EFFECT OF BLENDED NPSB FERTILIZER AND VERMICOMPOST ON GROWTH, YIELD AND YIELD COMPONENTS OF GARLIC (*Allium sativum* L.) UNDER RAINFED CONDITION IN ENORE DISTRICT, CENTRAL ETHIOPIA

MSc. THESIS

HLINA TILAHUN TEGODA

JUNE 2024

WOLKITE, ETHIOPIA

Wolkite University

School of Graduate Studies

Effect of Blended NPSB Fertilizer and Vermicompost on Growth, Yield and Yield Componentsof Garlic (*Allium sativum* L.) under Rainfed Condition in Enore District, Central Ethiopia

A Thesis Submitted to the Department of Horticulture College of Agriculture and Natural Resource in Partial Fulfillment of the Requirements for the Degree of Master of Science (MSc.) in Horticulture

Hlina Tilahun Tegoda

Major Advisor: Solomon Kebebew (PhD)
Co-Advisor: Birhanu Tsegaye (Asst. Prof.)

June 2024
Wolkite, Ethiopia

WOLKITE UNIVERSITY

SCHOOL OF GRADUATE STUDIES

APPROVAL SHEET

We hereby certify that we have read and evaluated this Thesis entitled **"Effect of Blended NPSB Fertilizer and Vermicompost on Growth, Yield and Yield Components of Garlic (*Allium sativum* L.) Under Rainfed Condition in Enore District, Central Ethiopia"** prepared under our guidance by Hlina Tilahun Tegoda. Hence, we hereby recommend that the thesis shall be submitted as fulfilling the requirements for the award of MSc. Degree in Horticulture.

Solomon Kebebew (PhD)	_____	_____
Name of Major Advisor	Signature	Date
Birhanu Tsegaye (Asst Prof.)	_____	_____
Name of Co- advisor	Signature	Date

As members of the Board of Examiners of the Master of Science Thesis open defense examination, we have read and evaluated this Thesis prepared by Hlina Tilahun Tegoda and examined the candidate. Hence, we hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science (MSc.) in Horticulture.

Essubalew Getachew (PhD)	_____	_____
Name of External Examiner	Signature	Date
Mekonnen Gebru (PhD Candidate)	_____	_____
Name of Internal Examiner	Signature	Date
Arif Abrahim (PhD Candidate)	_____	_____
Name of Chairman	Signature	Date

Final approval and acceptance of the Thesis are contingent upon the submission of its final copy to the Council of Postgraduate Program (CPGS) through the candidate's Department or School Graduate Committee (DGC or SGC).

DEDICATION

This thesis manuscript is so compassionately dedicated to my beloved family for their unwavering support and encouragement throughout my life. May God bless them in abundance.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my work. I have followed all ethical principles of scholarship in the preparation, data collection, data analysis, and completion of this thesis. All scholarly matter that is included in the thesis has been given recognition through citation. I affirm that I have cited and referenced all sources used in this document. Every effort has been made to avoid any plagiarism in the preparation of this thesis.

The thesis is submitted in partial fulfillment of the requirements for a degree from the School of Graduate Studies at Wolkite University. The thesis is deposited in the Wolkite University Library and is made available to borrowers under the rules and regulations of the library. I solemnly declare that this thesis has not been submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

Brief quotations from this thesis may be used without special permission provided that an accurate and complete acknowledgment of the source is made. Requests for permission for extended quotations from or reproduction of this manuscript in whole or in part may be granted by the Head of the School or Department or the Dean of the School Graduated Studies when in his or 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 of the thesis.

Name: **Hlina Tilahun**

Signature:_____

Date: June 2024

Department: Horticulture

BIOGRAPHICAL SKETCH

The author, Hlina Tilahun, was born at Yebuna Kebele near Dembecha town, in West Gojam Zone of Amhara Regional State, Ethiopia from her parents Tilahun Tegoda and Nitsuh Muluneh. She attended Yetsed Primary School from 2005 to 2013 G.C. Subsequently, she pursued secondary and preparatory education at Dembecha Senior Secondary and Preparatory School from 2013 to 2017 G.C.

After passing the Ethiopian Higher Education Entrance Certificate Examination, she then joined Wolkite University in 2018 and graduated with a BSc degree in Horticulture in January 2021 G.C. Soon after, she was recruited by Wolkite University as a Graduate Assistant and enrolled by the School of Graduate Studies of Wolkite University to pursue the Master of Sciences in Horticulture.

ACKNOWLEDGMENTS

First and foremost, I would like to praise and venerate the supreme Almighty God, the Savior, and Saint Virgin Mary for unwavering help and compassion in all aspects of my life, including the completion of this thesis.

It is my great pleasure to pay respect and express sincere thanks to my major advisor, Solomon Kebebew (PhD) for his constructive excellent guidance, advice, support, and priceless comments, which have been amicable motivation and scientific support from the early stage of proposing the research work to the final write-up of this thesis. I also extend my heartfelt gratitude to my research co-advisor, Mr. Birhanu Tsegaye (Assistant professor) for the guidance, encouragement, and consistent supervision at every stage of this thesis work.

I would like to thank Wolkite University, for giving me a chance to pursue my M.Sc. degree and granting me full sponsorship. I would like to thank the Gummer Agricultural office for assisting me in getting vermicompost. My great heart also goes to the Debre-Ziet Agricultural Research Center for their support for garlic cloves.

My glossary falls short of expressing my heartiest regards to my beloved family, relatives, and all my friends for their unwavering encouragement and kind support throughout this journey.

ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
CEC	Cation Exchange Capacity
C: N	Carbon to Nitrogen Ratio
CIMMYT	International Center for Wheat and Maize Improvement
CSA	Central Statistical Agency
CV	Coefficient of Variation
DAP	Di-Ammonium Phosphate
DZARC	Debre Zeit Agricultural Research Center
EARO	Ethiopian Agriculture Research Organization
EWPCO	Enor Wereda Plan Commissions Office
FAO	Food and Agricultural Organization
MoARD	Ministry of Agriculture and Rural Development
NPSB	Nitrogen, Phosphorus, Sulfur and Boron
SNNPRS	South Nation, Nationality and People
VC	Vermicompost

TABLE OF CONTENTS

APPROVAL SHEET ..... **III**

DEDICATION ..... **IV**

STATEMENT OF THE AUTHOR ..... **V**

BIOGRAPHICAL SKETCH ..... **VI**

ACKNOWLEDGMENTS ..... **VII**

ABBREVIATIONS AND ACRONYMS ..... **VIII**

TABLE OF CONTENTS ..... **IX**

LIST OF TABLES ..... **XII**

LIST OF FIGURES ..... **XIII**

LIST OF APPENDIX TABLES ..... **XIV**

LIST OF APPENDIX FIGURES ..... **XV**

ABSTRACT ..... **XVI**

1. INTRODUCTION **1**

2. LITERATURE REVIEW **5**

2.1. Origin, Distribution and Taxonomy of Garlic Crop 5

2.2. Nutritional Value of Garlic 6

2.3. Economic Importance of Garlic in Ethiopia 6

2.4. Ecological Requirements of Garlic 7

2.5. Production Status, Constraints, and Opportunity for Garlic Production in Ethiopia 7

2.5.1. Garlic Production and Productivity in Ethiopia 7

2.5.2. Production Opportunity of Garlic in Ethiopia 8

2.5.3. Production Constraint of Garlic in Ethiopia 8

TABLE OF CONTENTS (*Continued*)

2.6. The Effect of Blended NPSB Fertilizer on Growth and Yield Components of Garlic9

2.6.1. Effect of Blended NPSB Fertilizer on Growth Attributes 9

2.6.2. Effect of Blended NPSB Fertilizer on Yield Components 10

2.7. Response of Garlic to Vermicompost Application 11

2.8. Effect of NPSB Fertilizer and Vermicompost on Growth and Yield of Garlic 13

2.8.1. Effect of NPSB Blended and Vermicompost Fertilizer on Growth Attribute .. 13

2.8.2. Effect of NPSB Blended and Vermicompost Fertilizer on Yield Components 14

3. MATERIALS AND METHODS 15

3.1. Description of the Study Area 15

3.2. Experimental Materials 16

3.3. Treatments and Experimental Design 16

3.4. Vermicompost and Soil Sample Analysis 17

3.4.1. Vermicompost Sample and Analysis 17

3.4.2. Soil Sample and Analysis 18

3.5. Experimental Procedures and Crop Management 19

3.6. Data Collection 20

3.6.1. Phenological Parameter 20

3.6.2. Growth Parameter 20

3.6.3. Yield and Yield Related Parameter 20

3.7. Partial Budget Analysis 21

3.8. Data Analysis 23

4. RESULTS AND DISCUSSION 24

4.1. Post- harvest Analysis Results of Soil Chemical properties 24

4.2. Effect of NPSB and Vermicompost Fertilizer on Garlic Phenological Parameters 27

4.2.1. Days to 50% Emergence 27

TABLE OF CONTENTS (*Continued*)

4.2.2. Day to 75% Maturity 27

4.3. Effect of NPSB and VC Fertilizer on Growth Parameters of Garlic 29

4.3.1. Plant Height 29

4.3.2. Leaf Length 30

4.3.3. Number of Leafs per Plant 32

4.4. Effect of NPSB and VC Fertilizer on Yield Components of Garlic 34

4.4.1. Average Fresh Biomass Yield 34

4.4.2. Mean Bulb Weight 35

4.4.3. Number of Clove 36

4.4.4. Biological Dry Yield 37

4.4.5. Harvest Index 38

4.4.6. Marketable Bulb Yield 39

4.4.7. Unmarketable Bulb Yield 39

4.4.8. Total Bulb Yield 40

4.5. Correlation Analysis 42

4.7. Partial Budget Analysis 45

5. CONCLUSIONS AND RECOMMENDATIONS 47

5.1. Conclusions 47

5.2. Recommendations 48

6. REFERENCES 49

7. APPENDIX 66

LIST OF TABLES

Tables **Page**

1. Treatment Combinations 17
2. The interaction effects of NPSB and VC fertilizer application on soil properties of the experimental site. 26
3. The main effect of NPSB and VC fertilizers on the day to 75% maturity of garlic. 29
4. The interaction effect of blended NPSB and VC fertilizer on plant height and leaf length of Garlic. 32
5. The main effect of blended NPSB and VC fertilizer on the number of leaves per plant. 34
6. The interaction effect of blended NPSB and VC fertilizer on yield-related parameters of garlic. 37
7. The interaction effect of blended NPSB fertilizer and Vermicompost on yield parameters of garlic. 41
8. Correlation coefficients among growth and bulb yield attributes of garlic. 44
9. Partial budget analysis of the effect of blended NPSB and VC fertilizer on garlic. 46

LIST OF FIGURES

Figure 1. Map of the study area 15
Figure 2: Monthly mean minimum and maximum temperatures and rainfall of study area 16

LIST OF APPENDIX TABLES

Appendix Tables

1. Soil Physiochemical Properties and Characteristics of VC Before Planting.....66
2. Mean squares of ANOVA for Selected Chemical Properties of Soil after Harvest..... 66
3. Mean squares of ANOVA for Phenological and growth parameters of garlic as influenced by NPSB and VC fertilizer..... 67
4. Mean squares of ANOVA for average fresh biomass yield, mean clove weight, clove number per bulb and biological dry yield of garlic as influenced by NPSB and VC.....67
5. Mean squares of ANOVA for harvest index(%), marketable bulb yield (t ha^{-1}), unmarketable bulb yield and total bulb yield of garlic as influenced by NPSB and VC. 68
6. Interpretive values or Ratings for Selected Soil Properties..... 69
7. Ten years of monthly temperature and rainfall of the area Emdibir sub-station meteorological data.....70

LIST OF APPENDIX FIGURES

Appendix Figures

1. Preparation of experimental field layout 71
2. Planting garlic seed 71
3. Vegetative growth performance of garlic 72
4. Different yield data measuring 73

Effect of Blended NPSB Fertilizer and Vermicompost on Growth, Yield and Yield Components of Garlic (*Allium sativum* L.) Under Rainfed Condition in Enore District, Central Ethiopia

ABSTRACT

Garlic is economically important, though the productivity is below its potential due to inappropriate use of soil fertility management practices particularly fertilizer rate and type had significant role. Therefore, this study was conducted to investigate the effect of Blended NPSB and vermicompost fertilizers on the growth, yield and yield components of garlic under rain-fed conditions in Enore district, Central Ethiopia. The experiment consisted of four rates of blended NPSB fertilizer (0, 122, 244, and 366 kg ha^{-1}) and four rates of vermicompost fertilizer (0, 2.5, 5, and 7.5 t ha^{-1}). The treatments were laid out in a Randomized Complete Block Design in a 4×4 factorial arrangement with three replications. Data were collected on the phenological, growth, and yield parameters of garlic and analyzed using SAS software version 9.4. ANOVA results showed that all the tested parameters of garlic were affected highly significantly ($p < 0.01$) by the interaction effect, except days to maturity and the number of leaves per plant which was highly significantly ($p < 0.01$) affected by the main effects of blended NPSB and vermicompost fertilizers. Thus, the longest days to maturity of 126.7 and 127.6 were recorded at the rate of 244 kg ha^{-1} NPSB and 7.5 t ha^{-1} vermicompost fertilizer, respectively. Statistically the longest plant height (62.6) and leaf length (55.6 cm) of garlic were recorded from the combined applications of 366 kg ha^{-1} and 7.5 t ha^{-1}. The highest leaf number of garlic 12.98 was recorded from 7.5 t ha^{-1} VC rate, which is statistically similar with 11.2 and 10.7 were recorded from 366 and 244 kg ha^{-1} NPSB fertilizer rate, respectively. Similarly, the highest average fresh biomass yield (65.2 g/plant), mean bulb weight (36.8 g), number of clove (30.5), biological dry yield (47.5 g/plant) and harvest index (60.7%) were recorded from the combined application of 244 kg ha^{-1} NPSB and 7.5 tha^{-1}VC fertilizer. The highest marketable bulb yield 13 t ha^{-1}, total bulb yield 13.3 t ha^{-1}, and the lowest unmarketable yield 0.32 t ha^{-1} were recorded from the combined application of 244 kg ha^{-1} and 7.5 t ha^{-1}. The highest net benefit (3,392,556 ETB ha $^{-1}$) was recorded from the combined application of 244 kg ha^{-1} blended NPSB and 7.5 t ha $^{-1}$VC fertilizer with high MRR (1982.86). The study revealed that the integrated use of 7.5 t ha^{-1}VC and 244 kg ha^{-1} blended NPSB fertilizers improved soil fertility status for sustainable garlic production and productivity in the study area. However, more studies need to be conducted at various agro-climatic conditions to generate more reliable results for conclusive recommendations.

