvested bulbs was weighed after being cured and converted to tons per hectare.

Marketable and Unmarketable clove size category (MCS and UMCS): Marketable and unmarketable cloves were recorded both in weight and numbers to evaluate the effects of the applied treatments. According to Fikreyohannes Gedamu (2005) the marketable cloves were categorized in to three market sizes viz., very large size (greater than 2.5g) and large size (2-2.49g), (medium size (1.5-1.99g) and small size (1-1.49 g) for marketable, acceptably marketable and scarcely marketable cloves respectively, further the unmarketable clove included very small cloves with weight of less than 1 g.

Harvest index (%): It has been determined as the ratio of bulb dry weight to the total plant dry biomass weight 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

Bulb dry matter content (%): A homogenate was prepared from the bulbs of each plot of the sampled plants. For determination of percent dry matter contents, 25 g of the homogenate has been taken and oven dried at a temperature of 65 ^{0}C until a constant weight was obtained. Then the weight was measured using digital balance and the percent dry matter was calculated using a formula:

$$DMC\ (\%) = \frac{(DW+CW)-CW}{(FW+CW)-CW}\ X\ 100 \ \ldots\ldots\ldots\ldots.. (1)$$

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

Total soluble solids (TSS): An aliquot of juice prepared chopped by knife and squished with a mortar and 100 ml of slurry filtered using muslin cloth. The Total soluble solids of garlic were determined using a hand refractometer (Atago N1) with a range of 0 to 32 °Brix, and a resolution of 0.2 °Brix by placing 1 to 2 drops of clear juice on the prism. Between samples, the prism of the refractometer was washed with distilled water, dried before use, and expressed as ^{0}Brix (Robert and Bradley, 2010).

pH determination: The pH of garlic was determined in a 10% solution of the sample using a pH meter.

3.7. Data Analysis

3.7.1. Agronomic data analysis

The collected data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) of SAS software version 9.31 (SAS, Institute Inc., 2012) and the means were separated by using Tukey's Honestly Significant Difference (HSD) at a 0.05 probability level of significance.

3.7.2. Economic data analysis

The partial budget analysis, as described by CIMMYT (1988), has been done to determine the economic feasibility of garlic production using the prevailing market prices for inputs at planting and the outputs at the time of crop harvest. It has been calculated by taking into account the additional input and labor costs involved due to the additional inputs and the gross benefits obtained from garlic production. The average yield was adjusted downward by 10% to reflect the difference between the experimental yield and farmers' yield obtained under their management practices as described by CIMMYT (1988).

The field price of garlic is calculated as (the sale price minus the costs of harvesting, cleaning, bagging, and transportation). The net benefit is calculated as the difference between the gross field benefit in Ethiopian Birr per hectare and the total variable costs (ETB/ha):

$$\text{Marginal rate of return (\%)} = \frac{change\ in\ \ net\ benefit}{change\ in\ total\ cost} X\ 100 \ \ \ldots\ldots\ldots\ldots (2)$$

Marginal rate of return (MRR %) is calculated by dividing the change in net benefit or gross benefit by the change in cost, the measure of increasing in return by increasing input. This means subtracting the gross benefit at the control treatment from the gross benefit of each treatment divided by the total variable cost of each treatment and multiplying each value by 100%.

4. RESULTS AND DISCUSSION

4.1. Physical and Chemical Properties of the Soil and Vermicompost

4.1.1. Physical and chemical properties of the experimental soil

The textural class of the soil was based on the soil textural triangle of the International Society of Soil Science system (Moodie *et al*., 1954; Rowell, 1994). The pH of the experimental soil is 5.5 which is moderately acidic based on the pH limit (5 to 7) described by Jones (2003). The pH in the range of 6.5 to 7.5 is favorable for garlic production (Bachmann, 2001).

The CEC of the experimental site's soil was 9.79 Cmol (+)/ kg soil, which was low (Landon, 1991). According to Landon (1991), CEC of soils greater than 40 cmol (+)/kg are rated as very high 25-40 cmol (+) /kg as high, and CEC of soil from 15-25, 5-15 and < 5 cmol (+) /kg of soil are classified as medium, low, and very low, respectively. High CEC indicates that the soils can strongly hold nutrients and this is mainly due to high clay content. The amount and type of clay might have been very important in contributing to higher CEC values. Moreover, the high CEC values imply that the soil has a high buffering capacity against induced chemical changes (Hazelton and Murphy, 2007).

The organic carbon of the soil was 1.39% which was low Tekalign Taddese (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. The organic matter of 2.396% is also considered low. Tekalign Taddese (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. The development of soil aggregates, which lowers soil bulk density and compaction, is mostly dependent on organic matter. It thus raises the soil's capacity to hold water. These are essential for the soil nitrogen cycle and decomposition. Hence, the soil might respond to the applied VC and mineral KCl fertilizers, as its organic matter content was low.

The soil's available P concentration was 11.89 mg/kg. According to Olsen *et al*. (1954), the available P of the soil 10-17 mg/kg is rated as medium. According to Olsen *et al* (1954), P classified soil P availability of <3 ppm very low, 4-7 ppm low, 8-11 ppm medium, and 12-20 ppm high, >20 ppm very high.

Soil has a high total nitrogen concentration of 0.81 percent (Table 1). According to Goronski *et al.* (2010), soil nitrogen level is classified as medium if it is between 0.15 and 0.25 percent, and high if it is higher than 0.25 percent.

The exchangeable K content of the soil was 0.26 (Cmol (+)/kg). According to FAO (2006), a cation exchangeable soil potassium content of less than 0.5 (Cmol $^{(+)}$/kg) soil is low. The EC was non saline (USSLS, 1954).

Table 1. Physical and chemical properties of the soil of the experimental site at Debre Berhan, Ethiopia

Soil property	Values	Rating	Reference
Sand (%)	21		
Clay (%)	51		
Silt (%)	28		
Textural class	Clay		Tekalign Tadesse (1991)
pH (H_2O)	5.5	Slightly acidic	Landon (1991)
OC (%)	1.39	low	Tekalign Taddese (1991)
OM (%)	2.396	low	Landon (1991)
Total N (%)	0.81	High	Goronski *et al*. (2010)
Available P (mg /kg)	11.89	Medium	Olsen *et al* (1954)
EC (ds/ml)	0.168	Medium	Hazelton and Murphy (2007)
Exchangeable K(Cmolc /kg)	0.26	low	FAO (2006)
CEC (Cmol $^{(+)}$ /kg)	9.79	High	Hazelton and Murphy(2007)

OC=organic carbon; OM=organic matter; pH=Potential of Hydrogen; N=nitrogen; P=phosphorus; K=potassium; EC=electric conductivity; CEC=cation exchange capacity.

4.1.2. Physical and chemical properties of vermicompost

Analyzing the nutrient contents of VC is essential since it is a soil conditioner, activator, and fertility booster that contain all necessary vitamins, enzymes, growth hormones, and helpful microorganisms (Fikru Tamru and Fikreyohannes Gedamu, 2019).

The chemical analysis of VC is given in Table 2. Its component is with EC=5.82 msm^{-1}, pH=6.13, total N=1.35 %, available P=14.48 ppm, exchangeable K=17.63 Cmol (+)/kg OM=15.39 % and OC=4.39%. This VC increases soil fertility without polluting the soil, as well as the quantity and quality of crops.

Table 2. Chemical properties of vermicompost.

No.		Chemical properties					
VC	Total N (%)	Available P (ppm)	Exchangeable K [$Cmol^{(+)}$/kg]	OM (%)	OC (%)	pH	EC (Msm^{-1})
Value	1.35	14.48	17.63	15.39	4.39	6.13	5.82
Rating	Very high	Moderate	Very High	Very high	Very high	Neutral	Very high

pH=Potential of Hydrogen; N=nitrogen; P=phosphorus; K=potassium; OC=organic carbon; OM=organic matter; VC=vermicompost; EC=electric conductivity.

4.2. Phenological Parameters as Affected by Vermicompost and KCl Fertilizers

4.2.1. Days to emergence

The analysis of variance on days to 50% emergence indicated that the main effect of VC and KCl fertilizers, as well as their interaction, were non-significant ($P \geq 0.05$) (Appendix Table 1). The non-significant difference among different levels of VC and KCl fertilizers on the days to 50% emergency of the garlic may be due to the very low nutrient uptake capacity of the crop at the initial stage, due to the small growth of roots. This idea agrees with Diriba Shiferaw *et al*. (2015), who reported that the nutrient uptake capacity of the crop was very low because of the small growth of roots at the initial stage.

4.2.2. Days to Maturity

The analysis of variance showed that the effects of KCl and VC, as well as their interaction, had a significant impact on the number of days to maturity ($P \leq 0.001$), (Appendix Table 1). The longest days (151.67) to maturity was recorded from plants grown with fertilizer application of 7.5 t/ha of VC and 140 KCl kg/ha. On the other hand, the shortest days (142.67) to maturity was recorded from the control treatment (Table 3). The lowest amount of fertilizer (2.5 t VC/ha with 70 kg KCl/ha) delayed maturity by 6.34 days when compared to the control, while the application of VC 7.5 t/ha with KCl 140 kg/ha delayed it by 21.34 days (Table 3).

Table 3. Interaction effects of vermicompost and KCl on days to emergence and maturity of garlic

VC (t/ha)	KCl (kg/ha)	Days to emergence	Days to maturity
0	0	8	130.33[j]
	70	9.33	131[j]
	140	8.67	132[ij]
	210	8.33	133[i]
2.5	0	9	135[h]
	70	9.67	136.67[g]
	140	8.67	137.67[fg]
	210	9	138.67[f]
5	0	9	139[f]
	70	10	141.67[e]
	140	9.33	148[c]
	210	8	149.67[b]
7.5	0	9.67	147.67[c]
	70	10.33	145[d]
	140	10.33	151.67[a]
	210	8.33	151[ab]
Significance level		ns	***
CV (%)		11.76	0.68

Means in the table followed by different letter(s) within the same column are significantly different from each other; ns=non-significant; ***=significant at $p \leq 0.001$; CV = Coefficient of variation.