Keywords: Garlic, NPSB fertilizer, Total bulb yield, Vermicompost.

1. INTRODUCTION

Garlic (*Allium sativum* L.; 2n=16) is a spice of bulbous plants in the family of Amaryllidaceae various allium species, the garlic plant ranks second after onion in the world (Yadav *et al*., 2017). About 10,000 years ago, garlic was adopted on the western slope of the Tien Shan Mountains and distributed from there to Central Asia, Africa, Europe, and America (Ipek *et al*., 2008). In Ethiopia, garlic is one of the main vegetables and widely cultivated spice crops for both consumption and medicinal purposes (Tamiru and Gedamu, 2019), such as being used for the treatment and control of various diseases (Abdel-Razzak and El-Sharkawy, 2013). Along with the Allium species, garlic is a unique commercially significant vegetable produce grown aimed at family use, sale, nourishment treatment, and enhancement in the form of oil, minerals, or powder (Teshale and Tekeste, 2021).

Garlic is known to have a wide range of adaptations and cultivation across the world (Mohammed *et al*., 2012). The global total area covered by garlic is 1,659,236 ha, with a total production of 28,494,130 tons and 18.42 t ha^{-1} productivity (FAOSTAT, 2023). China, India, Bangladesh, South Korea, Egypt, Spain, USA, Uzbekistan, Russia, and Myanmar are known to be the major garlic producer countries in the world (FAOSTAT, 2023). In Ethiopia, garlic is an important bulb crop concerning its production and economic value, both for smallholder and commercial growers (Da Silva *et al*., 2013). However, garlic production declined from 16,411.19 ha during 2013/14 to 15,980 ha during 2020/21, with a total production of 113,928.43 tons from 14,576 hectares of land and an average productivity of 7.8 t ha^{-1} (FAOSTAT, 2023).

The current garlic productivity in Ethiopia 7.8 t ha^{-1} is below potential (CSA, 2021; Shege *et al*., 2021), this generally indicates that Ethiopian garlic production is very low when compared to the world average of 18.4 t ha^{-1}. This could be due to various problems such as low soil fertility, inappropriate use of fertilizers, high costs of chemical fertilizers, a lack of improved varieties, diseases, and insect pests (Mohamed *et al*., 2014; Shafeek *et al*., 2015). Among these, low soil fertility and inappropriate use of fertilizer are the most commonly adopted bottlenecks to limit the production and productivity of garlic in Ethiopia (Gezu, 2015; Kahsay *et al*., 2016).

Garlic requires a relatively high amount of nutrients for normal growth and development due to unbranched, shallow root system with low nutrient extraction capacity (Yayeh *et al*., 2017). The soil should be fertile, rich in organic matter, well-drained, and capable of holding adequate moisture (Diriba, 2016). Most Ethiopian soils contain insufficient macronutrients (N, P, and S) and micronutrients (Cu, B, and Zn) (Tegbaru, 2016). Due to this, crop yields have reduced as expected even when the recommended rates of N and P fertilizers are applied (Chillot and Hassan 2010). On the other hand, farmers in Ethiopia in general, and in the study area, in particular, have used only two types of fertilizers (DAP and Urea), which contain only nitrogen and phosphorus with the national blanket recommendation application rate of 105 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} for garlic production (EIAR, 2007). Moreover, the nutrients in these fertilizers are poorly utilized due to the limited incorporation of organic fertilizers and soil-related factors such as P-fixation, leaching, and volatilization of NO_3 and N_2O, respectively (Rop *et al.*, 2019).

The Ministry of Agriculture of the country has introduced a new blended fertilizer (NPSB), which contains N, P, S, and B with a ratio of 19%–38%–7%–1% (ATA, 2016). NPSB fertilizer has been recommended to ensure balanced fertilizer use, improve soil fertility, and result in substantial increases in crop production (Tegbaru, 2016). However, fertilizer has been applied based on blanket recommendations without considering soil fertility differences across locations or levels of a specific area, thus leading to an economic threshold for NPSB fertilizer (Melaku *et al*., 2017). Additionally, inappropriate use of chemical fertilizers is the major cause of nutrient imbalance and environmental damage through poisoning and exterminating soil fertility, thereby adversely changing the chemical and physical properties of soil (Mbithi *et al*., 2015).

Therefore, the application of organic fertilizers like vermicompost (VC) is recognized as an effective means for improving soil fertility, porosity, aeration, drainage, water holding capacity, microbial diversity, enhancing cation exchange capacity (CEC), and large surface area, by providing a strong capacity to hold and retain plant-available nutrients : nitrates, exchangeable phosphorus, soluble potassium, calcium, and magnesium (Hargreaves *et al*., 2008).

Vermicompost can be used as a resource for improving crop productivity on a sustainable basis and is more financially safe in comparison to this inorganic fertilizers (Singh and Chauhan, 2009). It is locally available, accessible and affordable to many farmers, and it gets accepted as a good option for minimizing the risk of nutrient losses (Yohanne *et al*., 2013). However, due to limited organic resources, competing uses such as animal feed and fuel, and labor shortages for the preparation and transport of compost, given the bulkiness of the compost required for an adequate supply of plant nutrients, small-scale farmers cannot afford to add the required amounts of vermicompost (Nigussie *et al*., 2015). On the other hand, the application of inorganic fertilizers combined with organic fertilizers may reduce the use of synthetic fertilizers, improve soil health and plant nutrient availability, and in higher crop yields (Bhagwan *et al*., 2012). Furthermore, integrated nutrient application not only ensures the supply of essential nutrients to plants but also has some positive interactions to increase nutrient use efficiency, while also being environmentally safe (Bewuket *et al*., 2017).

In Gurage zone and particularly in the Enore district, garlic is one of the most economically important vegetable crop (EWPCO, 2020). However, the production and productivity of garlic in the district are low because of insufficient nutrient availability in the soil (EWPCO, 2020). The main task of sustainable agriculture is to maintain soil fertility and stabilize crop production from year to year, taking into account soil degradation and yield reduction. In the study area, smallholder farmers apply imbalanced fertilizers, which is a much lower rate compared to the countrywide comprehensive recommendation for garlic production. On the other hand, farmers have limited awareness about balanced soil fertility management; there is no well-proven information about site-specific optimum recommendations for using blended NPSB and VC fertilizers for garlic production in the area. Moreover, limited studies have been reported on the effect of blended NPSB and VC fertilizers on the performance of garlic in the district (EWPCO, 2020).

Hence, there is a need to conduct research to site-specific recommendation rates of commonly available blended NPSB and VC fertilizers for improving garlic production in the study area. Therefore, the study has been initiated to achieve the following objectives:

1.2. General objective

To improve the productivity of garlic through optimum nutrient management in Enore district, Central Ethiopia

1.3. Specific objectives

- ✓ To assess the effects of blended NPSB and vermicompost fertilizer rates on the growth, bulb yield and yield components of garlic crops in the study area
- ✓ To determine the optimum combination rate of blended NPSB and vermicompost fertilizer for garlic production in the study area
- ✓ To determine economically feasible NPSB and vermicompost fertilizer rates in the study area

2. LITERATURE REVIEW

2.1. Origin, Distribution and Taxonomy of Garlic Crop

Garlic originated in Central Asia (India, Afghanistan, Western China, and Russia) and spread to other parts of the world through trade and colonization (James, 2008). It is a shallow-rooted vegetable crop (Allen, 2009). It is known that about 750 species belong to the genus Allium, although only seven of them are widely cultivated in various parts of the world (Shafeek *et al*., 2015). Recently, garlic has been cultivated all over the world from the equator to 50° latitude in both hemispheres. However, garlic is most popular in China, the Mediterranean region, and Latin America. In tropical Africa, garlic is grown in the cold season at high altitudes in eastern and southern Africa. It is a popular crop in the savanna zone and local cultivars show high genetic variability. It is rarely, if ever, found in warm, humid lowlands (Westerfield, 2015). Garlic is an erect herbaceous plant that is cultivated as an annual and its bulbs consist of many fibers that are split and wrapped in a whitish skin (Hector *et al*., 2012).

In addition, it contains 4-6 types of segments with a typical spicy taste. This annual herb has a 60 cm tall cylindrical stem and thin, flat, and strong leaves that are 2-3 cm wide (Vanaclocha *et al*., 2019). Garlic exhibits a wide morphological and agronomic diversity between cultivars in characteristics such as bulb color and size, plant height, number and size of cloves, days to harvest, harvest period, dormancy, and adaptation to agro-climatic conditions (Westerfield, 2015). They are sown in full sun, which requires a lot of water and fertilization. Like onions, garlic plants have thin, narrow leaves that are about 30cm long. The roots reach a depth of up to 50 cm or a little more. The heads or bulbs are white and divided into sections called helmets. Each head may contain 6-12 keys covered with a white or reddish paper layer or shell (Hector *et al*., 2012). The leaves begin to turn brown and the tops fall, indicating maturity (Tadesse Abadi, 2015). When they ripen, the bulbs are dug up and stored in a cool, ventilated place, often dried with smoke, which reduces weight loss and partially prevents germination teeth become dry or scaly (Vanaclocha *et al*., 2019).

2.2. Nutritional Value of Garlic

Garlic has a higher nutritional value than other bulbous plants (Abou El-Magd *et al*., 2012). It is a source of volatile compounds and sulfur-containing compounds that are responsible for its strong aroma, unique taste, bioactive properties, and health benefits (Walag, 2020). Garlic is clinically very responsible for lowering blood pressure, cholesterol, and glucose levels, as well as treating arteriosclerosis, blood clotting, flu, cancer, and cryptosporidium in AIDS patients (Tsai *et al*., 2012). It also contains several minerals and vitamins that are used for human health (Kumar *et al*., 2010). In addition to vitamins, garlic contains many macro and micro elements and minerals. Its pungent taste allows it to be used mainly as a seasoning, spice, and flavor in foods with both green tops and onions (Zeru *et al*., 2023). Garlic has been as a raw vegetable (fresh leaves or dried cloves) or after processing as garlic oil, garlic extracts, or garlic powder, the different forms have different chemical compositions and concentrations of bioactive compounds (Lanzotti *et al*., 2014).

2.3. Economic Importance of Garlic in Ethiopia

Garlic has played an important role as a cultivated spice and medicinal plant for more than 5000 years (Bizuayehu *et al*., 2021). Therefore, garlic is a highly demanded crop in Ethiopia (Alemayehu and Abate, 2021). Consequently, it is one of the most important economic crops for poor smallholders in the highlands of Ethiopia (Alemayehu and Abate, 2021; Diriba, 2016). Garlic is one of the high-value vegetable crops in Ethiopia for local market (Da Silva *et al*., 2013). Economically, the demand for medicinal use, seasoning, and cooking provides opportunities for many farmers to improve domestic production and marketing in Ethiopia (CSA, 2021). In Ethiopia, garlic is the most widely cultivated crop and an important cash crop for smallholders because its unit price is significantly higher than most other vegetables (Emana *et al*., 2015). It is not only produced for domestic use in making soup, pickles, and other preservatives (Degwale, 2014) but also contributes to the national economy as an export commodity through Europe, the Middle East, and North America (DzARC, 2006; Da Silva *et al*., 2013).

2.4. Ecological Requirements of Garlic

Garlic grows in various climate and soil adaptations and is cultivated worldwide in all temperate and subtropical regions (Mohammed *et al*., 2012). It is well suited for areas with an altitude of 800 to 2500 meters above sea level (m.a.s.l.) with cool weather conditions (MOANR, 2016). Rainfall in the 4-6 month growing season should be 600-700 mm, and the best growing conditions for garlic production are 12-24°C (MOANR, 2016). The soil must be sand, silt, and clay, rich in organic matter, well-drained, and tolerate, with sufficient moisture during the growing season and a pH value of 5.8-7.2 (CVR, 2009).

The lower soil pH inhibits plant growth and soil pH below 5.0 can cause plant death (Yadav *et al*., 2020). However, the application of organic fertilizer is recommended a few weeks before planting to improve the physical properties of the soil. Well-composted manure, spread and added at 20 to 30 tons per acre, has also been found to be ideal for soil improvement, especially on low organic soils where the optimum soil pH is below 5.8 spreading amounts must be well-filled so that there is an open growing bed for the bulbs to grow (Carl Rosen, 2011). Beside this, application of optimum fertilizer is indispensable to enhance crop growth and yield (Melaku *et al*., 2015).

2.5. Production Status, Constraints, and Opportunity for Garlic Production in Ethiopia

2.5.1. Garlic Production and Productivity in Ethiopia

Garlic is mainly produced in the central and highlands of the country, and garlic for the domestic market is mainly produced in the home gardens of subsistence farmers and is mainly produced in cash. Garlic is widely cultivated in home gardens, but nowadays it is produced in a few large farms (Ayed *et al*., 2019). According to CSA (2021), garlic production, area coverage, production and productivity of garlic declined from 16,411.19 ha during 2013/2014 to 15,980 ha during 2020/21, with 113,928.43 tons from 14,576 hectares of land and 7.8 t ha^{-1},respectively (FAOSTAT, 2023). The South Nations and Nationalities region, next to Amhara and Oromia, was ranked third for the potential of garlic production in a report by the Ethiopian Central Statistical Agency in 2018 (Teshale and Tekeste, 2021). In the 2019/2020 cropping season also,148.2 hectares of land were

covered with a production and productivity of 1778.4 tons and 12 t ha^{-1}, respectively, according to the unpublished report from the Gurage Zone Agriculture and Developmental Office (2019/2020). However, the current garlic productivity in Ethiopia 7.8 t $ha^{-1}$is below its potential (CSA, 2021; Shege *et al*., 2021). Ethiopia's yield differences compared to the world average (18.42 t ha^{-1}) and developed countries such as China (28.15 t ha^{-1}) probably reflect differences in inappropriate fertilizer use, low soil fertility and technological resources, and lack of improved varieties, poor agronomic management practices, diseases and pests (Mohamed *et al*., 2014 and Shafeek *et al*., 2015) and lack of improved and more productive cultivars and germplasm (Atinafu *et al*., 2021; Ayalew *et al*., 2015).

2.5.2. Production Opportunity of Garlic in Ethiopia

Ethiopia is one of the countries in Africa which have huge potential for the development of different varieties of horticultural crops, including garlic (Selamawit and Tesfaye, 2019). It has favorable agroecology and natural resources, government policy encouragement, proximity to European and Middle Eastern markets, and cheap labor, which are suitable for the cultivation of garlic crop (Serbessa *et al*., 2023). However, the farmers have not yet reached their full potential for garlic crop production (Kassa, 2015). Moreover, Tabor *et al*., (2016) shows that, due to conducive policy framework, irrigation potential, market proximity and niche, high labor force, agroecology and diversity of horticultural crops (temperate to tropics), high yield per unit area as compared to other crops, suitable agro-processing (fresh, semi-processed,etc.), high demand of vegetables in local and export markets, and availability of improved varieties and technologies.

2.5.3. Production Constraint of Garlic in Ethiopia

Despite its importance, great potential for production and high market demand, the current garlic production and productivity is limited and remain seasonal. Low soil fertility is one of the factors limiting the productivity of garlic in Ethiopia mainly accounted for removal of surface soil by erosion, nutrients removal by crops from the soil, complete removal of plant residue from farm-land and lack of crop rotation system on the farm land resulting in lower crop yields (Abay, 2016; Belay, 2015). Ethiopia's smallholder garlic production and management system is founded on tradition, which is not well-supported by scientific advice (Hunde, 2019). It is evident that the supply of

garlic produced is impacted by insufficient farmer skills, production expertise, product management, efforts to apply sufficient amount of fertilizers, and conventional crop management techniques (Hunde, 2019). Additionally constraints like limited access to pest and disease control, a lack of fertilizer, theft, and limited extension services must be overcome in order to maximize output and ensure desired outcomes (Habtamu *et al*., 2023).

2.6. The Effect of Blended NPSB Fertilizer on Growth and Yield Components of Garlic

2.6.1. Effect of Blended NPSB Fertilizer on Growth Attributes

Application of NPSB blended fertilizers is needed to meet the nutritional requirements of vegetables and improve soil nutrient status (Gopinath *et al*., 2009). Generous application of different rates of NPSB blended fertilizer directly enhancing the growth of garlic plant or indirectly improve soil fertility. Plant growth is highly dependent on soil nitrogen (N) supply and proper management (Adhikari *et al*., 2016). The rate, timing, and method of application of N fertilizers are closely related to plant growth (Shrestha *et al*., 2018). Application of P fertilizer is critical in the early stages of growth for normal meristem development and rapid growth of garlic (Diriba, 2016).

Sulfur plays an important role in the formation of chlorophyll and therefore helps give plants their green color. Sulfur is known to be involved in many reactions in all living cells (Marsic *et al*., 2019). It contributes to the formation of plant proteins and improves plant growth (Abdallah *et al*., 2010). Boron is also an important element for better utilization of macro nutrients by plants and thus for a greater transfer of photoassimilates interconnecting network during the growing season (Ali *et al*., 2013).

Geleta (2014), reported that morphological characteristics such as plant height and the concentrations of N, P, and S nutrients, as well as their uptake by garlic plants, were significantly influenced by the applications of different compound fertilizers, seasons, and soil types at different growth stages. Yayeh (2015) found that the highest mean plant height of garlic (69.2 cm) was achieved with the application of 105:122.6:22.6 kg ha^{-1} N: P_2O_5:S fertilizer. They also identified that the highest number of garlic leaves (12.1) and the longest leaves (48.6 cm) were observed at a rate of 140:122.6:22.6 kg ha^{-1} N: P_2O_5:S.

Plants that did not receive N: P_2O_5:S fertilizer had the lowest leaf number as well as the shortest leaves of garlic crop.

Research conducted by Nigatu *et al*. (2018) on onions indicated that the longest onion plants (60.07 cm) were observed with the application of NPS fertilizer at a rate of 73.5:92:16.95 kg ha^{-1} N: P_2O_5:S, while the shortest plants were observed with no application. On the other hand, they confirmed that the longest (51.07 cm) and widest (1.44 cm) onion leaves were observed in onion plants fertilized with 136.5:119.6:22 kg ha^{-1} N: P_2O_5:S, while the shortest (44.33 cm) and narrowest (1.33 cm) leaves were observed in onions planted in the control plot. According to Manna (2014), the application of 0.5% boron significantly increased plant height and the number of leaves per plant compared to the control.

2.6.2. Effect of Blended NPSB Fertilizer on Yield Components

The application of blended NPSB fertilizer leads to an increase in the yield parameters of garlic, improving soil fertility status (Gopinath *et al*., 2009). Nitrogen is an essential nutrient in the soil and is associated with the synthesis of carbohydrates, thus increasing the bulb weight and total yield of garlic (Abera *et al*., 2023). Yield parameters such as the number of cloves, mean bulb weight and total bulb yield of garlic are also affected by nitrogen fertilizer (Zaman *et al*., 2011). Phosphorus is an important nutrient for the development of crop roots and reproductive organs. It is required for photosynthesis, sugar and starch formation, energy transfer, and carbohydrate movement (Hamza, 2008). However, P deficiency negatively affects root development, bulb size, and yield and may also affect ripening (Tekalign *et al*., 2012). Plant leaf, bulb yield, and quality traits increase with sequential sulfur application (Diriba *et al*., 2015).

On the other hand, sulfur deficiency in the soil reduces the growth, yield, and quality of garlic and significantly affects the agricultural economy (Scherer *et al*., 2008). Boron also directly affects yield and yield-related traits by altering root development and facilitating nutrient uptake through new root and stem development, which increases tuber and bulb production (Epstein and Bloom, 2005). Boron can also increase bulb size, the number of cloves per bulb, and the total yield of garlic (Mondel *et al*., 2016).

Alemayehu *et al*. (2018) reported that the addition of nitrogen, phosphorus, sulfur, and boron both individually and in combination had a positive response on the yield characteristics of garlic. According to Degwale (2014), it was also reported that the maximum number of cloves, fresh biomass yield, and total bulb yield of garlic were recorded with the combined application of N and phosphorus. Research conducted by Nigatu *et al*. (2018) indicated that the highest fresh weight (51.83 g) and dry weight (5.20 g) of above-ground biomass in onion plants were observed with a treatment combination of 136.5:64.4:11.86 kg ha^{-1} N: P_2O_5:S fertilizer. They also observed that the maximum bulb weight (198.83 g), highest marketable bulb yield (20.9 t ha^{-1}), and higher total bulb yields (21.4 t ha^{-1}) were obtained from onion plants supplied with a fertilizer rate of 105:119.6:22 kg ha^{-1} N: P_2O_5:S, respectively.

2.7. Response of Garlic to Vermicompost Application

Vermicompost is known to contain micronutrients apart from major nutrients (Manaig, 2016). Additionally, VC stimulates to influence the microbial activity of soil, increases the availability of oxygen, maintains normal soil temperature, increases soil porosity and infiltration of water, improves nutrient content and increases growth, yield and yield components of the garlic (Irfan *et al*., 2021). Traditional compost farm yard and chicken manure can also provide nutrients for plant to grow, but its salinity, nitrogen immobilization and pathogen levels may be problematic due to this VC is better (Ansari and Hanief, 2015).

Vermicompost is prepared by using pit methods (sized 0.4m*0.6m*1m wood box) under shade to protect worms from sunlight and rain. The roof of shade was covered by steel sheet and its wall covered by mesh wire and wood to protect birds and other animal attack, Cattle manure, fresh animal dung and enset leaves were obtained from farmers around the site ; vermiworms (*Eisenia Fetida*) is obtained from Oliso District Agricultural Office, and enset leaves chopped to a smaller size to make favorable to worm action and to provide more surface area per volume, which facilitates microbial activities as well as moisture availability (Gummer District Agricultural Expert, 2024). Then the raw materials (cattle manure fresh animal dung, and chopped enset leaves) were mixed in 8:4:1 ratio (Rameshwar *et al*., 2016) and water were sprayed to the mixture to moist enough and make ready for warms. The mixtures were left with moisture for 30 days to

degrade into smaller particles to make it palatable for the worms. Then after one month 11 kg of a substrate a mixture of pre decomposed bedding material and food source was taken into the box and 300 number of worms (*Eisenia fetida*) were introduced and sprayed with water to moisten it (Rameshwar*et al*., 2016). At the starting, the moisture of the substrates was determined and water was sprayed every three to five days or whenever drying was observed to maintain moisture at approximately 60-80% and temperature till the entire set up is moist, but not wet. Because less water kills the worms and too much water chases them away (Manaig, 2016).

During the process of the various organic wastes by earthworms, many of the nutrients that it contains are changed to forms that are more readily available for plants in the form of nitrate or ammonium nitrite, available phosphorous and soluble potassium, calcium and magnesium (Suthar and Singh, 2008). This leads to improving the microbial activity of the soil, increasing the availability of oxygen, maintaining soil temperature, improving soil porosity and movement of water, improving nutrient content, and increases growth, yield, and quality of the plant (Aslam *et al*., 2020). An increase in vegetative growth, all the growth attributes such as plant height, leaf height, and number of leaves and weight of fresh biomass in response to the increased rate of VC (Alemu *et al*., 2016).

Vermicompost acts as a soil activator, soil conditioner, and soil fertility booster with all required plant nutrients, vitamins, enzymes, growth hormones, and beneficial microorganisms (Anonymous, 2009). Different research indicates the maximum fresh weight of the bulb, dry weight of the bulb, mean bulb weight, number of cloves, and total yield of garlic in positive response to the application of sulfur-containing VC (Patidar *et al*., 2017). The application of VC can be enhanced the uptake of nutrients by the root system, and increasing chlorophyll content, photosynthesis activity, and protein content of plants (Kumar *et al*., 2019).

It has been available to promote essential soil micronutrients and microbial populations, to ultimately promote plant growth and production on a sustainable basis (Kumar *et al*., 2019). Pramanik *et al*. (2007) reported that VC releases humic acids which enhance nutrient uptake by the plants by increasing the permeability of root cell membrane and stimulating root growth. According to Verma *et al*. (2013), increased VC applications also signify response to garlic which is the application of 7.5 t ha^{-1} VC produced maximum plant height, number of leaves per plant, chlorophyll content in leaves, fresh

weight of leaves, number of cloves per bulb, weight of bulb, bulb diameter and bulb yield of garlic.

2.8. Effect of NPSB Fertilizer and Vermicompost on Growth and Yield of Garlic

2.8.1. Effect of NPSB Blended and Vermicompost Fertilizer on Growth Attribute

Combined application of NPSB blended, and VC fertilizer is a method that helps agricultural production and makes the environment safe for prospective generation. It has been defined as the application of soil fertility management practices that improve fertilizer and organic resource use efficiency and improve crop production (Mucheru e*t al*., 2021). Moreover, integrated nutrient management requires proper plant growth, and proximity with effective crop, soil, water, and land management, which are important for sustaining agriculture over the long term (Mahajan *et al*., 2008) and also plant growth is improved by increasing the population of microorganisms (Shaheen *et al*., 2007). The growth parameter of garlic increased with increasing application rates of NPSB fertilizer and organic fertilizer, including VC, which is increasing in plant height and leaf number (Diriba, 2014). It also brings excellent biochemical changes in soil structure, which ultimately promotes plant growth and production (Kumar *et al*., 2019).

The increase in leaf number per plant is obtained from the higher rate of NPSB fertilizer attributed to the availability of Vermicompost which permits leaves to grow vigorously. Nitrogen and sulfur fertilization interaction with vermicompost has the potential to increase nutrient availability in the soil and thus enhance the uptake of nutrients by the Plant (Bhagwan *et al*., 2012). It also enhances protein synthesis, leading to an increase in the buildup of carbohydrates and an increase in plant growth parameters (Zaman *et al*., 2011). This is probably due to the combined positive effects of phosphorous and sulfur existing in NPSB fertilizer on the metabolic processes of garlic (Arif *et al*., 2016). According to Alemu *et al*. (2016), it is reported that the plant height of garlic is significantly affected by the combination of mineral fertilizer and VC interaction. The increase in height is due to an increased rate of the combination application of N, P, S, and other micronutrients, and vermicompost fertilizers are required for healthy plant growth (Surindra, 2009).