The increase in maturity in response to the highest rate of VC fertilizer application might be attributed to sufficient nutrients availability, which enhances plant biochemical processes that in turn extends vegetative growth then, leads to a delayed maturity. Whereas earliest days to maturity in response to less fertilizer application could be due to less available nutrients for the plant growth, which leads to reduced vegetative growth that accelerated maturity. This result is supported by the findings of Alemu Degwale (2016) who reported that maturity of garlic was prolonged by 136 days for maturity in response to 5 t/ha rate of VC. Similarly Olle (2019) stated that VC contains significant amounts of micronutrients elements such as copper, zinc, iron, and manganese, which materials aid plants in completing their life cycle free from nutrient stress and speeds up senescence.

The fertilizer, KCl (Muriate of potash, MOP), provides two essential elements, the macronutrient potassium as a cation (K^+) and the micronutrient chlorine as an anion (Cl^-) and is the source of 90% of mineral K applied to crops throughout the world (Geilfus, 2018). It is readily soluble in water and on application to the soil. The K^+ enters the soil solution and exchange complex and can then be rapidly taken up by plant roots (Sharma *et al.,* 2016). Potassium is taken up by the plant in very large quantities, as nitrogen, and plays a fundamental role in plant physiology and biochemistry, especially concerning N metabolism (Pandey, 2018). The longer bulb development time also might be caused by the increased fertilizer dose, which increases the bulb's absorption of potassium. This is supported by the findings of Octaviany and Fuskhah (2020) who reported prolonged maturity of garlic in response to the combined application of K. Similarly, Netsanet Tena and Bzuayehu Desta (2024) also published a report regarding the crop's (garlic) delayed maturity by 10.67 days as compared to the control treatment in the application of 157.5 kg/ha nitrogen fertilizer. The physiological and biochemical roles played by K in crop plants are mostly well understood and have been extensively investigated being constituent of component of protoplasm and cell wall of the cell might have imparted a favorable effect on the chlorophyll content of leaves (Pandey and Mahiwal, 2020). Therefore, the delay in days to maturity with high levels of VC and potassium chloride could be attributed to delayed senescence of the canopy of the crop and extended physiological activity and continuing photosynthesis. That in turn might have led to an increase in the synthesis of photosynthesis, which was further utilized in building up new cells which contributed to the prolonged maturity of garlic.

4.3. Growth Parameters

4.3.1. Plant height

The analysis of variance showed that plant height was significantly ($p < 0.001$) influenced by the interaction effect of blended VC and KCl fertilizer as well as the main effects of VC and KCl fertilizers (Appendix Table 1). The longest plant height (81.47 cm) was recorded from plants that grow with the combined application of 7.5 t/ha VC with 140 kg/ha KCl which was statistically similar with 7.5VC t/ha and 70 kg KCl/ha. On the other hand, the shortest plant height (61.43 cm) was recorded from the control treatment, which increased plant height by 32.61% (Appendix Table 1). The highest application of 7.5 t/ha VC and 140 kg/ha KCl fertilizer increased plant height by 20 cm as compared to the control treatment. This effect might be due to the role of the abundant nutrient availability, which enhances assimilation and production that favors vigorous vegetative growth.

Vermicompost based products may increase garlic growth by adding organic matter, growth hormones, humic compounds, and plant nutrients from bio enriched soil. Results of the present study agree with the finding of Alemu Degwale (2016) who reported that application of 5 t VC/ha increased plant height by 36.01%. Similarly, Hassan, (2015) supports this idea as it increases the garlic growth due to the addition of organic matter, humic chemicals, enzymes, and many growth hormones, including auxins, and plant nutrients from bio-enriched soil by VC made products. Furthermore, Derib Kifle *et al*. (2017) indicated that VC, as compared to NPK fertilizers, contains a wide variety of other vital micronutrients that are necessary for optimal plant growth.

Diriba Shiferaw *et al*. (2013) showed that applying varying rates of nutrient combinations had a substantial impact on the heights of garlic plants. Additionally, it also might be due to K^+ that release from KCl is involved in a variety of physiological processes, including translocation, photosynthesis, the activation of enzymes within plants, and the control of stomata's opening and closing. This is supported by Hayati *et al.* (2021) that KCl fertilizer application on shallot at a treatment of 200 kg/ha showed the average plant height of 40.60 cm which is not different from application of 150 kg/ha of KCl with an average of 39.47 cm. Hence, Hayati *et al.* (2021) recommended that for optimum and efficient fertilizing application dosage of 150 kg/ha KCl is better than other treatments.

Table 4. Interaction effects of vermicompost and potassium chloride on plant height, leaf length, leaf number, and leaf width of garlic.

VC (t/ha)	KCl (kg/ ha)	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Leaf number
0	0	61.43^{f}	47.13^{j}	2.2^{e}	10.6^{i}
	70	61.57^{f}	48.7^{i}	2.22^{e}	10.87^{i}
	140	61.7^{f}	49.33^{hi}	2.24^{e}	11.07^{hi}
	210	67.83^{e}	49.77^{gh}	2.24^{e}	11.13^{g-i}
2.5	0	68.47^{de}	50.17^{gh}	2.34^{de}	11.57^{f-h}
	70	70.33^{de}	50.30^{g}	2.4^{d}	11.67^{f}
	140	70.83^{d}	50.7^{e-g}	2.54^{cd}	11.73^{f}
	210	77.17^{c}	50.57^{fg}	2.62^{bc}	11.83^{ef}
5	0	78.73^{bc}	52.17^{b-d}	2.62^{bc}	11.93^{d-f}
	70	78.83^{bc}	52.27^{b}	2.62^{bc}	12.03^{d-f}
	140	80.17^{a-c}	51.37^{c-f}	2.64^{bc}	13.3^{b}
	210	79^{abc}	52.27^{b}	2.64^{bc}	12.9^{bc}
7.5	0	79.07^{a-c}	51.6^{c-e}	2.75^{b}	12.4^{c-e}
	70	81.43^{a}	52.57^{b}	2.89^{a}	12.5^{cd}
	140	81.46^{a}	53.87^{a}	2.91^{a}	14.17^{a}
	210	80^{ab}	52.6^{b}	2.71^{b}	13.37^{b}
Significance Level		***	*	**	*
CV%		5.26	7.02	6.23	8.71

Means in the table followed by different letter(s) are significantly different to each other ***=significant at p≤ 0.001**=significant at p≤ 0.01; *= significant at p≤ 0.05; CV = Coefficient of variation.

4.3.2. Leaf length

Leaf length of garlic was significantly (p<0.001) influenced by the main and interaction effects of VC and KCl fertilizer rate (Appendix Table 1). The maximum leaf length (53.87cm) of garlic was recorded from the application of 7.5 t/ha VC and 140 kg/ha KCl fertilizer rate. On the other hand, the shortest leaf length (47.13 cm) was recorded from the control treatment (Table 4). Garlic plants supplied with 7.5t/ha of VC and 140 kg/ha of KCl fertilizers increased the leaf length by 6.74cm, which is 14.30% when compared with the control treatment. This increase in vegetative growth might be due to the effect of nutrients that are exerted by bio-enrichment from the VC and physiological K^+ process that is released from KCl, which plays a great role in photosynthesis in the chlorophyll.

The result of the present study is in agreement with the findings of Ismail *et al.* (2014). This outcome is also consistent with that of Fikru Tamiru and Fikreyohannes Gedamu (2018), who found that under well-watered, moderate, and severe stress conditions, the applied municipal solid waste and VC considerably enhanced the leaf area index of garlic. Hasanuzzaman *et al*. (2018) stated that the leaf length of garlic increased with the increased rate of KCl. Similarly, Mujadidi *et al.* (2020) reported that the leaf length of garlic was increased with an increased rate of fertilizer, which accounts for a higher percentage of the variation in leaf length when KCl was increased from 70 to 140 kg/ha.

4.3.3. Leaf width

Leaf width was significantly affected by application of VC and potassium chloride ($P \leq 0.01$) (Appendix Table 1). The widest leaf width (2.91cm) was obtained by the application of the highest level of VC (7.5 t/ha) and KCl 140 kg/ha, which was statistically similar to the application of the same rate of VC with 70 KCl kg/ha. On the other hand, the narrowest leaf width (2.2cm) was obtained from the control treatment.

The widest leaf width due to the excess amounts of organic matter and organic carbon of VC as well as high CEC due to K^+ level might be the vigorous vegetative growth and optimum leaf expansion of garlic. Results of the present study agree with the finding of Fikru Tamru and Fikreyohannes Gedamu (2019), who reported that VC supplement at a rate of 7.5 t/ha increased leaf area index of garlic by 56.32% compared to control. These researchers stated that the leaf area index of garlic treated with different levels of fertilizers was significantly increased over the untreated (control) plot at all sampling growth stages. In addition to this, Astaneh *et al.* (2018) reported that chlorophyll contents of garlic leaf that contribute to leaf width increased significantly with increasing K^+ concentration.

4.3.4. Leaf number

Leaf number was significantly affected by application of VC and potassium chloride ($P \leq 0.01$) as well as their interaction (Appendix Table 1). The highest number of leaves per plant was recorded when the combined application of maximum rate of VC and KCl rates are presented in (Table 4). Application of 7.5 t/ha VC in combination with 140 kg/ha KCl increased leaf number (14.17) which was statistically far with the application of 210 kg KCl/ha while the lowest leaf number (10.6) was obtained from the control treatment. The greater dose-integral function of VC and KCl in the leaves increases, which is more crucial for the synthesis of chlorophyll for photosynthesis, might promote cell division and enlargement, resulting in the highest leaf count. The combined application of VC with chemical fertilizer KCl might increase the availability of essential soil micronutrients and promote microbial population, which ultimately promotes plant growth and production on a sustainable basis. Laila *et al.* (2020) supported that the use of VC is more beneficial when combined with inorganic fertilizers. In agreement with this, leaf number per plant in garlic was significantly increased by the application of the higher rates of VC (Patidar *et al*., 2017). Aftab *et al.* (2017) and Hossain and Salam (2019) found a higher number of leaves per plant of onion with the application rate of 120 kg/ha. Similarly Suparman *et al*. (2021) reported that the dosage of KCl 150 kg/ha was more optimal than other treatments.