2.8.2. Effect of NPSB Blended and Vermicompost Fertilizer on Yield Components

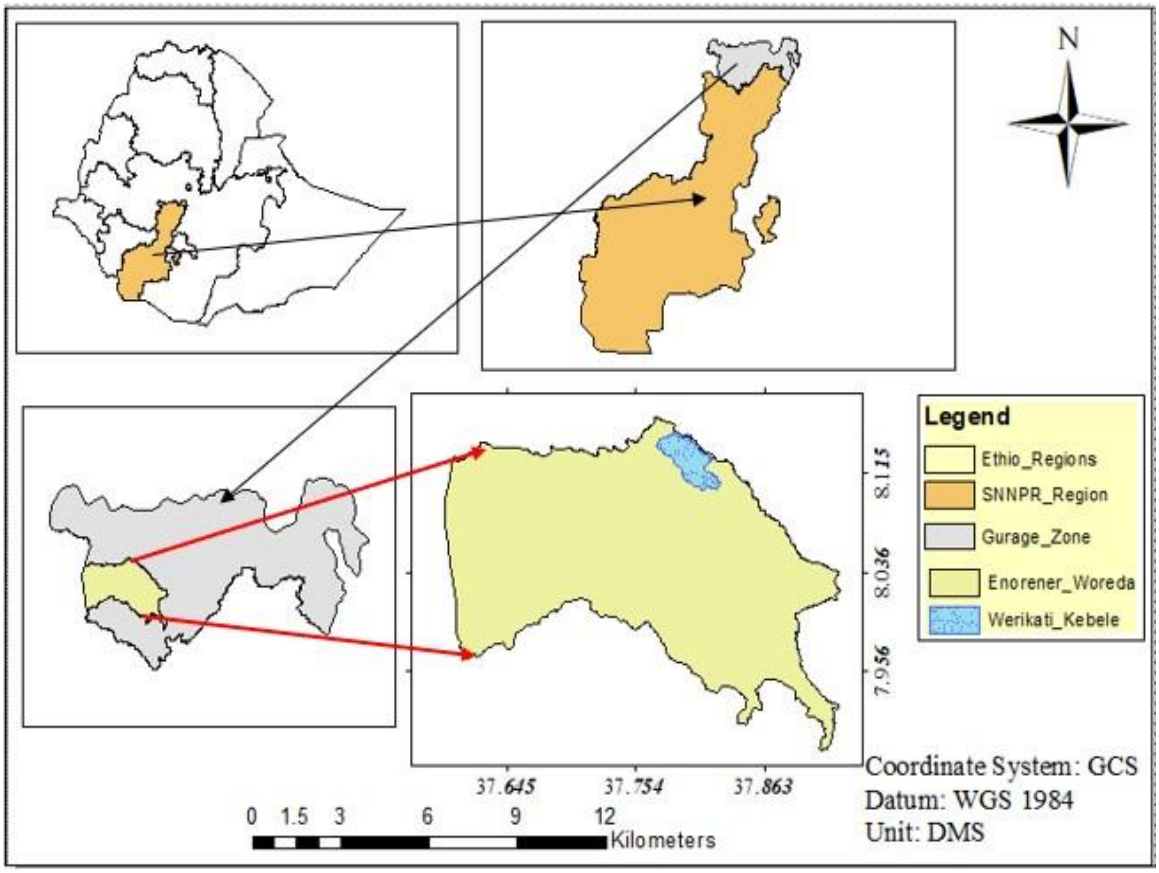
The importance of combining inorganic and organic fertilizers often improves soil organic matter, nutrient cycling, soil physical structure, and soil water holding capacity, and improves and helps maintain soil nutrient status, cation exchange capacity, and soil biological activity (Vongdala *et al.,* 2019). Which combined application of inorganic and organic fertilizer has greater advantages than just input and positive interaction with soil biological, chemical, and physical properties (Bekunda *et al*., 2010). The combined use of inorganic and organic fertilizers promotes soil health and crop productivity, especially for heavy fodder crops such as garlic (N'Dayegamiye, 2009). Garlic yield and performance characteristics increased significantly with increasing nitrogen, phosphorus, and sulfur content. Correspondingly, the higher total yield may be due to boron. This is the translocation of sugar and carbohydrates to different parts of the plant body (Diriba *et al*., 2015).

The combination of NPSB blended fertilizer rates with Vermicompost has a significant effect on total fresh biomass yield, mean bulb weight, marketable bulb yield, and total bulb yield (Alemu *et al*., 2016; Arif *et al*., 2016). Verma *et al*. (2012), reported that the combined application of sulfur and vermicompost was significantly positive for the number of cloves per bulb, weight of the bulb, bulb yield, and net returns of garlic. According to Ababulgu (2018), it was reported that the highest total tuber yield (40.23 t ha^{-1}) and highest marketable tuber yield (39.79 t ha^{-1}) was obtained with the combined application of 150 kg ha^{-1} blended NPS fertilizer + 30 t ha^{-1} Cattle Manure, while lowest was from nil treatment. Mohammadi *et al*. (2013), also reported that the presence of nutrients in manure and balanced supplement of nitrogen and phosphorus through mineral fertilizers might have contributed to increased cell division, expansion of cell wall, meristematic activity, photosynthetic efficiency and regulation of water intake into the cells, resulting in the enhancement of yield parameters.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted under rainfed conditions during the rainy season of 2022 at Werkiati kebele, Enore District, Gurage Zone Central Ethiopia. The site is located 189 km from Addis Ababa and about 39 km from the Administrative Zone of Wolkite town in South -West direction. Geographically located at a latitude of 8° 12′ 28″ to 8° 18′ 32″ N and 37° 36′ 15″ to 37° 60′ 28″ E longitudes with an elevation point of 1930 m.a.s.l. (EWPCO, 2020). The study area is characterized by well-drained clay loam soil; the major crops grown in the area are Enset, coffee, avocado, mango, maize, teff, barley, wheat, chat, potatoes, onion, and garlic. There are also different other horticultural crops, and field crops, both under rainfed and irrigated conditions (EWPCO, 2020).



Source : (Author's, 2024)
Figure 1. Map of the study area

According to the 10 years (2013-2023) meteorological data obtained from the former Southern Nation, Nationality and Peoples' Region State, Meteorological Agency and Emdibir sub-station, the mean annual rainfall; annual mean minimum and maximum temperatures of the study area were 850-1400 mm, 10.5 ^{0}C and 24.62 ^{0}C, respectively (Appendix Table 7).

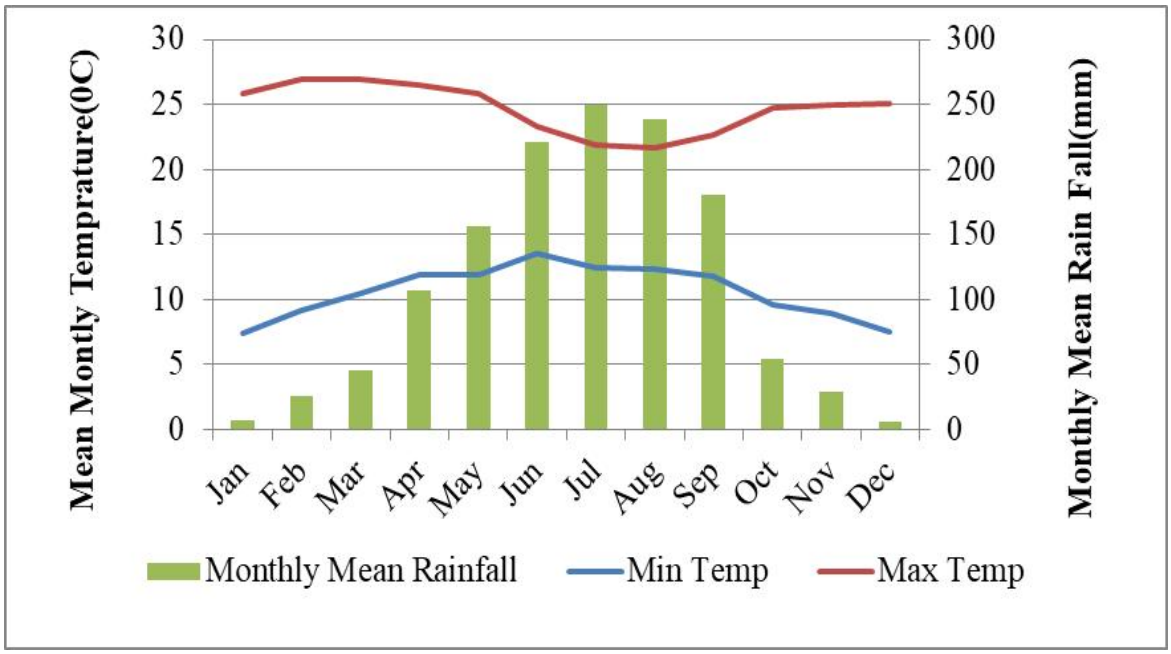


Figure 2: Monthly mean minimum and maximum temperatures and rainfall of study area

3.2. Experimental Materials

The released garlic variety Tseday 92, which was obtained from the Debre-Ziet Agricultural Research Center (DZARC) was used for the study. The variety was released in 1999/2000 by Debre Zeit Agricultural Research Center (DZARC/ EIAR), which grows in 1900-2600 geographical area. It has white-colored bulbs, green leaves, and a soft neck and takes about 110-130 days to reach maturity with productivity higher than 8.5 t ha^{-1} (DZARC, 2019).

3.3. Treatments and Experimental Design

The treatments consisted of four levels of blended NPSB fertilizer rates (0, 122 kg ha^{-1}, 244 kg ha^{-1}, and 366 kg ha^{-1}) and four vermicompost rates (0, 2.5 t ha^{-1}, 5.0 t ha^{-1}and 7.5 t ha^{-1}). A total of sixteen (4 × 4) treatment combinations in factorial arrangement were laid out in a Randomized Complete Block Design (RCBD) with three replications.

The two sources of fertilizers, i.e. NPSB and VC fertilizer are new to the area, so they lack baseline information about the levels of NPSB and VC fertilizer. Therefore, to determine NPSB fertilizer rates, 50% below and above the blanket recommendation (92 kg ha^{-1} P_2O_5) with the concentration of N: P_2O_5: S: B, a ratio of 18.7%, 37.7%, 6.95% and 0.1%), respectively. The gross plot area was 2.0 m by 1.8 m (3.6 m^2), which accommodated six rows with 20 plants per row, a total of 120 plants per plot at the spacing of 0.3 m and 0.1 m between row and plant, respectively. The distances between plots and blocks were 0.5 m and 1 m, respectively. The net plot area was 1.8 m by 1.2 m (2.16 m^2) and data were collected randomly from the four central rows and left plants at the most ends of each row as border plants.

Table 1. Treatment Combinations

Vermicompost rate (t ha^{-1})	NPSB Fertilizer rate (kg ha^{-1})	Treatment combination	Treatment
0 (VC)	0NPSB	(0,0)	T1
	122NPSB	(0,122)	T2
	244NPSB	(0,244)	T3
	366NPSB	(0,366)	T4
2.5 (VC)	0NPSB	(2.5,0)	T5
	122NPSB	(2.5,122)	T6
	244NPSB	(2.5,244)	T7
	366NPSB	(2.5,366)	T8
5 (VC)	0NPSB	(5,0)	T9
	122NPSB	(5,122)	T10
	244NPSB	(5,244)	T11
	366NPSB	(5,366)	T12
7.5 (VC)	0NPSB	(7.5,0)	T13
	122NPSB	(7.5,122)	T14
	244NPSB	(7.5,244)	T15
	366NPSB	(7.5,366)	T16

3.4. Vermicompost and Soil Sample Analysis

3.4.1. Vermicompost Sample and Analysis

Vermicompost, which was obtained from Gummer's agriculture office, was prepared from animal dug and enset byproduct of read vermiworm (*Eisena fetida*) and analyzed before applying it to the soil. Composite samples were taken, crushed into small pieces, and prepared for chemical characterization. The chemical properties of the collected samples were analyzed at the Wolkite soil laboratory; such as pH, cation exchange

capacity (CEC) (Cmol (+) kg^{-1}), organic carbon (%), total nitrogen (%), available phosphorus (ppm), available sulfur (ppm) and available boron (ppm) using standard laboratory procedures at the soil laboratory of Wolkite and Areka. The vermicompost pH was determined using a 1:2.5 (w/v) ratio of VC sample to water using a pH meter (Motsara and Roy, 2008).Cation exchange capacity (CEC) was determined using the following ammonium acetate (1 N NH_4OAc) extraction method (Van Reeuwijk, 2002). Total nitrogen was analyzed using the Kjeldahl fermentation, distillation, and titration method described by Dewis and Freites (1970). Available phosphorus was determined by Olsen's methods in VC by extraction with sodium bicarbonate (Olsen, 1954). Boron was extracted by hot water and measured by the Azomethine-H colorimetric method Bingham, (1982), and available Sulfur was measured with 0.01M Ca $(H_2PO_4)_2$ (Hoeftet *et al*., 1973).

Laboratory analysis results of the vermicompost is presented in (Appendix Table 1). The chemical properties of VC were moderately alkaline pH value (7.4), high OC (10.9 %), and total nitrogen (0.91%) contents (Tekalign, 1991). On the other hand, the cation exchange capacity of the VC was (45 cmol(+) kg^{-1}) and characterized by very high (Landon, 1991). The VC had a very high (35 ppm) available P (Cottenie, 1980) whereas, according to Jones (2003) ratings, the available S (21.6 ppm) and B (1.53 ppm) contents of VC were characterized by medium status (Appendix Tables 1 and 6).

3.4.2. Soil Sample and Analysis

Soil samples from the experimental area were collected before planting randomly from ten spots on the experimental field. Samples were collected in a zigzag pattern by using auger from the topsoil layer (0-30 cm) depth before planting, thoroughly mixed to make a composite sample that was representative of the whole experimental field. The soil samples were air dried, grained, and sieved, passed through 2 mm for determination of physiochemical properties of the soil of the experimental site; except for soil OC and total N, where the samples were crushed further to pass through a 0.5 mm sieve.

The composite soil sample was analyzed for physiochemical properties of the experimental site, mainly textural analysis, soil pH, total nitrogen, available phosphorus, available sulfur, available boron, cation exchange capacity (CEC), and organic carbon (OC) (Appendix Table 1) using standard laboratory procedures at the soil laboratory of Wolkite and Areka. Soil texture was analyzed using the Bouyoucos hydrometer method

(Bouyoucos, 1965). Soil samples were creried out from each plot after harvest and analyzed for selected soil properties following the standard laboratory procedures for respective soil parameters. The chemical content of the soil was determined using similar procedures used for the above vermicompost analysis.