4.3.5. Neck diameter

Neck diameter was influenced by interaction effects of VC and KCl application and their main effect (Appendix Table 1). Significantly maximum neck thickness was recorded with the combined application of 7.5 t/ha VC and 140 kg/ha KCl fertilizer rates and followed by 7.5 t/ha VC and 210 kg/ha KCl rates, which is statistically similar while significantly lowest neck diameter with unfertilized plots.

This might be due to the fact that higher application of VC and KCl rates allocated assimilates from plants to the dry matter storage organs of bulbs which at the same time increased the growth of the neck. Similarly, Bargaz *et al*., (2018) reported; when VC and chemical fertilizer are combined, the microbial population is increased and the budget of important soil micronutrients is increased. Fikru Tamru and Fikreyohannes Gedamu, (2018) indicated that also the highest onion neck diameter growths due to the application of potash, which indicate the positive cumulative effects of two or more nutrients available in the compound fertilizers than the fertilizer containing single element on the growths of the crop.

Table 5. Interaction effects of vermicompost and potassium chloride on the neck diameter of garlic.

VC (t/ha)	KCl (kg/ha)	Neck diameter (cm)
0	0	0.85[k]
	70	0.89[jk]
	140	0.94[ij]
	210	0.98[hi]
2.5	0	1.01[hi]
	70	1.03[h]
	140	1.12[g]
	210	1.21[f]
5	0	1.29e
	70	1.31[e]
	140	1.32[de]
	210	1.4[cd]
7.5	0	1.44[bc]
	70	1.44[bc]
	140	1.84[a]
	210	1.51[b]
Significance level		***
CV%		5.8

Means in the table followed by different letter(s) are significantly different from each other *** =significant at p≤ 0.001; CV = Coefficient of variation.

4.3.6. Shoot dry weight

Analysis of variance showed that the main effect of VC and KCl fertilizer significantly (P ≤ 0.001) affected shoot dry weight but there was no significant observation due to interactions of them (Appendix Table 1).

The maximum dry weight shot (7.56g) was determined by using VC 7.5 t/ha and the lowest shoot dry weight was noted at 5.75g from the treatment under control. The rise in dry weight demonstrated that VC might supply the macro and micro nutrients that crops need to produce garlic plant shoots.

Vermicompost as a soil amendment builds up soil organic carbon that helps in the slow release of nutrients in the soil and enables plants to absorb available nutrients. Amante (2024) described that increasing C/N ratios in soil with an increasing application dose of VC indicate a higher supplementation rate ensuring the availability of a considerable extent of micronutrients. Amante (2024) further stated that VC boosts crop biomass and soil fertility while maintaining the integrity of the soil. Furthermore, improved aeration of the plant roots increase available water and readily. Similarly, Fikru Tamru and Fikreyohannes Gedamu (2018) reported a significant increase in the shoot dry weight of garlic with the application of a higher rate of VC (7.5 t/ha).

Potassium chloride fertilization at the rate of 210 kg/ha gave significantly higher shoot dry weight over the other low KCl rates (Table 6). Increased from 0 to 210 kg/ha leaf shoot dry weight was increased by 9.24%. Adequate application of KCl might play an important role in the production of vigorous vegetative growth of garlic. The induction of macro nutrients may all contribute to the beneficial effects of KCl and on plant growth in situations where there is a water deficit. Hayati *et al.,* (2021) reported that the addition of KCl fertilizer at the dose of 100 kg/ha increased K nutrient uptake by the plant, increasing the rate of plant growth leads to increased fresh and dry bulb weight of shallot. Similarly, Suparman *et al.,* (2021) claim that for shallot crops, KCl fertilizer plays a role in facilitating photosynthesis process, growth plant at the starting level, and strengthening the stem which increases shoot dry weight.

Table 6. Effect of VC and KCl fertilizers on shoot dry weight of garlic

VC rate (t/ha)	Shoot dry weight (g)
0	5.75[c]
2.5	6.06[c]
5	6.56[b]
7.5	7.56[a]
Significance level	***
KCl rete (kg/ha)	
0	6.17[b]
70	6.51[ab]
140	6.53[ab]
210	6.74[a]
Significance level	*
CV (%)	6.72

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

4.4. Yield and Yield Components

4.4.1. Bulb length

Bulb length was significantly ($P \leq 0.001$) influenced by the interaction as well as the main effect of blended VC and KCl fertilizer (Appendix Table 2). The longest bulb length (5.57 cm) was attained by the application of 7.5 t/ha treatment with 140 kg KCl/ha while the shortest bulb length (3.29 cm) was obtained from the control. The reason for the application of VC and KCl treatment could be supply the required macro and micronutrients in the soil that promotes early, strong root growth parallel with improving the soil that brought about the larger leaf area index resulting in a greater building up of photo assimilates and transfer to the bulbs, which in the end caused the bulb's length to rise.

Similarly (Fikru Tamru and Fikreyohannes Gedamu, 2018) reported that the optimum bulb length was recorded with application 7.5 t VC/ha. Şahin *et al.,* (2018) also states that VC has all the necessary plant nutrients, vitamins, enzymes, growth hormones, and helpful microorganisms to act as a soil conditioner, activator, and fertility enhancer. Paczka˛ *et al.*, (2021) also reported that the quantitative addition of VC, produced from the waste mass of littoral plants, to mineral soil classified as heavy clay, would affect selected garlic traits and the content of macronutrients and microelements in their storage organs.

Additionally, Suparman *et al*. (2021) revealed that KCl fertilizer helps to strengthen the stem, promote photosynthesis, grow plants in the beginning, and lessen shallot crop yield deterioration.

4.4.2. Bulb diameter

Bulb diameter significantly ($P \leq 0.001$) influenced by VC and KCl the interaction effect of fertilizer application (Appendix table 2). From the combined application of 7.5 t VC/ha and 140 kg KCl/ha the widest bulb diameter (5.79 cm) was recorded followed by the application of VC (7.5 t/ha and KCl 210 kg/ha) which is statistically far by 0.31 to the widest. On the other hand, the control gave a minimum bulb diameter (3.29cm).

The appropriately available VC due to high porosity, aeration, drainage, water-holding capacity, enhanced cation exchange capacity (CEC), large surface area and K^+ plays a great role in water-splitting reaction of photosynthesis in the evolution of oxygen, charge compensation, and osmoregulation of the whole plant, from KCl in the soil may have contributed to the early, in turn caused a higher accumulation of photo assimilates and their translocation to the bulbs, ultimately resulting in an increase in bulb diameter. This could explain the rise in bulb diameter observed in the application of 7.5 t/ha and 140 kg/ha of VC and KCl fertilizer, respectively.

Organic matter plays an important role in soil because of its higher CEC and water holding capacities as well as its chelation ability and influence on soil stability (Angelova *et al*., 2013). Similarly, the combined application of 2.5 t VC/ha and 52.5 kg N/ha gave a significant effect on bulb diameter (Fikru Tamru and Fikreyohannes Gedamu, 2018).

Table 7. Interaction effects of vermicompost and potassium chloride on bulb length, bulb diameter, average bulb weight and average clove weight of garlic.

VC (t/ha)	KCl (kg/ ha)	Bulb length (cm)	Bulb diameter (cm)	Mean bulb weight (g)	Mean clove weight (g)
0	0	3.29^{g}	3.29^{h}	32.30^{i}	1.78^{k}
	70	3.36^{fg}	3.48^{g}	34.14^{hi}	2.03^{j}
	140	3.39^{fg}	3.53^{g}	35.70^{hi}	2.08^{j}
	210	3.42^{fg}	3.58^{g}	36.77^{h}	2.28^{i}
2.5	0	3.46^{fg}	4.59^{f}	42.36^{g}	2.45^{h}
	70	3.57^{d-g}	4.61^{f}	46.85^{f}	2.50^{gh}
	140	3.62^{d-g}	4.63^{f}	50.37^{e}	2.52^{f-h}
	210	3.72^{de}	4.70^{f}	51.53^{de}	2.56^{e-h}
5	0	3.77^{d}	4.86^{e}	53.25^{cd}	2.59^{d-g}
	70	4.71^{c}	4.92^{e}	54.09^{cd}	2.60^{d-g}
	140	4.26^{c}	5.37^{bc}	54.44^{c}	2.63^{d-f}
	210	4.37^{c}	5.23^{cd}	59.00^{b}	2.67^{c-e}
7.5	0	4.39^{c}	5.17^{d}	57.12^{b}	2.69^{cd}
	70	4.53^{bc}	5.31^{cd}	58.27^{b}	2.77^{bc}
	140	5.57a	5.79^{a}	63.19^{a}	2.90^{a}
	210	5.39^{a}	5.48^{b}	62.20^{a}	2.86^{a}
Significance level		***	***	**	***
CV (%)		4.09	2.01	3.21	2.63

Means in the table followed by 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.

4.4.3. Mean bulb weight

The high yield of garlic bulbs was influenced by several factors, including consistent vegetative growth, optimal photosynthetic activity and mineral absorption, high dry matter accumulation, and improved growth performance as a result of applying KCl 150 kg/ha fertilizer, which produced bulbs with a diameter of 33.09 cm (Ruswandi *et al*., 2022). Purba, (2014) also reported that, shortage of potassium in onion plants will inhibit the growth of leaf; that photosynthesis process also becomes inhibited and resulting in the size of the resulting small bulb of shallots.

Mean bulb weight was significantly ($P \leq 0.001$) influenced by the interaction effect of VC and KCl fertilizer application (Appendix Table 2). The highest bulb weight was recorded from fertilization at the highest rate of 7.5 t/ha VC and 140 kg/ha KCl with respective bulb weight of 63.19g, whereas the lowest fresh bulb weight (32.3g) was recorded from the control treatment (Table 7). The increasing of the weight of the bulb with the increasing rate of both VC and KCl fertilizers might be due to the cooperative function that the crop's provision of balanced nutrients plays because the availability of sufficient nutrients, which enhanced vegetative growth and facilitate photosynthetic activities that promotes carbohydrate accumulation and partitioning to the bulbs at maturity, resulted in bulb size as well as bulb weight which was increased by 95.63% over the control, in turn increase average bulb yield of garlic.

In line to this Fikru Tamru and Fikreyohannes Gedamu, (2019) found that application of VC at the rate of 7.5 t/ha increased mean bulb weight by 29.23% as compared to the control plots. In parallel to this, application of VC at the rate of 5 t/ha increased mean bulb weight by 8% as compared to the control plots (Alemu Degwale, 2016). Similarly, Bewuket Gashaw and Kebede Woldetsadik (2020) found that the application rate of 5 t/ha VC resulted in mean bulb weight values (37.85 g).

It could be also by the fact that the bulb's diameter increased and its physiological maturity lengthened in response to fertilization, which also increased the number and length of garlic leaves. The amount of assimilation generated and devoted to the bulbs may have increased as a result of all these factors. In line with (Zhou and Nunes, 2015) showed that KCl treatment gave rise to a considerably average bulb size, 309 g, which was significantly larger than that of the control. On the other hand, (Purba, 2014) reported that application of 100 kg KCl/ha gave the best growth and yield shallots weight of the wet bulb 66.78 g per cluster.

4.4.4. Mean clove weight

The interaction effects of VC and KCl fertilizer application rates as well as their main effect showed significant ($P < 0.001$) difference on the mean clove weight (Appendix Table 2). Highest clove weights (2.9 g) were recorded at the application rate of VC 7.5 t/ha with KCl 140 kg/ha whereas the lowest (1.78 g) was recorded which was increased by 62.92% over the control treatment (Table 7). The increased mean clove weight due to increase in VC and KCl rate could be due to the role of VC which is known to contain micronutrients apart from major nutrients and KCl the soil's sufficient supply of potassium which serves as a key activator of multiple enzymes critical to plant metabolism and cell turgor maintenance may have contributed to the maximum VC (7.5t/ha) and 140 kg/ha KCl treatment's highest mean clove weight by promoting better leaf growth and photosynthetic activities, which in turn increased the amount of assimilates partitioned to the storage organ.

According to Alemu Degwale, (2016), adding 5 t/ha of VC boosted the mean clove weight by 7.99% when compared to the control treatment. Similarly, (Gashaw Bewuket and Kebede Woldetsadik (2020) reported that fertilized with 5t/ha VC produced the highest mean clove weight (5.31 g) which was 155% more than the least mean clove weight recorded from the control. Inline to these, (Paczka, *et al*., and 2021) stated that VC has a crumbly structure with high porosity, which promotes good aeration and high water holding capacity. Similarly, Gashaw Bewket and Kebede Woldetsadik, (2020) reported that fertilized with 5t/ha VC which is known to contain major nutrients produced the highest mean clove weight (5.31 g). In addition, the highest bulb output in terms of potassium chloride was achieved by 100 kg/ha of KCl for shallot crop (Ruswandi *et al*., 2022).

4.4.5. Clove length

The interactions as well as their main effect of VC and KCl fertilizers showed significance ($P \leq 0.001$) differences among the treatment means on clove length (Appendix Table 2). The highest clove length from treatment VC 7.5 t/ha and KCl 140 kg/ha (2.9 cm) followed by 7.5 t/ha VC and 210 kg/ha (2.89cm) which is statistically more similar result was recorded. While the shortest clove length (2.38cm) was recorded from the control. This could be due to VC that releases nutrients gradually into the soil environment and KCl fertilizer which increases K level in the soil so that it can be absorbed by plants which play a role in photosynthesis process, translocation and storage of assimilates and increasing clove size. Similarly, Amante, (2024) reported that VC addition in soil enhanced organic carbon status, decreased bulk density, improved soil porosities and water holding capacities, increased microbial populations and dehydrogenase activity in the soils.

4.4.6. Clove diameter

The main effect of VC and KCl well as their interaction, significantly ($p < 0.001$) affected clove diameter (Appendix Table 2). The widest clove diameter (1.86 cm) was obtained from the plot which receives VC, 7.5 t/ha, with KCl, 140kg/ha treatment followed by the same VC (7.5 t/ha) and KCl fertilizer application 70 kg/ha recorded 1.77cm which is statistically far by 0.09cm. On the other hand, the narrowest clove diameter (0.96 cm) was obtained from the control treatment.

Table 8. Interaction effects of vermicomposting and potassium chloride on clove length, clove diameter, and clove number per bulb of garlic

VC (t/ha)	KCl (kg/ha)	Clove length (cm)	Clove diameter (cm)	Clove number
0	0	2.38[i]	0.96[h]	15.89[j]
	70	2.40[i]	0.97[h]	16.27[ij]
	140	2.42[i]	0.97[h]	16.93[i]
	210	2.43[hi]	0.98[h]	18.17[h]
2.5	0	2.48[h]	1.09[g]	19.03[g]
	70	2.57[g]	1.34[f]	19.57[fg]
	140	2.58[g]	1.39[f]	20.20[f]
	210	2.62[fg]	1.50[e]	21.90[de]
5	0	2.64[ef]	1.57[de]	21.57[e]
	70	2.68[de]	1.68[b-d]	21.87[de]
	140	2.71[d]	1.63[cd]	21.13[c-e]
	210	2.84[bc]	1.64[cd]	22.73[c]
7.5	0	2.79[c]	1.71[bc]	22.60[cd]
	70	2.85[b]	1.77[ab]	23.57[b]
	140	2.90[a]	1.86[a]	24.30[a]
	210	2.89[a]	1.73[ab]	24.92[a]
Significance level		***	***	***
CV%		5.12	4.30	6.04

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

The increasing clove size (clove width and clove length) with increasing application rate of both VC and KCl fertilizers might be due to VC (organic) that releases macronutrients and microelements gradually into the soil environment and KCl (inorganic) fertilizer which increases K level in the soil so that it can be absorbed by plants which play a role in photosynthesis process, translocation and storage of assimilates, increasing clove size. Inline to these Wang et al., (2024) VC is rich in macro and micro-elements which are beneficial to improving soil fertility and releases nutrients slowly. In addition, applying KCl fertilizer may have increased the cloves' and bulbs' diameters and decreased bulb size variances. Ruswandi *et al*., (2022) reported that combined fertilizer application of KCl 150 kg/ha produced a bulb diameter of 33.09 mm.

4.4.7. Clove number

The main as well as their interaction effect of VC and KCl fertilizers application rates influenced the number of cloves per bulb VC and KCl fertilizer significantly ($P \leq 0.001$) affected clove number per bulb (Appendix Table 2). The highest clove number (24.92) was obtained from the VC 7.5t/ha and 210 KCl kg/ha treatment which was statistically similar with 7.5 t/ha VC and 140 KCl kg/ha application. On the other hand, the lowest clove number (15.89) was obtained from the control treatment (Table 8). The increase in clove number per bulb from the highest treatment application could be due to the sufficient organic matter from VC and K fertilizer released from KCl that led to vigorous vegetative growth which enhanced a higher leaf area index that contributed to the higher accumulation of photoassimilates and translocation to cloves and this ultimately caused an increase in clove number per bulb.

This result is in line with the result of Fikru Tamru and Fikreyohannes Gedamu, (2018) which reported that the highest clove number (13.57) recorded from the application rate of 7.5 t/ha VC. VC is a nutrient dense organic fertilizer that is rich in macro and micronutrients as well as beneficial soil microbes including nitrogen fixing bacteria and mycorrhizal fungus and the nutrient of K increases rate of photosynthesis and it will work optimally. Whereas (Suthar, 2008a) revealed that the maximum number of cloves was recorded by the application of 15t/ha VC in garlic.

Yatoo *et al*. (2020) state that VC contains enzymes including lipase, cellulase, chitinase, and amylase that decompose organic debris in the soil and release nutrients for plant roots to use. Wang *et al*., (2022) also reported that the KCl fertilizer application increased the quantity of cloves and bulbs while reducing differences in bulb size.

4.4.8. Total dry biomass

The results of the analysis of variance revealed that the interaction as well as the main effect of VC and KCl fertilizers had a significant difference ($p \leq 0.001$) on total dry biomass of garlic (Appendix Table 2). The application of 7.5 t/ha VC and 140 kg/ha KCl produced the highest total dry biomass (33.92 g), while the control treatment produced the lowest total dry biomass (28.12 g) (Table 9). The maximum treatment's increase in total dry biomass may have been caused by the soil's adequate availability of nutrients, which encouraged vigorous plant growth as measured by leaf number, diameter, length, height, and root weight. These factors improved the rate of photosynthesis and assimilation production in the vegetative part of the plant and their partitioning to the bulbs, which in turn produced a higher total dry biomass.

According to On *et al.* (2024), VC's growth promoting qualities can be attributed to the nutrients it contains, which include nitrogen, potassium, phosphorus, and other vital micronutrients. These compounds promote the growth of the vegetative system, increase the capacity for photosynthesis, facilitate CO_2 fixation, and stimulate meristematic growth. Similar to those, the minerals found in nano-fertilizers which include zinc, iron, phosphorus, potassium, and nitrogen are responsible for growth-promoting actions. These components are essential for promoting meristematic growth, facilitating CO_2 fixation, increasing the capacity for photosynthesis, and aiding in the vegetative system's development.