Laboratory analysis results of physiochemical properties of experimental soil before planting is presented in (Appendix Table 1). The textural class of the experimental soil was silty clay with 20% of sandy, 48% silt, and 32% clay (Rowell, 1994). The soil pH (H_2O) value of the experimental soil was (6.2) and characterized by slightly acidic (Tekalign, 1991). Soils having a pH value in the range of 5.5 to 7.5 are considered to be favorable for most garlic production (Landon, 1991). Cation exchange capacity CEC of the soil was (22.0 cmol(+) kg^{-1}) and was characterized by moderate (Landon, 1991). The contents of soil OC and total N were (0.45%) and (0.038%), respectively, and characterized by very low (Tekalign, 1991). According to the rating of Jones (2003), experimental soil has low available S (17.83 ppm) and very low B (0.084 ppm) content. According to the rating of Cottenie (1980), the soil had a low 8.66 ppm content of available P (Appendix Table 1).

3.5. Experimental Procedures and Crop Management

The experimental land was plowed three times using oxen-driven local plowing implement and then leveled, and divided into new rows and plots. The experimental field was well prepared and each treatment was randomly assigned to each plot within an independent block. Two weeks before planting, vermicompost was applied to the assigned plot and mixed with the soil. Healthy and uniform medium-sized bulbs of 1.5 - 2.5 grams were selected (Fikreyohannes *et al*., 2008) and planted at a depth of 3-4 cm. Planting was done on the ridge with 30 cm rows and 10 cm plant spacing. Based on the treatments, the total amount of NPSB fertilizer was applied at planting. Agricultural operations, weed control, and appropriate cultivation were done manually starting from sprouting and emerging out of the soil to harvesting day at two-week interval in each plot uniformly (EIAR, 2007). Harvesting was done properly when the crop reached 100% physiological maturity.

3.6. Data Collection

The phenological parameter, growth, yield, and yield-related parameters were collected and recorded from the central rows of each net plot area using the procedures described below.

3.6.1. Phenological Parameter

Days to 50% emergence: It was recorded by counting the days from planting to when 50% of the planted cloves sprouted and emerged out of the soil.

Days to 75% maturity: It was recorded by counting the number of days elapsed from the time of planting up to the time when 75% of plants in each plot became dry and collapsed at the neck.

3.6.2. Growth Parameter

Plant height (cm): It was measured from the soil surface to the top of the longest leaf of 10 randomly selected plants at physiological maturity by using a ruler and the average plant height was taken.

Leaf length (cm): It was measured from the attachment of the pseudo-stem up to the leaf tip at physiological maturity by using a ruler and the average leaf length was taken from ten randomly selected plants.

Number of leaves per plant: It was determined by counting the total number of leaves taken from ten randomly selected plants per plot at physiological maturity and the average number per plant was recorded.

3.6.3. Yield and Yield Related Parameter

Average fresh biomass yield (g/plant): It was determined by taking the total weight of ten randomly selected plants from the central four rows of each plot by using a sensitive balance and the average value is recorded as total fresh biomass yield per plant.

Mean bulb weight (g/plant): The weight of bulbs from ten randomly selected plants from the central four rows was recorded and divided by the total number of bulbs.

Number of cloves: It was recorded as the actual number of cloves collected from ten randomly selected plants from the central four rows of each plot at harvest and calculated as an average clove number.

Biological dry yield (g/plant): It was determined by oven-drying the biological yield (total garlic plant including above and below-ground yield) at the temperature of 65 ^{0}C for 72 hours and the weight of ten randomly selected plants from the central four rows of each plot by using a sensitive balance and the average value is recorded as biological dry yield.

Harvest index (%): was calculated as the ratio of economical yield to biological yield (total weight of garlic plant including above and below ground biomass yield) of plant harvested from the central four rows and multiplied by 100. The following equation to calculate the harvest index was taken from (Pessarakli, 2001).

$$\text{HI}\ (\%) = \frac{Economic\ yield}{Biological\ yield} \times 100$$

Marketable bulb yield (t ha^{-1}): was recorded as bulbs which were free of mechanical bruise, disease, and insect pest damages, uniform in color, and greater than 1g clove sized bulb was considered as marketable (Fikreyohannes *et al*., 2008). The weight of such bulbs obtained from four central rows was measured in kilograms using scaled balance and converted into tons per hectare.

Unmarketable bulb yield (t ha^{-1}): Bulbs that were unhealthy bulbs (defected, diseased, immature, badly stained skins, damaged) and less than 1g clove sized that may not acceptable or unattractive observation, were considered as unmarketable. The weight of such bulbs obtained from four central rows was measured in kilograms using scaled balance and expressed as a ton per hectare.

Total bulb yield (t ha^{-1}): It was calculated as the sum of marketable and unmarketable bulb yields and expressed as a ton per hectare.

3.7. Partial Budget Analysis

In this study, the partial budget analysis was done according to the methodology of (CIMMYT, 1988). The experimental field used different rates of interaction of NPSB with VC fertilizer. The total variable cost was estimated during the period of experimental field that includes the cost of 122 kg, 244 kg, and 366 kg of blended NPSB and 2.5 ton, 5.0 ton, and 7.5 ton VC fertilizer, the cost of its application and transportation for each

treatment, while the bulb used for planting, and labor for cultural practice was considered as a fixed cost. The marketable bulb yield of garlic was reduced by 10% to reflect the difference between farmer's and experimental field yield. Partial budget analysis included gross benefit, the total variable cost, and net benefit of each treatment.

The gross benefit of each treatment was calculated by multiplying the adjusted yield and field price of garlic, while the net benefit of each treatment was calculated by subtracting total variable cost from gross field benefit (CIMMYT, 1988). To estimate the total costs, the mean current prices of each treatment used at the time of planting and labor cost involved due to additional input and the gross benefits obtained from garlic production were calculated. All costs and benefits were calculated on a hectares basis in Ethiopian birr ($ETBha^{-1}$). The treatments were adjusted in an increasing the order of variable cost to recommended economically profitable treatments (CIMMYT, 1988).

Adjusted Bulb Yield (ABY): was the average yield reduced by 10% to reflect the difference between the experimental yield and the yield of farmers

Gross Field Benefit (GFB) (ETB ha^{-1}): was computed by multiplying the field/farm gate price that farmers receive for the crop when they sell it as adjusted yield as GFB = ABY × field/farm gate price for the crop.

Total Variable Cost (TVC) (ETB ha^{-1}): was determined by summing up the cost that varies including the cost of NPSB, VC, and its application costs.

Net benefit (NB): was calculated as the difference between the gross field benefits and total variable cost (TVC).

Marginal Rate of Return (MRR%): was determined by dividing the change in net benefit by the change in total variable cost which was the measure of increasing in return by increasing input. This means subtracting the net benefit of nil from the net benefit of each treatment dividing by the total variable cost of each treatment and multiplying each value by 100%.

$$\text{Marginal rate of return (\%)} = \frac{\text{Change in net benefit}}{\text{Change in total cost}} \times 100$$

3.8. Data Analysis

The collected data were subjected to Analysis of Variance (ANOVA). The analysis was computed using the GLM procedure of SAS version 9.4 (SAS, 2011). Treatment means comparisons were done using the least significant difference (LSD) test at a 5% level of significance using the procedures as described by Gomez and Gomez (1984). Correlation analysis among selected parameters was also done using Pearson's simple correlation coefficient (Rebekic *et al*., 2015).

4. RESULTS AND DISCUSSION

4.1. Post- harvest Analysis Results of Soil Chemical properties

The chemical properties of the soil after harvest are shown in (Appendix Table 2 and Table 2). The application of blended NPSB and VC fertilizer had a positive response to improve the nutrient status of experimental soil. The result revealed that the main and interaction effects of blended NPSB and VC fertilizer were significant ($p < 0.01$) influenced by OC, available S, available B, and CEC and followed the main effect of NPSB and VC were significantly ($p < 0.01$) influenced on total N, available P, and soil pH (Table 2). The contents of soil OC (3.2 %), available S (38.03 ppm) and cation exchange capacity CEC (35.08 cmol(+) kg^{-1}) recorded from the combined application of 366 kg ha^{-1} and 7.5 t ha^{-1}showed an increment trend compared to the initial value. On the other hand, the total N, available P, and soil pH of the experimental site after harvest (0.21 and 0.22 %), (14.19 and 14.25 ppm) and (7.05 and 7.4) were obtained from the main effect of NPSB and VC fertilizers, respectively (Table 2).

The contents of soil OC(0.22%) showed an increment trend compared to initial values and were characterized by medium status as described by Tekalign (1991). The available P showed an increment from low (8.66 ppm)to medium (14.19 and 14.25 ppm)levels after the application of NPSB and VC fertilizers, respectively. Available S, available B, and CEC were increased from the initial (17.83 to 38.03 ppm), (0.084 to 1.92 ppm), and (22 to 35.08 cmol(+) kg^{-1}), respectively. Soil pH was also increased from 6.2 to 7.05 and 7.4 as compared to the initial value which, could be characterized by moderately alkaline (Tekalign, 1991).

The observed increment in soil available P in response to the increased levels of NPSB application could be due to the applied P in the soil not being fully utilized by the crop and remaining in the soil. For instance, the contents of total N, OC, and available P of the soil increased significantly as the level of VC and NPSB fertilizers increased from 0 to 7.5 t ha^{-1} and 366 kg ha^{-1}, respectively, which significant increase in available S (21.6-27.18 ppm), available B (1.07-1.24 ppm) and available P (11.98-14.19 ppm) of the soil as an increasing level of NPSB fertilizer from 122 to 366 kg ha^{-1}. Similarly, the increase in the levels of vermicompost fertilizers from 2.5 to 7.5 t ha^{-1} significantly increased the CEC from (26.1 to 30.9 cmol(+) kg^{-1}) and the soil pH from (6.48 to 7.4), available B

from (0.34 to 1.63 ppm), available S (20.5 to 31.2 ppm), available P (12.8 to 14.25 ppm), total N (0.17 to 0.22 %) and OC (1.9 to 2.68 %) (Table 2).

In general, compared to the initial status of the soil before planting, the application of blended NPSB combined with VC fertilizer at the rate of 366 kha^{-1} and 7.5 t ha^{-1} attributed to the improved nutrient status of soil OC, available S, CEC by 84, 53, 37.3 and 21.5 percent, respectively. Similarly available B also increased by 95.6% plot that received 244 kg ha^{-1} NPSB and 7.5 t ha^{-1}. This indicated that the application of both blended NPSB and VC fertilizers changed the nutrient status of experimental soil. However, in all soil parameters, the lower chemical properties of soil after harvest were recorded from the unfertilized plots.

Table 2. The interaction effects of NPSB and VC fertilizer application on soil properties of the experimental site.

Treatment Combination								
NPSB	VC	OC	TN	AP	AS	AB	CEC	pH
0 0 0	0	0.41^{g}	0.12^{i}	8.87^{e}	13.13^{i}	0.027^{e}	22.94^{g}	6.13^{e}
	2.5	1.61^{f}	0.14^{ghi}	10.45^{e}	16.39^{gh}	1.11^{d}	24.28^{fg}	6.28^{de}
	5	1.79^{ef}	0.16^{fgh}	11.22^{de}	18.45^{fg}	1.2^{cd}	25.72^{ef}	7.13^{bc}
	7.5	2.46^{b}	0.17^{efg}	11.65^{de}	18.66^{fg}	1.31^{bcd}	27.46^{de}	6.85^{bcd}
122	0	0.41^{g}	0.13^{hi}	10.67^{e}	14.09^{hi}	0.034^{de}	27.49^{de}	6.32^{de}
	2.5	1.65^{ef}	0.17^{fg}	11.51^{de}	19.93^{ef}	1.39^{bc}	28.26^{d}	6.38^{de}
	5	1.95^{def}	0.21^{bcd}	12.45^{cd}	21.6^{de}	1.41^{bc}	28.56^{d}	6.78^{de}
	7.5	2.03^{cde}	0.22^{abc}	13.31^{bc}	30.9^{b}	1.44^{b}	26.82^{de}	7.33^{abc}
244	0	0.39^{g}	0.14^{fghi}	12.36^{cd}	19.9^{ef}	0.14^{e}	25.89^{ef}	6.33^{de}
	2.5	1.93^{def}	0.18^{def}	13.6^{bc}	21.6^{ed}	1.42^{b}	28.37^{d}	6.38^{de}
	5	2.38^{bc}	0.23^{abc}	13.44^{bc}	27.2^{c}	1.500^{b}	31.32^{c}	6.85^{bcd}
	7.5	3.03^{a}	0.24^{ab}	15.65^{a}	36.5^{a}	1.92^{a}	34.11^{ab}	7.5^{ab}
366	0	0.38^{g}	0.14^{fghi}	12.6^{cd}	16.3^{gh}	0.035^{e}	24.53^{fg}	6.33^{de}
	2.5	2.3^{bcd}	0.2^{cde}	13.6^{bc}	24.1^{d}	1.42^{b}	23.48^{g}	6.88^{bcd}
	5	2.62^{b}	0.24^{ab}	14.17^{b}	29.6^{bc}	1.45^{b}	32.95^{bc}	7.1^{bc}
	7.5	3.2^{a}	0.25^{a}	16.38^{a}	38.03^{a}	1.87^{a}	35.08^{a}	7.9^{a}
LSD (5%)		0.4	0.03	1.45	2.85	0.21	1.9	0.7
Sign		**	ns	ns	**	**	**	ns
CV (%)		13.4	11.6	6.9	7.4	11.45	4.05	6.15

*Where, OC, Organic carbon (%), TN, Total nitrogen (%); AP, Available phosphorous (ppm); AS, Available sulfur (ppm), AB, Available boron (ppm),CEC; Cation exchange capacity (cmol(+) kg−1); pH (1:2.5 soil to H_2O), potential of hydrogen in water suspension; **highly significant at $P < 0.01$; *significant at $P < 0.05$; ns, not significant at $P \geq 0.05$; CV (%), Coefficient of variation; means in a column followed with the same letter are not significantly different at $P \geq 0.05$.*

The result revealed that most of the soil chemical properties significantly increased as the combined effect of VC and blended NPSB fertilizers levels increased (Table 2). These results were also in harmony with findings reported by Kathuku *et al*. (2011) who reported an increase in soil nutrients contributed by mineral NP fertilizer combined with organic fertilizer when compared with sole applications. The application of 7.5 t ha^{-1} VC combined with 366 kg ha^{-1} blended NPSB fertilizers showed a significantly higher soil OC 3.2 %, total N 0.25%, available P (16.38 ppm), and available S (38.03 ppm) than control treatment followed by 7.5 t ha^{-1} VC combined with 244 kg ha^{-1} blended NPSB fertilizers but the highest available B was recorded.

The increased available P by 47% over the initial status might be due to the reduced P fixing capacity of the soil whereas soil OC was increased by 84.4% over the initial status of the soil indicating that the application of combined VC and inorganic fertilizer

improved the soil properties that could help for the decomposition of organic materials. The increase in available P could be attributed to organic fertilizers due to VC facilitating the release of the higher amount of P from the complex site of the soil. This finding is supported by Tolanur and Badanur (2003) who reported that the increased available P content of the soil might be due to the release of organic acids during decomposition which in turn helped in releasing P.

4.2. Effect of NPSB and Vermicompost Fertilizer on Garlic Phenological Parameters

4.2.1. Days to 50% Emergence

The ANOVA showed that both the main effects of NPSB fertilizer and VC as well as their interactions did not influence days to 50% emergence (Appendix Table 3).

The non-significant difference among different rates of NPSB and VC fertilizer may be due to pre-emergency and growth initiation of garlic seed clove before planting. It may also be the movement of P in soil is very low and its uptake generally depends on the concentration gradient and diffusion in the soil near the roots (Wang and Lambers, 2020). In line with this, nitrogen and phosphorous nutrients did not significantly influence the sprouting and shoot growth stages of garlic (Youssef, 2013; Betewulign and Solomon, 2014). However, the current result disagrees with Getachew and Temesgen, (2020) who observed early emergence (9 days) by the application of 105 : 92 : 17 kg ha^{-1} NPS. This result generally indicated that the highest rate of NPS boosted the garlic bulbs to emerge faster.

4.2.2. Day to 75% Maturity

The analysis of variance showed that the main effect of blended NPSB and VC fertilizer was highly significant ($p < 0.01$) influencing the parameter days to 75% maturity of garlic. However, their interaction did not influence this parameter (Appendix Table 3).

The longest days to maturity (126.7) and (127.6) were recorded by the independent application of (244 kg ha^{-1}) blended NPSB fertilizer and 7.5 t ha^{-1} VC fertilizers, respectively. This was statistically in parity with treatment 366 kg ha^{-1} NPSB which took

123.4 days to reach maturity and 7.5 t ha^{-1} rate of VC which was statistically parity with treatment 5 t ha^{-1} which took 123.6 days to reach maturity. However, the shortest days to maturity (116.8 and 117.5) were recorded from the control treatments 0 t ha^{-1} VC and 0 kg NPSB ha^{-1}, respectively (Table 3). The independent application of VC and NPSB at the maximum rate of 7.5 t ha^{-1} and 366 kg ha^{-1} exceeded the days required for maturity at control treatment by 8.46% and 4.78%, respectively. The increased level of NPSB from 0 to 244 kg ha^{-1} showed significant increase in the days required to maturity significantly.

Similarly, the increased rates of VC from 0 to 5 t ha^{-1} significantly increased the days to maturity. However, the increased rates of NPSB fertilizer further to 366 kg ha^{-1} and VC fertilizer to the maximum rate of 7.5 t ha^{-1} did not bring a significant change on days to maturity. This showed that increasing the level of fertilizer to the optimum increased the days to maturity. The delayed days to maturity in response to an increasing rate of VC may be attributed to the availability of optimum nutrient supply in VC that may have led to delayed maturity through continued vegetative growth. The application of the optimum rate of blended NPSB fertilizer delayed the days to maturity which could be due to the role of nitrogen which can extend the vegetative growth period of plants in spite of maturity.

The result agrees with Akuamoah (2016) who reported that organic fertilizer combined with inorganic fertilizers delayed horticultural maturity compared with unfertilized treatments and sole application of mineral fertilizers. Alemu (2014) also reported increasing the rates of VC fertilizers and prolonged maturity days of garlic plants. Moreover, Nebret *et al*. (2012) reported that a high rate of nitrogen application significantly delayed physiological maturity. The day of earliest maturity recorded at control treatment might be due to insufficient availability of nutrients that entered vegetative growth. When plants have insufficient N they mature early, which is one of the escape mechanisms of plants from stress conditions for normal growth (Jasso *et al*., 2005). The result agrees with the findings of Abadi (2015) who identified a significant influence of interaction effects of cultivars and nitrogen rates on plant maturity. Getaneh (2011) also observed that plants grown with the highest level of nitrogen took the longest period to complete vegetative growth.

Table 3. The main effect of NPSB and VC fertilizers on the day to 75% maturity of garlic.

Factor	Treatment	Day to 75 % maturity
NPSB (kg ha^{-1})	0	117.5^{c}
	122	121.9^{bc}
	244	126.7^{a}
	366	123.4^{ab}
LSD (0.05)		4.52
VC (t ha^{-1})	0	116.8^{c}
	2.5	121.6^{b}
	5.0	123.6^{ab}
	7.5	127.6^{a}
LSD (0.05)		4.52
CV (%)		4.4

Means followed by the same letter within a column are not significantly different at 5% level of significance; LSD) = least significant difference; CV = coefficient of variation.

4.3. Effect of NPSB and VC Fertilizer on Growth Parameters of Garlic

4.3.1. Plant Height

The analysis of variance revealed that the main effect of blended NPSB and VC fertilizer as well as their interaction were highly significant ($p < 0.01$) in influencing the plant height of garlic (Appendix Table 3).

The longest height of garlic (62.6 cm) was recorded from a combined application of 366 kg ha^{-1} NPSB and 7.5 t ha^{-1} VC which was in statistical parity with a combined application of 366 kg ha^{-1} NPSB and 5 t ha^{-1}VC (57.9 cm). However, the shortest height of garlic (23.1 cm) was recorded from the unfertilized plot (Table 4). Thus, the height of garlic plants obtained from the combined applications of 366 kg ha^{-1} with 7.5 t ha^{-1}, and 366 kg ha^{-1} with 5 t ha^{-1} exceeded the height of garlic in the control treatment (0, 0) by 63% and 60.1%, respectively. The result showed that the height of garlic was increased with increased and combined use of inorganic blended NPSB and organic VC fertilizers from 0 to 366 kg ha^{-1} and 0 to 7.5 t ha^{-1} VC, respectively.

The progressive increase in height of plants might be the response to increased rates of inorganic NPSB and organic VC fertilizer application attributed to a significant role in the building block of amino acids, nitrogen fixation, enhancing cell division, cell elongation, and chlorophyll and protein synthesis and encourage root growth which promotes the growth of garlic plants. The presence of boron in the blended fertilizer nutrient source also significantly increased plant height due to its important role in cell division and nitrogen absorption from the soil, enhancing plant growth and ultimately increasing plant height (Potarzycki, 2009). The highest and above vegetative development of garlic might be attributed to an enhanced photosynthetic activity which has been the response of chlorophyll synthesis in the presence of the enriched amounts of sulfur. Increased the height of plants gradually with increasing levels of sulfur (Zaman *et al.*, 2011).

Vermicompost with sulfur combination helped to increase adequate essential nutrients required for healthy plant growth. The present study agreed with Verma *et al*. 2012 And Kokobe *et al*. (2013) reported that the plant height increased significantly with the application of vermicompost, farm yard manure, and nitrogen. This result is also supported by the findings of Alemu *et al*. (2016) who reported that organic manure and inorganic fertilizer supplied all the essential nutrients in measured variables like plant height. Generally, it was observed that treatments that received both organic and inorganic fertilizers produced plants with more height as compared to plants in unfertilized plots. Gezahegn (2011) has also reported that plant height increased in response to increased application rate of N and P fertilizers, which could be related to the role of nitrogen in promoting vegetative growth and that of phosphate in favoring leaf expansion and stem elongation.

4.3.2. Leaf Length

According to the analysis of variance, the interaction effects of blended NPSB and VC fertilizer as well as the main effect had a highly significant ($p < 0.01$) effect on leaf length of garlic (Appendix Table 3).

The longest leaf length (55.6 cm) was recorded from the combined use of 366 kg ha^{-1} inorganic NPSB and 7.5 t ha^{-1} organic VC whereas the shortest leaf length (14.4cm) was recorded from the control treatment. This was closely followed by treatment interaction of 0 NPSB and 7.5 t ha^{-1} VC (40.5 cm); 122 kg ha^{-1} NPSB and 7.5 t ha^{-1} (40.9 cm); 244

kg ha^{-1} and 5 t ha^{-1} and 7.5 t ha^{-1} (40.7 cm and 42.9 cm); 366 kg ha^{-1} NPBS and 5 t ha^{-1} VC (40.5 cm) (Table 4). The result showed that the increased rates of NPSB from 0 kg ha^{-1} to the maximum rate of 366 kg ha^{-1} and VC fertilizer from 0 to 7.5 t ha^{-1} in combination resulted in increased leaf length of garlic. The combined application of 366 kg ha^{-1} blended NPSB and 7.5 t ha^{-1} VC resulted in an increased leaf length of garlic by 74%. The reason for the increase in leaf length of garlic plants at the highest doses of organic and inorganic fertilizers might be attributed to a good range of available soil macro and micronutrients for healthy and vigorous plant growth.

Similarly, it might also improve physio chemical properties of soil which is important for plant growth, and a good root system for the leaf length of garlic. The application of a sufficient amount of blended NPSB and VC fertilizer leads to promoted higher vegetative growth of garlic which is regarded as higher leaf length of garlic plant (Zhou *et al*., 2005). This result is supported by Diriba (2016) who reported that vigorous vegetative growth is the result of balanced soil fertility management which is essential for enriching the productivity of garlic. According to Zaman *et al*. (2011) combined application of NPSB fertilizer with VC enhances protein synthesis leading to an increase in the buildup of carbohydrates and an increase in plant growth parameters. Besides, Arif *et al*. (2016) reported that the combined positive effects of phosphorous and sulfur found in NPSB fertilizer on the metabolic processes of garlic could help to increase plant growth.

Table 4. The interaction effect of blended NPSB and VC fertilizer on plant height and leaf length of Garlic.

NPSB (kg ha^{-1})	Vermicompost (t ha^{-1})	Plant height (cm)	Leaf length (cm)
0	0	23.1^{l}	14.4^{j}
	2.5	32.2^{jk}	21.9^{hi}
	5.0	43.4^{gh}	31.3^{fg}
	7.5	50.7^{cdef}	40.5^{bc}
122	0	27.8l^{k}	18.6^{i}
	2.5	33.9^{ij}	23.8^{h}
	5.0	52.1^{bcde}	35.5^{de}
	7.5	52.5^{bcd}	40.9^{bc}
244	0	38.1^{hi}	29.8^{g}
	2.5	46.9^{defg}	32.8^{efg}
	5.0	54.7^{bc}	40.7^{bc}
	7.5	56.2^{bc}	42.9^{b}
366	0	46.4^{efg}	34.2^{def}
	2.5	44.9^{fg}	37.4^{cd}
	5.0	57.9^{ab}	40.5^{bc}
	7.5	62.6^{a}	55.6^{a}
LSD (%)		5.88	3.9
CV (%)		7.8	6.98

Means followed by the same letter are not significantly different at 5% level significance. LSD least significant difference; CV = coefficient of variation.

4.3.3. Number of Leafs per Plant

Based on the analysis of variance, the main effects of blended NPSB and VC fertilizer were highly significantly ($p < 0.01$) influenced the number of leaves per plant. However, the interaction showed a non-significant ($p < 0.05$) effect on the same parameter (Appendix Table 3).

Statistically the highest leaf number of garlic (12.98) was recorded from the maximum organic VC application rate of 7.5 t ha^{-1} which was closely followed by VC at the rate of 5 t ha^{-1} (11.5) whereas the lowest leaf number (8.2) was recorded from the nil rate of VC. On the other hand, the highest leaf number (11.2) was recorded from NPSB at the rate of 366 kg ha^{-1} which was statistically at par with the NPSB rate of 244 kg ha^{-1} (10.7) whereas the lowest leaf number of garlic (9.6) was obtained from nil rate of NPSB (Table 5). Thus, increasing rates of NPSB from 0 to 366 kg ha^{-1} increased the leaf number of garlic significantly. For the main effect of organic VC, the increased rate from 0 to 7.5 t ha^{-1} increased the leaf number significantly. Therefore, the leaf number of garlic at the

maximum rate of 7.5 t ha^{-1} exceeded the leaf number obtained at 5 t $ha^{-1.}$ and 2.5 t ha^{-1} and by 37%, 28.7% and 10.9%, respectively.

Blended fertilizer attributed to the availability of both macro and micronutrients that enhanced leaves to grow vigorously in size and number. Phosphorus is the constituent of cellular protein and nucleic acid that might have encouraged the meristematic activity of plants that might be enhancing root development, which might have led to effective nutrient uptake and water resulting in the increased number of leaves per plant. Similarly, nitrogen and sulfur fertilization may have also the potential to increase nutrient availability in the soil and thus enhance the uptake of nutrients by the plant. This result is in agreement with the findings of Shege *et al.* (2017) who described that the application of nitrogen, phosphorous, and sulfur alone or in combination increased the growth and development of garlic including the number and size of garlic leaves.

Gateri *et al.* (2018) reported that the highest leave number was recorded by the application of the highest rate of nitrogen and the lowest was recorded from the control. Uzma *et al*. (2016) reported that the low level of phosphorus fertilizer application resulted in a reduction in leaf expansion and leaf surface area, as well as the number of leaves in garlic. Similarly, Nasreen *et al,* (2007) reported that the maximum leaf number was recorded with an increased application rate of sulfur. Manna (2014) also obtained that, the maximum number of leaves as a result of the increased rate of boron application. Nigatu (2016) reported that the highest number of leaves was recorded as a result of the combined application of N: P_2O_5: S and the least number of leaves from unfertilized plants.