Potassium released from KCl in particular helps to increase the concentration of nutrients in leaves and facilitates their absorption. On *et al.* (2024) suggest that potassium activates the starch synthase enzyme, enhancing starch synthesis and photosynthesis efficiency, leading to higher outputs. Whereas (De and Paul, 2019) stated that the appropriate uses of Cl enhances appearance, nutritional qualities, and energy flux in garlic plants. It accumulates in stem and leaf organs, promotes organic matter synthesis, and delays leaf senescence by stimulating absorption of nutrients.

4.5. Marketable and unmarketable clove size category

4.5.1. Marketable clove size

All marketable clove weight and all marketable clove numbers were significantly ($P \leq 0.01$) affected by VC and KCl fertilizer and their interaction (Appendices Table 3). The application of VC 7.5 t/ha with KCl fertilizer at a rate of 140 kg/ha produced the largest clove weight large size clove weight was increased by 86.55%.

In line with this, (Fikru Tamiru and Fikreyohannes Gedamu, 2018) reported that the application of 7.5 VC t/ha gave 43.26 % over control. This increases marketable bulb yield due to adequate nutrients that contribute for good shape, appearances and health bulb yield that accounts for marketable bulb yield. Similarly, (Alemu Degwale, 2016) reported that increased VC from 0 to 5 t/ha increased garlic bulb yield by 10%.

Increased clove weight with higher rates of VC and KCl may have resulted from enhanced leaf growth and photosynthetic activities enabled by the soil's potassium supply and micronutrients like VC and KCl. Thakur *et al.,* (2021) justifies that, the quality of soils enhances with the application of VC in the field by increasing microbial activity and microbial biomass that are key components in nutrient cycling, production of plant growth regulators, and protecting plants from soil borne diseases and insect pest attacks. Furthermore, Kelali Haftu *et al*. (2023) observed that the bulk density of clay loam soils was significantly reduced from 1.24 g cm^{-3} to 1.22 g cm^{-3} by applying compost in conjunction with KCl at 300 kg/ha. Van Wesenbeeck *et al.* (2021) found that balanced fertilizer application significantly improves crop values and farm income, particularly in garlic, by promoting growth and plant height.

4.5.2. Marketable size clove number

Very large clove number (>2.5g), was significantly ($P \leq 0.001$) affected by VC and KCl fertilizer and their main effect (Appendix Table 3). The application of VC 7.5 t/ha and KCl fertilizer at 210 kg/ha resulted in the highest clove number (79.33), attributed might due to the sufficient supply of macro and micro nutrients, leading to vigorous vegetative growth, higher leaf area index, and increased photoassimilates.

Similarly, (Fikru Tamiru and Fikreyohannes Gedamu, 2019) reported that VC application significantly increased the garlic cloves number per bulb over the control as it is a nutritive organic fertilizer rich in macronutrients, micronutrients, beneficial soil microbes like nitrogen-fixing bacteria and mycorrhizal fungi. This result is in line with the findings of (Alemu Degwale, 2016) that showed that the effect of VC significantly increased clove number per bulb. (Paczką *et al*., 2021) also revealed that 50% VC addition had the most beneficial effect on number of cloves per bulb.

Jiku *et al.* (2020) reported that potassium at 200 kg/ha produced the highest number of cloves and yield. This is supported by Hayati *et al.* (2021) that with the application of 100 kg/ha of KCl fertilizer, the plant grows faster, absorbs more K nutrients, and produces more shallots both in fresh and dry bulb weight.

Table 11. Interaction effects of vermicompost and potassium chloride on marketable and acceptably marketable clove size category

Treatments		Marketable and acceptably marketable clove size category					
		Very large size cloves		Large size clove		Medium size cloves	
VC (t/ha)	KCl (kg /ha)	>2.5g (weight/g)	>2.5g (No)	2-2.49g (weigh/g)	2-2.49g (No)	1.5-1.99g (weight/g)	1.5-1.99g (No)
0	0	146.28^{m}	32.67^{j}	31.16^{h}	13.33^{h}	32.94^{g}	17^{j}
	70	205.91^{l}	34^{j}	31.31^{h}	15.00^{g}	32.95^{g}	18.33^{ij}
	140	208.28^{kl}	45.33^{i}	32.10^{gh}	15.33^{g}	33.23^{g}	19.33^{hi}
	210	212.72^{j-l}	47.33^{i}	33.17^{g}	16.00^{g}	34.28^{g}	20.67^{h}
2.5	0	219.33^{i-k}	52.67^{h}	41.93^{f}	18.33^{f}	50.39^{f}	27.67^{g}
	70	222.76^{ij}	54.33^{gh}	41.56^{f}	18.33^{f}	54.48^{e}	29.00^{g}
	140	227.66^{hi}	63.67^{ef}	42.37^{f}	19.00^{f}	55.61^{de}	33.67^{f}
	210	232.39^{g-i}	59.33^{fg}	47.54^{e}	21.67^{e}	56.50^{cd}	35.33^{f}
5	0	238.66^{f-h}	62.00^{f}	47.80^{e}	22.67^{e}	57.28^{b-d}	37.67^{e}
	70	244.63^{fg}	68.33^{de}	48.08^{e}	24.00^{d}	57.52^{bc}	39.00^{de}
	140	251.45^{ef}	72.00^{cd}	48.51^{e}	24.33^{d}	57.84^{bc}	39.33^{cd}
	210	259.52^{de}	73.67^{bc}	49.99^{d}	25.00^{cd}	58.51^{b}	40.00^{bc}
7.5	0	268.05^{cd}	76.00^{abc}	52.29^{c}	25.67^{c}	58.50^{b}	41.33^{ab}
	70	275.8^{bc}	77.00^{a-c}	56.37^{b}	27.67^{b}	58.74^{b}	42.00^{a}
	140	386.96^{a}	79.33^{a}	58.13^{a}	30.00^{a}	60.88^{a}	42.67^{a}
	210	307.53^{b}	77.67^{b}	56.35^{b}	28.67^{b}	60.65^{b}	42.33^{b}
Significance level		***	***	***	***	***	***
CV (%)		3.12	4.9	1.8	3.4	1.98	3.34

Means in the table followed by different letter(s) are significantly different to each other ***=significant at p≤ 0.001**; CV = Coefficient of variation.

Application of potassium (K) at 100 kg/ha registered maximum values for bulb yield and yield related attributes such as average number of clove bulbs (Magray, 2017).

4.5.3. Unmarketable size clove weight

Table 12. Main effects of vermicompost and potassium chloride on unmarketable clove size of garlic.

Treatments	Scarcely marketable clove size		Unmarketable clove size	
Vermicompost (t/ha)	Small size clove weight (g)	Small size clove number (No)	Very small size clove weight (g)	Very small size clove number (No)
0	37.18	28.83	33.46	52.92
2.5	34.61	28.83	32.31	54.25
5	37.00	31.42	33.56	55.17
7.5	39.49	33.00	34.82	56.83
Significance level	Ns	ns	ns	Ns
Potassium chloride (kg/ha)				
0	36.26	29.08[ab]	36.93	59.67
70	39.23	33.67[a]	33.09	53.67
140	39.35	32.25[a]	31.98	53.00
210	33.43	27.08[b]	32.13	52.83
Significance level	Ns	*	ns	Ns
CV (%)	18.5	17.98	21.63	25.92

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

The analysis of variance showed that both VC and KCl did not significantly affect this parameter (Appendix Table 4). The insignificant difference that was observed due to these treatment applications suggests that the translocation of prepared food by the plant to the higher amounts in the soil has a greater impact on the emergence and development of clove.

4.5.4. Unmarketable size clove number

The analysis of variance showed that both VC and KCl did not significantly affect this parameter (Appendix Table 4). The insignificant difference that was observed due to these treatment applications suggests that the unavailability of required amounts in the treatment has no impact on the emergence and development of small size cloves.

4.5.5. Total bulb yield

Total bulb yield was significantly ($P \leq 0.001$) influenced by the application of different rates of VC and KCl fertilizer as well as their main effect (Appendix Table 2). The highest total bulb yield (20.46 t/ha) was obtained by the application of 7.5 VC/ha and 140 kg/ha of KCl fertilizer application followed by 19.85 t/ha which is treated with 7.5 t/ha of VC and 210 kg/ha of KCl fertilizers. The increment in bulb yield due to the application of 7.5 t/ha of VC and 140 kg/ha of KCl fertilizers was by 56.66% as compared to the control treatment. On the other hand, the lowest total bulb yield (13.18 t/ha) was obtained from the control (Table 9).

The highest total bulb yield from 7.5VC t/ha and 140 kg/ha KCl fertilizer treatment application could be attributed to the sufficient required amount of nutrients in the soil which resulted in the increased formation of vegetative structure that led to increased photosynthesis and production of assimilates to fill the sink and in then increased bulb size and weight. Suthar (2008a) reported that the average weight was approximately 26.4% greater in 15t/ha of VC compared with zero application plots.

In keeping with this, Itelima *et al*. (2018) assert that both chemical and organic fertilizers are essential in agriculture and can significantly improve crop productivity and soil fertility. According to Chenping and Beiquan (2016), VC products improve the soil's capacity to retain water and exchange cations while also strengthening its structure and fostering a favourable environment for plant growth. They improve soil ventilation and help plants efficiently utilize nutrients in the soil (Şahin *et al.*, 2018). The integrated use of both the organic and inorganic fertilizers continuum inputs was felt the best option to increase both yield potential and quality of garlic crop and environment friendly sustainable farming systems and increase of profit margins for growers (Diriba Shiferaw, 2016b).

Wang *et al*., (2022) observed that the garlic bulb yields were increased with higher fertilizer KCl applications ranging from 0 to 225 kg/ha. For shallot, KCl fertilizer plays a role in facilitating photosynthesis process, growth plant at the starting level, strengthen the stem and reduce yield decay. Bhermana *et al.*(2021) reported that KCl fertilizer with dosage of 150 kg/ha implemented for farming practices and it increased the yield of shallots by 9.17 t/ha and significantly different from the control, KCl 50 and 100 kg/ha, but not significantly different with KCl 200 kg/ha.

On the other hand, Purba (2014) suggested that 100 kg/ha of KCl fertilizer be used to achieve the best shallot bulb output. According to Rajendran *et al*. (2009), bulb plants may be stunted, more prone to disease, and produce lower yields if K is inadequate or not provided in sufficient proportions.

Table 9. Interaction effects of vermicompost and potassium chloride on total dry biomass, total bulb yield, and harvest index of garlic.

VC (t/ha)	KCl (kg/ha)	Total dry biomass (g)	Total bulb yield (t/ha)	Harvest index (%)
0	0	28.12^{g}	13.06^{h}	76.60^{l}
	70	30.38^{f}	13.21^{h}	77.52^{k}
	140	30.49^{f}	13.36^{h}	78.64^{j}
	210	31.79^{cd}	13.64^{h}	78.81^{ij}
2.5	0	31.82^{cd}	14.31^{gh}	79.37^{hi}
	70	30.87^{ef}	15.06^{f-h}	79.71^{gh}
	140	31.28^{de}	15.03^{f-h}	80.02^{g}
	210	32.63^{a}	15.09^{e-g}	81.48^{f}
5	0	31.72^{cd}	15.99^{e-g}	82.22^{e}
	70	32.10^{bc}	16.38^{d-f}	82.93^{d}
	140	32.41^{bc}	17.05^{c-f}	83.05^{cd}
	210	33.73^{a}	18.76^{a-c}	83.41^{b-d}
7.5	0	32.25^{bc}	18.39^{b-d}	83.63^{a-c}
	70	32.48^{bc}	17.51^{c-f}	83.88^{ab}
	140	33.92^{a}	20.46^{a}	84.15^{a}
	210	33.63^{a}	19.85^{ab}	84.20^{a}
Significance level		***	***	***
CV (%)		5.26	7.24	4.42

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

4.6. Harvest index

Total harvest index was significantly (P<0.001) affected by the application of different rates of VC and KCl fertilizer as well as their main effects (Appendix Table 2). The highest harvest index (84.15%) was recorded from the treatment 7.5VC/ha and 210 kg/ha KCl fertilizer application. On the other hand, the lowest harvest index (76.6%) was recorded from the control (Table 9). The considerable impact of the interaction between VC and KCl fertilizer on the harvest index may be attributed to physiological processes that require organic carbon, nitrogen, and phosphorus fertilizers and other essential microelements, such as photosynthesis and stomata control.

In agreement with this, (Fikru Tamru and Fikreyohannes Tamru, 2018) reported that the highest value (63.94%) of harvest index in garlic were recorded with fertilizer application at the rate of 7.5t/ha, whereas the lowest value (51.76%) was recorded at the control treatment.

One significant characteristic of vermiculite (VC) is that many of its nutrients are converted in to forms that are easier for plants to absorb, such as nitrate or ammonium nitrate, exchangeable pH phosphorus and soluble potassium, calcium, and magnesium, by earthworms as they process the various organic wastes. Diriba Shiferaw *et al*., (2018) reported that, maximum harvest index (63.94%) was recorded at the rate of 7.5 t VC/ha application over the other rate of application.

According to Derib Kifle *et al.,* (2017), the integrated effect of all the nutrients present in VC could help to avoid plant nutrient imbalance when applied to the soil in general. Among the different combinations, VC obtained from soybean straw and cattle manure can be of paramount importance when it comes to nutrient composition in enhancing crop productivity, improving soil health and fertility.

Regarding potassium fertilizer, Hasanuzzaman *et al.,*(2018) claim that Potassium enhances antioxidant defense in plants, protecting them from oxidative stress. It also provides cellular signaling and regulates biochemical processes like protein synthesis and carbohydrate metabolism. These factors improve photosynthesis; assimilate production, and yield, leading to a higher harvest index.

4.7. Quality parameters

4.7.1. Total soluble solids

Total soluble solids were significantly ($P \leq 0.01$) affected by VC and KCl fertilizer and their interaction (Appendix Table 3). The application of VC 7.5 t/ha with KCl fertilizer at a rate of 140 kg/ha produced the highest total soluble solid content (31.19 ^{0}Brix), while the control treatment produced the lowest total soluble solid (25.55 ^{0}Brix). In contrast to 140 kg/ha, a further increase in KCl fertilizer application (210 kg/ha) did not, however, result in a rise in the total soluble solid content. This may have been caused by an overabundance of KCl, which promoted excessive vegetative growth at the expense of bulbs and may have contributed to the non-significant decline in the total soluble solid content trend.

The increase in VC and KCl fertilizer application from 0 kg/ha to 7.5t/ha and 140 KCl kg/ha, respectively, resulted in an increment in total soluble solid content. This increment could be attributed to the increased vegetative growth, which led to an increased photosynthetic area that enhanced assimilation (dry matter) production and partitioning to the bulbs.

In line to this study, Fikru Tamru and Fikreyohannes Gedamu (2019) reported that application of 7.5VC t/ha increased TSS by 6.7% compared to control, whereas, Alemu *et al.* (2014) also reported that application of 5 t VC/ha increased TSS by 11.04% compared to control. Alemu Degwale,(2016) who stated that more TSS in garlic due to application of VC as compared to the treatment to which VC was not applied. Similarly, (Alemu Degwale, 2016) revealed in onion, KCl had an intermediate TSS, significantly higher than the control. This finding is supported by the findings of (Siingh *et al.*, 2013), who used VC in place of a control treatment and observed higher TSS and increased fruit density in tomatoes.

Table 10. Interaction effects of vermicompost and potassium chloride on percent dry matter content and total soluble solidity of garlic.

Treatments			
VC (t/ha)	KCl (kg/ha)	Total soluble solid (^{0}Brix)	Percent dry matter (%)
0	0	25.55^{g}	38.56^{k}
	70	25.76^{fg}	39.27^{j}
	140	25.96^{efg}	39.75^{j}
	210	26.46^{ef}	40.40^{i}
2.5	0	26.55^{e}	42.29^{h}
	70	26.63^{e}	42.59^{h}
	140	27.75^{d}	43.51^{g}
	210	28.40^{cd}	43.81^{fg}
5	0	28.33^{cd}	43.87^{fg}
	70	28.04^{cd}	44.53^{f}
	140	28.31^{cd}	48.43^{b}
	210	28.75^{c}	45.67^{e}
7.5	0	28.41^{cd}	46.66^{d}
	70	28.58^{c}	47.71^{c}
	140	31.19^{a}	51.43^{a}
	210	30.35^{b}	48.09^{bc}
P		***	***
CV (%)		1.56	0.87

Means within the same column followed by different letter(s) are significantly different from each other ***=significant at p≤ 0.001; CV = Coefficient of variation.

4.7.2. Percent dry matter content

The main effect of VC and KCl, as well as their interaction, significantly ($p < 0.001$) affected percent dry matter content (Appendix Table 3). The application of VC 7.5 t/ha with KCl fertilizer at a rate of

140 kg/ha produced the highest dry matter content (51.43%), while the control treatment produced the lowest percent dry matter content (38.56%), which increased by 33.38% compared to the control.

The highest dry matter content from 7.5 t/ha VC and 140 kg/ha KCl could be due to the integrated application impact of the VC and KCl. These factors improved the rate of photosynthesis and assimilation production in the vegetative part of the plant and their partitioning to the bulbs, which in turn leads to higher dry matter. Results of the present study agree with the findings of Fikru Tamru and Fikreyohans Gedamu (2019) who reported that garlic bulb dry matter percent was increased by 21.10% due to VC application at 7.5 t/ha over the control. On the other hand, dry matter content was increased only by 5.86% due to the increased level of VC rate from 0 to 7.5 t/ha (Fikru Tamiru and Fikreyohannes Gedam, 2018).

This conclusion was further supported by Alemu Degwale (2016), who showed that VC increased the dry weight of the bulb by accumulating non-structural carbohydrates, whose distribution patterns altered and promoted the metabolism of fructan precursors. Alemu Degwale (2016) further stated that reserve substance accumulation symbolized by polysaccharide, occurs in the VC treatment for a longer duration since blubbing starts earlier. The bulbs grow twice as much in dry weight and size as a result of this reaction, improving their quality and production at harvest.

Rasheed *et al*. (2020) along with the biochemical contents (such as chlorophyll a and b, protein, sugar, carotenoid, phenol, and amino acid contents) observed at different applied potassium chloride concentrations, the maximum concentration of morphological parameters (shoot length, root length, fresh and dry weight, relative water contents, leaf area, leaf no, and root no) was analyzed.

4.8. Correlation Analysis for Growth, Yield 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 highly significantly and positively correlated with days to maturity (r=0.83***) plant height (r=0.80***), leaf length (r=0.82***), leaf width (r=0.78***), leaf number (r=0.72***), neck diameter (r=0.85***) and shoot dry weight (r=0.72***).

This indicated that the vigorous vegetative growth of the garlic plant significantly increased the production of photo assimilates that caused increased yield and quality of garlic (Table 13). Anteneh Aweke and Driba Shiferaw, (2024) also stated that the increment of total and marketable bulb yields may be due to an increase in bulb size and bulb weight by the applied fertilizer which may increase photosynthesis, and subsequently, enhanced growth and expansion of vegetative growth as a whole, and ultimately significantly higher carbohydrate to the bulbs of onion at maturity.

The correlation analysis further indicated that the total bulb yield of garlic significantly and positively correlated with bulb length (r=0.75***), bulb diameter (r=0.83***), average bulb weight (r=0.82***), average clove weight (r=0.85***), clove length (r=0.97***), clove diameter (r=0.90***), clove number (r=0.81***), total dry biomass (r=0.71***), harvest index (r=0.92***), dry matter content (0.93) and total soluble solid (r=0.93***) (Table 13). The increment in bulb yield was a result of increase in yield components of garlic which led to increased average bulb weight and average clove weight that caused increased yield and quality attributes of garlic.