The increase in leave number per plant due to an increasing rate of VC from 0 up to 7.5 t ha^{1} VC might be attributed to the availability of optimum nutrients contained in manure and it might be contained micronutrients apart from major nutrients and which, contain several enzymes that can promote plant growth, beneficial bacteria, and mycorrhizae (Gupta, 2005). The current result is supported by the findings of Fatma *et al*. (2014) who observed that, the increased application of VC had significantly increased vegetative growth characteristics, plant height, the average number of leaves, and fresh and dry weight of the whole plant and its different organs of the onion plant.

Table 5. The main effect of blended NPSB and VC fertilizer on the number of leaves per plant.

Factor	Treatment	Number of leaf's per plant (cm)
NPSB (kg ha^{-1})	0	9.6^{c}
	122	10.4^{b}
	244	10.7^{ab}
	366	11.2^{a}
VC (t ha^{-1})	0	8.2^{d}
	2.5	9.2^{c}
	5	11.5^{b}
	7.5	12.98^{a}
LSD (0.05)		0.7
CV (%)		8.3

Means followed by the same letter are not significantly difference at 5% level of significance. LSD = least significant difference; CV = coefficient of variation. VC= vermicompost

4.4. Effect of NPSB and VC Fertilizer on Yield Components of Garlic

4.4.1. Average Fresh Biomass Yield

The analysis of variance showed that the average fresh biomass yield of garlic was highly significant ($p < 0.01$) affected by the main effects of NPSB and VC fertilizers as well as by the interaction effect (Appendix Table 4).

The highest average fresh biomass yield per plant (65.2g) was recorded from the combined application of 244 kg ha^{-1} blended NPSB and 7.5 t ha^{-1} VC fertilizer which was followed by the interaction of 366 kg ha^{-1} NPSB and 7.5 t ha^{-1} VC fertilizer (57.5 g/plant). However, the lowest average fresh biomass yield (28.2g) was obtained from plots that did not receive either of the two fertilizers which are statistically on par with a nil application rate of NPSB and 2.5 t ha^{-1} (32.7 g/plant) (Table 6). The highest average fresh biomass yield obtained at an increased application rate of NPSB and VC might be because fertilizer applied efficiently may be attributed to enriched nutrients in the soil, which could have a positive effect on vegetative growth and root development of garlic. VC

improves soil's physical and chemical properties which finally results in a better accumulation of photosynthetic products as compared to the control.

The rate of blended NPSB fertilizer significantly increased fresh biomass yield probably due to its role in the synthesis of sulfur and boron-containing amino acids, proteins, activation of enzymes, and energy transformation, which in turn enhances carbohydrate metabolism and bulb setting (Adhikary *et al*., 2017).This result conformed with Tadilla (2018) who suggested that the use of increased inorganic nitrogen fertilizer alone had increased the weight of tubers. Moreover, the combined application of nitrogen and manure at different levels increased the average tuber fresh weight compared to the control treatment (Tadila and Nigusie, 2018). Gashaw *et al*. (2017) reported that the interaction effect of recommended N, P, and compost had a significant effect on the weight of garlic bulbs. Similar findings were reported by Damse *et al*. (2016) and Sitaula *et al*. (2020), on the key role of integrating organic fertilizers, inorganic fertilizers, and bio fertilizers increased crop yields.

4.4.2. Mean Bulb Weight

The analysis of variance showed that the mean bulb weight of garlic was highly significantly ($p < 0.01$) influenced by the interaction and main effect of blended NPSB and VC fertilizer (Appendix Table 4).

The highest mean bulb weight of garlic (36.8 g) was recorded from plots that received 244 kg ha^{-1} NPSB and 7.5 t ha^{-1} VC fertilizer whereas, the lowest mean bulb weight (10.9g) was recorded at the control treatment which was not significantly different with combined application of nil rate of NPSB and 2.5 t ha^{-1} (12.4 g), nil rate of NPSB and 5 t ha^{-1} (12.5 g), 122 kg ha^{-1} NPSB and nil rate of VC (12.6 g), 122 kg ha^{-1} and 2.5 t ha^{-1} VC (12.7 g). The present study indicated that the increased application of blended NPSB from 0 to 244 kg ha^{-1} and vermicompost fertilizer from 2.5 to 7.5 t ha^{-1} increased constantly in the mean bulb weight which increased by 70.4 % and 64.5 over the unfertilized plot, respectively (Table 6).

The current study is in agreement with the findings of Tadila (2011) who reported increased mean fresh bulb weight of garlic from increased rate of N. Melaku (2010) also indicated that increasing the rates of nitrogen fertilizer significantly increased mean bulb weight of onion. The weight of the bulb increased significantly up to the highest dose of 7.5 t ha^{-1} VC (Verma *et al*., 2013). Likewise, Alemu (2014) reported that increased P positively increased mean bulb weight by 20.72% over the control. The increased mean bulb weight as a result of using VC could be due to the availability of major macro and micronutrients in the VC. Besides, VC has been reported to contain several plant growth promoters, enzymes, beneficial bacteria, and mycorrhizae which increase plant growth (Gupta, 2005). Bewuket *et al.* (2017) also reported that the interaction effect of inorganic NP and organic VC significantly affected the mean bulb weight of garlic.

4.4.3. Number of Clove

The analysis of variance revealed that the main and interaction effects of blended NPSB and VC fertilizer were highly significantly ($p < 0.01$) influenced the number of cloves of garlic (Appendix Table 4).

The highest number of cloves per bulb (30.5) was recorded from the pooled application of 244 kg ha^{-1} NPSB and 7.5 t ha^{-1} VC fertilizers. However, the lowest number of clove per bulb (11.1) was recorded from the control or unfertilized plot which was in statistical parity with interaction of nil rate of NPSB and 2.5 t ha^{-1} (12.5), nil rate of NPSB and 5 t ha^{-1} (12.5), 122 kg ha^{-1} NPSB and nil rate of VC (11.4), 122 kg ha^{-1} and 2.5 t ha^{-1} (13.1) (Table 6). The present study showed that the interaction of blended NPSB and VC fertilizer application had a positive response on the number of cloves per bulb might be due to the adequate addition of nutrients to the soil could result in to increased bulb number and size of garlic.

This justification confirmed with Fanaei *et al.* (2014) number of cloves per bulb may be an important attribute in increase bulb yield that could be considered a nutrient supply. Application of an increasing vermicompost fertilizer results in an increased the cloves number per bulb. The result also agreed with Alemu *et al.* (2016) also reported that the application of VC showed a significant difference in the mean clove number. Similarly, Abraha *et al.* (2015) also figured out that the maximum number of cloves was achieved with the application of fertilizer while the lowest was with no application of fertilizer.

Table 6. The interaction effect of blended NPSB and VC fertilizer on yield-related parameters of garlic.

NPSB (kg ha^{-1})	VC (t ha^{-1})	AFBW (g/plant)	MBW (g)	NC	BDY (g/plant)	HI (%)
0	0	28.2^{i}	10.9^{h}	11.1^{g}	18.3^{j}	34.5^{j}
	2.5	32.7^{ghi}	12.4^{h}	12.5^{efg}	23^{i}	38.5^{hij}
	5.0	34.3^{fgh}	12.5^{gh}	13.2^{efg}	26.3^{h}	36.2^{ij}
	7.5	37.5^{ef}	15.1^{fg}	14.5^{cd}	31.5^{fg}	40.2^{ghij}
122	0	31.5^{hi}	12.6^{gh}	11.4^{fg}	24.6^{hi}	42.9^{gfgh}
	2.5	32.1^{hi}	12.7^{gh}	13.1^{efg}	25.8^{h}	38.8^{ghij}
	5.0	34.9^{efgh}	17.5^{def}	13.8^{c}	26.7^{h}	49.7^{cde}
	7.5	39.3^{e}	20.2^{d}	18.5^{c}	33.3^{ef}	51.3^{bcd}
244	0	39.2^{e}	16.5^{ef}	13.4^{ef}	33.7^{def}	41^{ghi}
	2.5	44.7^{cd}	20^{d}	16.2^{cd}	36^{d}	44.7^{efg}
	5.0	48.1^{cd}	26.8^{c}	22.1^{b}	45.3^{ab}	55.7^{ab}
	7.5	65.2^{a}	36.8^{a}	30.5^{a}	47.5^{a}	60.7^{a}
366	0	37^{efg}	17.5^{ef}	14.5^{de}	30.3^{g}	47.3^{def}
	2.5	43.8^{d}	18.7^{de}	16.9^{c}	34.7^{de}	42.7^{fgh}
	5.0	48.5^{c}	26.6^{c}	23.2^{b}	41.7^{c}	54.7^{bc}
	7.5	57.5^{b}	30.7^{b}	21.9^{b}	43.3^{bc}	54.8^{abc}
LSD(%)		4.54	2.7	2.3	2.6	5.9
CV(%)		6.7	8.4	8.3	4.8	7.8

Means followed by the same letter are not significantly different at a 5% level of significance. LSD Least significant difference; CV = Coefficient of variation; AFBW= Average fresh biomass weight, MBW= Mean bulb yield, NC = Number of cloves, BDY = Biological dry yield, HI = Harvest index.

4.4.4. Biological Dry Yield

The analysis of variance showed that the biological dry yield of garlic was highly significantly ($p < 0.01$) influenced by interaction and main effect of blended NPSB and VC fertilizers (Appendix Table 4).

The highest biological dry yield (47.5 g) was recorded for the combined application of 244 kg ha^{-1} NPSB and 7.5 t ha^{-1} VC fertilizers which was not significantly different from the treatment interaction of 244 kg ha^{-1} and 5 t ha^{-1} (45.3g/plant). However, the lowest biological dry yield (18.3g) was recorded at the control treatment. The highest biological dry yield obtained at the application of 244 kg ha^{-1} combined with 7.5 t ha^{-1} VC fertilizer exceeded the biological dry yield recorded at the control treatment by 61 % (Table 6).

The current result showed that increasing the levels of blended NPSB and VC fertilizer to the optimum increased the biological dry yield of garlic, this could be the major nutrient supplied by the inorganic fertilizers will be utilized quickly by the crops and all other

micro and macro nutrients available in organic manure will be released slowly which, supply of sufficient amount of nutrient into the soil from applied fertilizer which in turn increases vegetative growth and that could promote chlorophyll molecule through photosynthesis and proportional increasing of biological dry yield. The result is in agreement with the findings of Choudhary *et al*. (2013) whose reported showed that successive fertilization rates significantly increased bulb weight, number of cloves per bulb, and bulb yield. According to Yadav *et al*. (2017), the application of organic fertilizer gave the highest fresh weight of the bulb, dry weight of the bulb, number of cloves per bulb, and bulb diameter as compared to other treatments.

4.4.5. Harvest Index

The analysis of variance revealed that the harvest index of garlic was highly significantly ($p < 0.01$) influenced by the main and interaction effect of blended NPSB and VC fertilizers (Appendix Table 5).

The highest harvest index (60.7%) was recorded from the combined application of 244 kg ha^{-1} blended NPSB and 7.5 t ha^{-1} VC fertilizer which was not significantly different from the treatment interaction of 366 kg ha^{-1} NPSB and 7.5 t ha^{-1} VC (54.8%), 366 kg ha^{-1} NPSB and 5 t ha^{-1} VC (54.7%), 244 and 5 t ha^{-1} VC (55.7%). However, the lowest (34.5%) harvest index was recorded at control treatment (Table 6). The present study showed that the increased levels of organic and inorganic fertilizer to the optimum level increased in harvest index of garlic this might be due to VC and blended NPSB fertilizer enhancing more vegetative growth and bulb formation that can develop economical yield. Compared to the control treatment, the interaction effect of 244 kg ha^{-1} blended NPSB and VC, increased by about 43.1%. This result agrees with Geleta (2014) who reported that the highest harvest index was calculated at the combined application of 138 kg N + 40 kg P + 30 kg ha^{-1} S on Andosols and 138 kg N + 80 kg P + 0 kg ha^{-1} S on Vertisols.

The highest harvest index response at the highest blended NPSB and VC fertilizer might be the interaction of blended NPSB and VC fertilizer enhances the supplying power of essential nutrients by the soil that is required for plant growth in both below and above the ground parts. Wondimu (2009) reported that the highest harvest index for the Adama Red cultivar of onion was recorded from treatment that received N and FYM at 25 kg ha^{-1} N + 8 t ha^{-1} FYM, respectively. Similarly, this result is comparable to the research report

of Degwale (2014) who recorded the maximum harvest index recorded from a combination of 46 N kg ha^{-1} and 92 P_2O_5 kg ha^{-1}.

4.4.6. Marketable Bulb Yield

Analysis of variance showed that the marketable bulb yield of garlic was highly significantly ($p < 0.01$) influenced by the main and interaction effects of blended NPSB and VC fertilizer (Appendix Table 5).

Thus, the highest marketable bulb yield (13 t ha^{-1}) was recorded from the combined use of 244 kg ha^{-1} NPSB and 7.5 t ha^{-1} VC. However, the lowest marketable bulb yield (3.4 t ha^{-1}) was recorded at the control treatment (Table 7). The marketable bulb yield obtained from the interaction of 244 kg ha^{-1} and 7.5 t ha^{-1} exceeded the marketable yield at the control treatment by 73.85% (Table 7). The present study showed that increased blended NPSB and VC fertilizer to the optimum rate increased the marketable bulb yield of garlic. This might be due to the supply of adequate nutrients from the combined use of blended NPSB and VC resulting in marketable size bulbs of garlic. Sulfur from blended NPSB and VC fertilizer enriched the availability of micronutrients by amending the soil PH that could contribute to the increase in the yield of garlic. This result agrees with Degwale (2014) who reported the highest marketable yield at the combined application of N and P fertilizers at 46 kg ha^{-1} N and 92 kgha^{-1} P_2O_5. Moreover, Yayeh (2015) recorded the highest marketable yield of garlic (17.42 t ha^{-1}) from 140:122.6:22.60 N: P_2O_5: S kg ha^{-1}.