Table **13**. Correlation Analysis for Growth, Yield and Some Quality Parameters of Garlic

PAR	**DE**	**DM**	**PH**	**LL**	**LW**	**LN**	**ND**	**SDW**	**BL**	**BD**	**ABW**	**ACW**	**CL**	**CD**	**CN**	**TDB**	**TBY**	**HI**	**PDMC**	**TSS**
DE	1																			
DM	0.21^{ns}	1																		
PH	0.29^{ns}	0.87^{***}	1																	
LL	0.31^{*}	0.89^{***}	0.87^{***}	1																
LW	0.40^{**}	0.86^{***}	0.89^{***}	0.84^{***}	1															
LN	0.25^{ns}	0.92^{***}	0.81^{***}	0.87^{***}	0.84^{***}	1														
ND	0.26^{ns}	0.92^{***}	0.87^{***}	0.89^{***}	0.89^{***}	0.90^{***}	1													
SDW	0.28^{*}	0.77^{***}	0.74^{***}	0.76^{***}	0.78^{***}	0.77^{***}	0.82^{***}	1												
BL	0.32^{*}	0.89^{***}	0.78^{***}	0.82^{***}	0.83^{***}	0.87^{***}	0.91^{***}	0.82^{***}	1											
BD	0.29^{*}	0.92^{***}	0.92^{***}	0.93^{***}	0.89^{***}	0.88^{***}	0.90^{***}	0.74^{***}	0.81^{***}	1										
ABW	0.25^{ns}	0.93^{***}	0.93^{***}	0.90^{***}	0.91^{***}	0.86^{***}	0.92^{***}	0.76^{***}	0.84^{***}	0.96^{***}	1									
ACW	0.29^{*}	0.86^{***}	0.91^{***}	0.92^{***}	0.86^{***}	0.84^{***}	0.86^{***}	0.74^{***}	0.78^{***}	0.94^{***}	0.93^{***}	1								
CL	0.29^{*}	0.96^{***}	0.91^{***}	0.91^{***}	0.90^{***}	0.89^{***}	0.93^{***}	0.82^{***}	0.89^{***}	0.92^{***}	0.86^{***}	0.94^{***}	1							
CD	0.31^{*}	0.91^{***}	0.93^{***}	0.87^{***}	0.91^{***}	0.83^{***}	0.92^{***}	0.76^{***}	0.82^{***}	0.93^{***}	0.96^{***}	0.88^{***}	0.94^{***}	1						
CN	0.27^{ns}	0.92^{***}	0.95^{***}	0.91^{***}	0.91^{***}	0.87^{***}	0.91^{***}	0.81^{***}	0.85^{***}	0.95^{***}	0.96^{***}	0.94^{***}	0.95^{***}	0.94^{***}	1					
TDBM	0.21^{ns}	0.81^{***}	0.80^{***}	0.87^{***}	0.72^{***}	0.80^{***}	0.81^{***}	0.72^{***}	0.73^{***}	0.82^{***}	0.81^{***}	0.88^{***}	0.82^{***}	0.75^{***}	0.86^{***}	1				
TBY	0.41^{**}	0.83^{***}	0.80^{***}	0.82^{***}	0.78^{***}	0.72^{***}	0.85^{***}	0.72^{***}	0.75^{***}	0.83^{***}	0.82^{***}	0.76^{***}	0.87^{***}	0.86^{***}	0.81^{***}	0.71^{***}	1			
HI	0.26^{ns}	0.93^{***}	0.95^{***}	0.91^{***}	0.89^{***}	0.85^{***}	0.92^{***}	0.78^{***}	0.84^{***}	0.93^{***}	0.96^{***}	0.92^{***}	0.95^{***}	0.95^{***}	0.96^{***}	0.84^{***}	0.92^{***}	1		
PDMC	0.34^{**}	0.94^{***}	0.89^{***}	0.92^{***}	0.89^{***}	0.93^{***}	0.94^{***}	0.81^{***}	0.87^{***}	0.95^{***}	0.92^{***}	0.90^{***}	0.93^{***}	0.91^{***}	0.92^{***}	0.81^{***}	0.93^{***}	0.91^{***}	1	
TSS	0.25^{ns}	0.89^{***}	0.84^{***}	0.87^{***}	0.85^{***}	0.89^{***}	0.93^{***}	0.79^{***}	0.86^{***}	0.87^{***}	0.92^{***}	0.90^{***}	0.93^{***}	0.91^{***}	0.92^{***}	0.810^{***}	0.93^{***}	0.91^{***}	0.90^{***}	1

Where: PAR=parameter, DE- days to emergence, DM- days to maturity, PH-plant height, LL – lea – leaf width, LN-leaf number per plant, SDW- shoot dry weight, ND – neck diameter, BD- bulb diameter, BL- bulb length, CL- clove length, CD- clove diameter, ACW – average clove weight, CN- clove number per bulb, TDB- total dry biomass, ABW-average bulb weight, TBY – total bulb yield, PDM- percent dry matter, TSS-total soluble solid. ns = no significant; * = significant at P ≤ 0.05; ** = significant at P ≤ 0.01, and *** = significant at P ≤ 0.001f length, L

4.8.1. Economic Analysis

As indicated in Table 14, partial economic analysis was done for economic performance of garlic under VC and mineral KCl fertilizer application. The variable cost considered was VC and mineral KCl fertilizer cost with their application cost as well as extended days for labor cost ETB per day of each management over round the growing season was considered.

From the result of this study, the average yield of 4 treatments was obtained. According to CIMMYT (1988), the average yield was adjusted downwards by 10%. This is for the reason that, researchers assumed that using the same treatments the yields from the experimental plots and farmers' fields are different, thus average yields should be adjusted downward. Based on this, the recommended level of 10% was adjusted from all 4 treatments to get the net yield. In addition to this, to obtain the gross field benefits, it is essential to know the field price value of one kg of garlic bulb during harvesting time. Then finally, adjusted yield was multiplied by field price to obtain gross field benefit of garlic. For the treatment combinations the total costs and net benefits were calculated. The different costs of this experiment included cost for VC and KCl. The purchasing price of VC was 7000 ETB/t, KCl 50 ETB/kg. The field price of garlic during the harvesting season was 150 Birr/kg. All the variable costs were subtracted from gross benefit to obtain net benefit.

The partial budget analysis's findings showed that, for garlic production in the study area, the combined application of 7.5 t VC/ha and 210 kg KCl/ha produced the highest net benefit (2710250 ETB/ha) and MRR of 11492.86%, followed by the application of 7.5 t VC/ha and 210 kg KCl/ha, which produced a net benefit of 2623000 Birr/ha and MRR of 6234.58%, and the application of 5 t/ha VC combined with 210 kg/ha KCl produced a net benefit of 2486500 ETB/ha and 6500.00% MRR (Table 14). Thus, the first, second, and third options for garlic production in the study area are the application of 7.5 t/ha of VC with 140 kg/ha of KCl, 7.5 t/ha of VC with 210 kg/ha of KCl, and 5 t/ha of VC with 210 kg/ha of KCl.

Similarly, Fikru Tamiru and Fikreyohannes Gedamu, (2019) reported that maximum net benefit (364250 ETB/ha) was obtained with from the application of 7.5 t VC/ha fertilizer while the least net benefit cost (309600 ETB/ha) was obtained from the unfertilized. On the other hand, Wang *et al*. (2022) found that KCl fertilizer increased net income by 37.1%, with the most economical application being 253.8 kg/ha.

Table 1 4. Summary of partial budget and marginal rate of return analysis for garlic production as influenced by VC and KCl fertilizer rates during the growing season of 2023.

Treatments		Averag e yield (t/ha)	Adjusted yield(t/ha)	GFB (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)	MRR (%)
VC(t/ha)	KCl (kg/ha)						
0	0	13.05	11.74	1761000	-	1761000	-
	70	13.21	11.89	1783500	3500	1780000	542.86
	140	13.36	12.02	1803000	7000	1796000	457.14
	210	13.64	12.28	1842000	10500	1831500	1014.28
2.5	0	14.31	12.88	1932000	17500	1914500	1185.71
	70	15.06	13.55	2032500	21000	2011500	2771.43
	140	15.03	13.53	2029500	24500	2008500	
	210	15.09	13.58	2037000	28000	2009000	14.28
5	0	15.99	14.39	2158500	35000	2123500	1635.71
	70	16.38	14.74	2211000	38500	2172500	140.00
	140	17.05	15.34	2301000	42000	2259000	2471.43
	210	18.76	16.88	2532000	45500	2486500	6500.00
7.5	0	18.39	16.55	2482500	52500	2430000	-
	70	17.51	15.76	2364000	56000	2308000	-
	140	20.46	18.41	2761500	59500	2710250	11492.86
	210	19.85	17.86	2679000	63000	2623000	-

Where:- GFB =gross field benefit; ETB= Ethiopian birr per hectare; MRR=marginal rate of return, NB=net benefit; TVC=total variable cost

5. SUMMARY, CONCLUSION AND RECOMMENDATION

Garlic, a popular Allium vegetable crop, is a significant bulb cash crop for smallholder farmers and a source of income for many Ethiopian peasant farmers. In addition, garlic is widely used as a seasoning in various dishes around the world. It contains numerous sulfur compounds that contribute to its strong odor, unique flavor, pungency, and health benefits.

However, garlic production in the Amhara region is very low due to factors like soil depletion and inadequate fertilizer use. A balanced fertilization strategy is needed for optimal plant growth. Given this, the current study is conducted to evaluate the effects of various VC and KCl fertilizers on garlic growth, yield, quality, and their interaction, as well as their economic feasibility for garlic production in the study area.

The study was conducted at Debre Berhan University's research farm in Ethiopia from June to November 2023 G.C. The experimental materials used were Tsedey 92, an improved variety, and treatments included VC and KCl fertilizer. The treatment consisted of four rates of VC (0, 2.5,5 and 7.5t/ha) and KCl (0, 70,140, and 210 kg /ha), and data were analyzed using the general linear model and Tukey's Method.

The application of the highest levels of VC (7.5t/ha) with KCl 140 kg/ha produced the highest neck diameter, shoot dry weight, clove number, total dry biomass, harvest index, and medium clove size, while the application of the highest levels of VC (7.5t/ha) and KCl (210 kg/ha) produced the highest plant height, leaf length, leaf diameter, leaf number, bulb length, bulb diameter, mean bulb weight, mean clove weight, clove length, clove diameter, total bulb yield, percent of dry matter content, large clove weight, and large clove number. Thus, the increase in total bulb yield due to the application of 7.5t/ha VC and 140 kg/ha KCl was 4.31% and 9.31%, respectively, as compared to the application rates of 5 t/ha VC with 210 kg/ha KCl. Moreover, the application of VC and KCl at the rates of 7.5t/ha and 210 kg/ha resulted in the highest SDW 7.56 and 6.74, respectively, while the lowest SDW was recorded from the control treatment, which had an increment by 0.82 and 0.99, as compared to the nil application of VC and KCl fertilizer respectively. The TSS study found that an application of VC 7.5 t/ha with 140 kg/ha KCl fertilizer resulted in the highest total soluble solid content. The correlation analysis of most yield parameters, such as total bulb yield and average bulb weight indicated that correlated with each other.

The economic analysis also revealed that 140 kg/ha KCl and 7.5 t/ha VC combined fertilizer application was the highest (2710250 ETB/ha) garlic output in the study area. Hence, for economical garlic production in the study area and similar agro-ecologies, it is recommended to apply 7.5 t/ha and 140 kg/ha VC and KCl fertilizers. However, as the results were limited to one season, additional studies need to be conducted in the future at different seasons and locations to give conclusions and recommendations.

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7. APPENDICES

Appendix Table 1. Mean square values of days to emergence, days to maturity, plant height, leaf length, leaf width, leaf number, neck diameter and shoot dry weight of garlic as influenced by VC and KCl fertilizer

Source of variation	DF	DE	DM	PH	LL	LW	LN	ND	SDW
Rep	2	1.72 ns	395.67 ***	401.41 ***	20.12 ***	0.38 ***	6.72 ***	0.5 ***	4.11 ***
VC	3	2.35 ns	711.5 ***	767.31 ***	35.02 ***	0.75 ***	11.07 ***	0.93 ***	7.56 ***
KCl	3	4.24 ns	239.5 ***	35.51 ***	5.22 ***	0.02 ns	2.37 ***	0.07 ***	0.66 **
VC X KCl	9	0.67 ns	12.52 ***	14.12 ***	0.79 **	0.02 **	0.4 **	0.03 ***	0.21 ns
Error	32	1.14	0.92	2.77	0.27	0.0067	0.11	0.002	0.19
CV (%)		11.76	0.68	5.26	7.02	6.23	8.71	5.80	6.72

DF=degree of freedom, DE=days to emergency, DM=days to maturity, PH=plant height, LL=leaf length, LW=leaf width IN= leaf number, ND=neck diameter, SDW=shoot dry weight

Appendix Table 2. Mean square of bulb length, bulb diameter, average bulb weight, average clove weight, clove length, clove diameter, clove number, total dry biomass, and total bulb yield and harvest index of garlic as influenced by VC and KCl fertilizer.

Source of variation	DF	BL	BD	ABW	ACW	CL	CD	CN	TDB	TBY	HI
Rep	2	1.57 ***	1.85	311.42 ***	0.29 ***	0.1 ***	0.32 ***	24.01 ***	6.34 ***	17.02 ***	19.42 ***
VC	3	6.30 ***	8.84 ***	1451.50 ***	1.27 ***	0.45 ***	1.51 ***	108.68 ***	18.65 ***	73.72 ***	90.35 ***
KCl	3	6.64 ***	0.30 ***	84.29 ***	0.10 ***	0.03 ***	0.05 ***	9.69 ***	8.59 ***	2.80 ***	5.02 ***
VCX KCl	9	0.31 ***	0.05 ***	7.10 **	0.02 ***	0.003 ***	0.02 ***	0.56 **	1.49 ***	3.67 **	0.57 ***
Error	32	0.88	0.009	2.53	0.004	0.0008	0.004	0.18	0.16	1.36	0.12
CV (%)		4.09	2.01	3.21	2.63	5.12	4.30	6.04	5.26	7.24	4.42

DF=degree of freedom, BL= bulb length, ABW=average bulb weight, ACW=average clove weight, CL=clove length, CD=clove diameter, TDB=total dry biomass, TBY=total bulb yield, HI=harvest index.

Appendix Table 3. Mean square values of percent dry matter content, total solute solubility, very large clove weight, very large clove number, large clove weight and large clove number of garlic as influenced by VC and KCl fertilizer.

Source of variation	DF	PDMC	TSS	VLCW	VLCN	LCW	LCN	MCW
Rep	2	40.64 ***	7.63 ***	4371 ***	703.77 ***	261.48 ***	82.08 ***	360.49 ***
VC	3	174.47	29.47 ***	17650.21 ***	3186.08 ***	1254.66 ***	386.08 ***	1773.86 ***
KCl	3	177.62 ***	5.51 ***	2616.31 ***	248.58 ***	33.33 ***	18.08 ***	17.15 ***
VC X KCl	9	3.71 ***	1.05 ***	529.57 ***	28.06 **	6.48 ***	2.08 ***	3.81 ***
Error	32	0.15	0.19	55.06	9.04	0.66	0.46	1.03
CV (%)		0.87	1.56	3.12	4.93	1.8	3.14	1.98

DF=degree of freedom, PDMC=percent of dry matter content, TSS= total soluble solids, VLCW=very large clove weight, VLCN=very large clove number, LCW=large clove weight, LCN=large clove number, MCW=medium clove weight, MCN=medium clove number

Appendix Table 4. Mean square values of small clove weight, small clove number, very small clove weight and very small clove number of garlic as influenced by VC and KCl fertilizer

Source of variation	DF	SCW	SCN	VSCW	VSCN
Rep	2	71.41 ns	78.83 *	38.58 ns	80.39 ns
VC	3	47.65 ns	50.58 ns	12.66 ns	32.47 ns
KCl	3	95.18 ns	107.08 *	64.50 ns	128.30 ns
VC X KCl	9	53.82 ns	20.63 ns	54.53 ns	179.06 ns
Error	41	47.01	30.12	52.62	201.71
CV(%)		18.51	17.98	21.63	25.92

DF= degree of freedom, SCW=small clove weight, SCN=small clove number, VSCW=very small clove weight, VSCN=very small clove number

Appendix Table 5. Effect of VC and KCl on bulb length, bulb diameter, mean bulb weight and mean clove weight of garlic

VC (t/ha)	BL (cm)	BD (cm)	MBW (g)	MCW (g)
0	3.36[c]	3.47[d]	34.90[d]	2.04[d]
2.5	3.59[c]	4.63[c]	47.77[c]	2.51[c]
5	4.28[b]	5.09[b]	55.20[b]	2.62[b]
7.5	4.97[a]	5.44[a]	60.19[a]	2.81[a]
Significance level	***	***	***	***
KCl (kg/ha)				
0	3.73[b]	4.48[b]	46.43[c]	2.38[c]
70	4.04[a]	4.58[b]	48.34[b]	2.48[b]
140	4.21[a]	4.83[a]	50.92[a]	2.53[ab]
210	4.22[a]	4.75[a]	52.37[a]	2.59[a]
Significance level	***	***	***	***
CV (%)	7.35	2.82	3.79	3.58

BL=bulb length, BD=bulb diameter, MBW=mean bulb weight, MCW= mean clove weight

Appendix Table 6. Effect of VC and KCl on clove length, clove diameter, clove number and total dry biomass of garlic

VC (t/ha)	CL (cm)	CD (cm)	CN	TDB (g)
0	2.41[d]	0.97[d]	16.81[d]	30.20[d]
2.5	2.56[c]	1.33[c]	20.17[c]	31.65[c]
5	2.72[b]	1.63[b]	22.07[b]	32.49[b]
7.5	2.86[a]	1.77[a]	23.85[a]	33.07[a]
Significance level	***	***	***	***
KCl (kg/ha)				
0	2.65[b]	1.33[b]	19.77[c]	30.98[c]
70	2.57[c]	1.46[a]	20.73[b]	31.46[c]
140	2.62[b]	1.44[a]	2047[b]	32.02[b]
210	2.70[a]	1.47[a]	21.93[a]	32.95[a]
Significance level	***	***	***	***
CV (%)	1.40	6.09	2.47	2.11

CL=clove length, CD=clove diameter, CN=clove number, TDB=total dry biomass

Appendix Table 7. Effect of VC and KCl on total bulb yield, harvest index, percent of dry matter content and total soluble solids of garlic

VC (t/ha)	TBY (t/ha)	HI	PDMC (%)	TSS (^{0}Brix)
0	13.31[d]	77.89[d]	39.49[d]	25.93[d]
2.5	15.07[c]	80.14[c]	43.05[c]	27.33[c]
5	17.23[b]	82.90[b]	45.58[b]	28.35[b]
7.5	18.86[a]	83.96[a]	48.47[a]	29.63[a]
Significance level	***	***	***	***
KCl (kg/ha)				
0	15.44[a]	1.47[a]	21.93[a]	32.95[a]
70	16.26[a]	1.46[a]	20.73[b]	32.02[b]
140	16.32[a]	1.44[a]	2047[b]	31.46[c]
210	16.47[a]	80.46[a]	19.77[c]	30.98[c]
Significance level	***	***	***	***
CV (%)	8.48	0.57	2.18	2.21

TBY=total bulb yield, HI=harvest index, PDMC=percent dry matter content, TSS=total soluble solids