4.4.7. Unmarketable Bulb Yield

The Analysis of variance showed that the main and interaction effects of blended NPSB and VC fertilizer were highly significantly ($p < 0.01$) influenced the unmarketable bulb yield of garlic (Appendix Table 5).

As indicated in table 7, the lowest unmarketable bulb yield (0.32 t ha^{-1}) was recorded from the treatment interaction of 244 kg ha^{-1} NPSB and 7.5 t ha^{-1} VC fertilizers whereas the highest yield for unmarketable bulb yield (1.24 t ha^{-1}) was obtained from the unfertilized plot. The current result showed that an increased rate of organic and inorganic fertilizer to the optimum level decreased the yield of unmarketable bulbs might be due to the availability of sufficient amounts of nutrients in the soil promoting the growth and

large-size bulb yield of garlic. Contrary to this the highest unmarketable yield at unfertilized plots might be the inadequate nutrients in the soil decreased growth and increased yield of small-sized bulb which are undersized and unmarketable. This might be attributed to the lower fertilizer rates reducing quantity and quality of production, leading to irregularly shaped bulbs and undersized.

Moreover, the low contribution of photosynthetic products towards clove reduces the growth of photosynthetic leaves could increase unmarketable bulb yield in unfertilized plots. However, the combination of inorganic and organic fertilizers could be more appreciated than a single fertilizer to reduce the unmarketable bulb yield of garlic. This result agreed with the findings of Alemu *et al*. (2016) reported that unmarketable bulb yield was significantly influenced by the main effect of VC and the interaction effect of N and P fertilizers. Dargie (2015) also reported that increased rates of fertilizer application decreased unmarketable bulb yield.

4.4.8. Total Bulb Yield

According to the analysis of variance total bulb yield of garlic was highly significantly ($p < 0.01$) influenced by the interaction and main effects of blended NPSB and VC fertilizers (Appendix Table 5).

The highest total bulb yield per hectare (13.3 t ha^{-1}) was recorded from the combined use of NPSB 244 kg ha^{-1} and 7.5 t ha^{-1}VC fertilizer whereas; the lowest total bulb yield per hectare (4.7 t ha^{-1}) was recorded at the control treatment which was in statistical parity with combined use of 122 kg ha^{-1} NPSB and 0 t ha^{-1} (5.02 t ha^{-1}) (Table 7). There was an increase of 64.7% in the total bulb yield of garlic at an optimum application rate of 244 kg ha^{-1} NPSB and 7.5 t ha^{-1} over the control treatment. A possible reason for the increase in total yield was revealed in the combined use of NPSB and VC fertilizers, which were associated with improved soil fertility and a change in the soil environment that favors better vegetative growth, which promotes crop yield and produces more harvest photosynthesis. The increase in total garlic yield with the application of NPSB and VC fertilizers was due to the positive effect of both nitrogen and phosphorus (Israel *et al*., 2012).

This is probably due to improved conditions that increased the vegetative growth of aerial parts and thus the transfer of photosynthesis to storage parts (Alemayehu *et al*., 2015). Similar results were attained by Ramandeep *et al*. (2015), Falodun*et al*. (2013), and Rizk *et al.* (2014), whose findings recorded the highest yield of onion bulbs by the combination of organic with inorganic fertilizers than with mineral fertilizers alone. The current study also corroborated with the findings of Ngullie *et al.* (2011) who reported that maximum yield was obtained with the application of 50% VC +50% RDF N.

The result is also in line with the finding of Yadav (2015) who reported that the maximum yield recorded under the application of 50% VC + 50% RDF which caused 70.63% more yield than untreated control.

Table 7. The interaction effect of blended NPSB fertilizer and Vermicompost on yield parameters of garlic.

NPSB (kg ha^{-1})	Vermicompost (t ha^{-1})	Marketable yield (t ha^{-1})	Unmarketable bulb yield (t ha^{-1})	Total bulb yield (t ha^{-1})
0	0	3.4^{h}	1.24^{a}	4.7^{i}
	2.5	4.4^{g}	0.94^{b}	5.37^{hi}
	5.0	5.4^{f}	0.84^{bc}	6.3^{g}
	7.5	5.8^{f}	0.76^{cde}	6.56^{fg}
122	0	4.2^{g}	0.82^{cde}	5.02^{i}
	2.5	5.3^{f}	0.95^{b}	5.99^{gh}
	5.0	6.4^{e}	0.7^{defgh}	7.1^{ef}
	7.5	7.2^{d}	0.58^{gh}	7.75^{de}
244	0	7.2^{d}	0.81^{bcd}	7.9^{d}
	2.5	7.5^{d}	0.78^{cde}	8.1^{d}
	5.0	10.4^{b}	0.65^{efgh}	11.1^{b}
	7.5	13^{a}	0.32^{i}	13.3^{a}
366	0	7.6^{d}	0.72^{cdefg}	8.3^{d}
	2.5	9.0^{c}	0.6^{fgh}	9.65^{c}
	5.0	10.2^{b}	0.54^{h}	10.77^{b}
	7.5	9.2^{c}	0.61^{fgh}	9.9^{c}
LSD (%)		0.7	0.15	0.81
CV (%)		5.7	12.3	6.1

Means followed by the same letter are not significantly difference at 5% level significance. LSD= Least significant difference; CV = Coefficient of variation

Combined application of blended NPSB and VC rate of fertilizer improved the yield of garlic due to the moderation effect on soil chemical properties such as OC, total N,available P, and soil pH thus made available to plants that contributed positively to total bulb yield. Israel *et al*. (2012) reported that increasing the rate of blended NPSB fertilizer response with an increase in total bulb yield was due to the positive effect of both nitrogen and phosphorus on total bulb weight. Increasing the rate of sulfur also increases total bulb yield significantly this might be due to the synthesis of sulfur-containing amino acids which enhances carbohydrate metabolism and photosynthetic activity of plants (Juszczuk and Ostaszewska, 2011).

The present study conformity with the findings of Rodriguez *et al*. (2012), Verma *et al*. (2013), and Agegnehu *et al*. (2016) who reported that the application of VC in addition to mineral fertilizer that contains nitrogen, phosphorus, and boron tends to increase the yield of potato when compared to fertilizer applied alone. The application of the higher rates of VC and NPSB resulted in higher yields (Agegnehu *et al*., 2016). Moreover Shibabaw *et al*. (2018) also stated that the integrated application of inorganic and organic fertilizers has a great importance in maintaining and supplying a higher-level nutrient that could improve the soil fertility and productivity of garlic than their separated applications. Similarly, highly vegetative growth was observed as the result of a balanced nutrient supply in the soil which may be available for good bulb formation and enhancing productivity of garlic (Diriba, 2016). However, furthermore application of fertilizer results in excessive vegetative growth and also induces toxicity to plants could negatively affect bulb formation and productivity of garlic (Tadila and Nigusie, 2018).

4.5. Correlation Analysis

The correlation coefficient of plant growth and bulb yield of garlic were analyzed for different response variables which helped to show how the yield components and growth characters were affecting the total yield of garlic. Results on simple correlation coefficients revealed that mean bulb weight, marketable bulb yield, and total bulb yield of garlic exhibited significant ($p < 0.01$) and positive correlation with all growth characters (Table 8).

The mean bulb weight was significantly and positively correlated with plant height (r=0.73***) leaf length (0.72***) and number of leaves per plant (r=0.66***). Similarly, the correlation analysis also indicated that marketable bulb yield showed significant ($p<0.01$) and positive correlation with plant height (r=0.71***), leaf length (r=0.72***), number of leaves per plant (r=0.56***), average fresh biomass yield (r=0.88***), mean bulb weight (r=0.92***), number of clove (r=0.89***), biological dry yield (r=0.94***), harvest index (r=0.81***), and total bulb yield (r=0.99***). On the contrary, unmarketable bulb yield was highly significantly and negatively correlated ($p < 0.001$) with plant height (r=-0.74), leave length(r=-0.73), number of leaves per plant (r=-0.61), average fresh biomass yield (r=-0.74), mean bulb yield (r=-0.77), number of cloves (r=-0.76), biological dry yield (r= -0.76), harvest index (r=-0.75), marketable bulb yield (r=-081), total bulb yield (r=-0.78) (Table 8). A similar result was reported by Rice et al. (1993) who reported that onion bulb size can be increased by the application of N during the growing period. Moreover, Khandakhar *et al*. (2004) also observed a positive and significant correlation of total dry matter yield with total N, P, and K uptake.

The positive and significant correlation (r-value) between growth parameters and yield components of garlic indicated that yield components are highly influenced by growth parameters. Therefore, the application of inorganic and organic fertilizers positively influenced the growth and yield components of garlic. This indicated that photosynthetic and metabolism activity were positive in response to the application of NPSB and VC fertilizers attributing to garlic productivity.

Table 8. Correlation coefficients among growth and bulb yield attributes of garlic.

	PH	LEL	NLPP	AFBY	MBW	NC	BDY	HI	MBY	UMBY	TBY
PH	1										
LEL	0.92***	1									
NLPP	0.79***	0.83***	1								
FB	0.69***	0.722***	0.70***	1							
MBW	0.73***	0.723***	0.66***	0.96***	1						
NC	0.66***	0.66***	0.68***	0.93***	0.92***	1					
BD	0.75***	0.78***	0.67***	0.90***	0.91***	0.88***	1				
HI	0.69***	0.69***	0.66***	0.82***	0.86***	0.81***	0.73***	1			
MBY	0.71***	0.72***	0.56***	0.88***	0.92***	0.89***	0.94***	0.78***	1		
UMBY	-0.74***	-0.73***	-0.61***	-0.74***	-0.77***	-0.76***	-0.76***	-0.75***	-0.81***	1	
TBY	0.70***	0.72***	0.55***	0.88***	0.92***	0.88***	0.93***	0.77***	0.99***	-0.78***	1

*Where, PH = Plant height; LEL= Leaf length; NLPP = Number of leaf per plant; AFBY average fresh biomass yield ; MBW = Mean bulb yield; NC = Number of clove; BDY = Biological dry yield; HI = Harvest index; MBY = Marketable bulb yield; UMBY = Unmarketable bulb yield; TBY = Total bulb yield and ******* and - = highly significant at ($p < 0.001$) and negatively correlated, respectively.*

4.7. Partial Budget Analysis

The economic analysis revealed that the highest net benefit (3,392,556 ETB ha^{-1}) was recorded at the combined application of 244 kg ha^{-1}NPSB and 7.5 t ha^{-1}VC fertilizer with their acceptable high MRR, and (2,698,556 ETB ha^{-1}) net benefit was followed by combined application of 244 kg ha^{-1} NPSB and 5 t ha^{-1}VC fertilizer. However, the lowest (91,800 ETB ha^{-1} net returns) was received with the control treatment (Table 10). Diriba *et al*, (2015) reported that the highest net benefit was obtained with the combined application of fertilizers for garlic crops. Similarly, Melaku *et al*. (2015) reported that 50% of recommended NP fertilizer plus 30 t ha^{-1} poultry manure gave in the highest mean bulb weight that resulted in the highest net benefit. From the economic point of view, it was apparent from the above results that the combined application of 244 kg ha^{-1} NPSB and 7.5 t ha^{-1} gave the highest net benefit with acceptable MRR and was more profitable than the rest of the treatment combinations, Therefore, this combination could be provisionally recommended for garlic production in the study area.

Table 9. Partial budget analysis of the effect of blended NPSB and VC fertilizer on garlic.

Treatment combination		MBY(t ha^{-1})	Ajd. Y	GB	T VC	NBT	MRR
NPSB (kg ha^{-1})	VC (t ha^{-1})		(t ha^{-1})	(ETB t ha^{-1})	(ETB t ha^{-1})	(ETB t ha^{-1})	(%)
0	0	3.4	3.06	918,000	0	91,800	-
0	2.5	4.4	3.96	1,188,000	35,000	1,153,000	3,032
0	5	5.4	4.86	1,458,000	70,000	1,388,000	671.43
0	7.5	5.8	5.22	1,566,000	105,000	1,461,000	208.57
122	0	4.2	3.78	1,134,000	6,222	1,127,778	D
122	2.5	5.3	4.77	1,431,000	41,222	1,389,778	748.57
122	5	6.4	5.64	1,692,000	76,222	1,615,778	645.71
122	7.5	7.2	6.48	1,944,000	111,222	1,832,778	620
244	0	7.2	6.48	1,944,000	12.444	1,931,556	D
244	2.5	7.5	6.75	2,025,000	47,444	1,977,556	131.43
244	5	10.4	9.27	2,781,000	82,444	2,698,556	2,191.43
244	7.5	13	11.7	3,510,000	117,444	3,392,556	1,982.86
366	0	7.6	6.84	2,052,000	18,666	2,033,334	D
366	2.5	9	8.1	2,430,000	53,666	2,376,334	980
366	5	10.2	9.18	2,754,000	88,666	2,665,334	825.7
366	7.5	9.2	8.28	2,484,000	123,666	2,360,334	D

Where, MBY= marketable bulb yield, Adj-Y=adjusted yield downwards by10%, GB= Gross benefit, TVC= Total variable cost, NB= Net benefit, MRR = Marginal rate of return, D = Dominated. Cost of NPSB = 46 birr per kg , application cost (NPSB =500 BIRR 100 kg ha^{-1} and VC= (1000 birr t ha^{-1}), and market price of garlic = 300 birr kg^{-1}

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Low soil fertility and inappropriate use of fertilizer are the most limiting factors for the production and productivity of garlic in Ethiopia which needs to integrate blended and organic fertilizers.Production per unit area increases through the use of inorganic and organic fertilizers could be important to sustain the productivity of agriculture. Therefore, the study was conducted to determine the effect of NPSB fertilizer and VC on the growth, yield and yield components of garlic under rainfed conditions in Enore district, central Ethiopia. The experiments were laid out in Randomized Complete Block Design in factorial arrangements of four levels of blended NPSB fertilizer (0, 122, 244, and 366 kg ha^{-1}) and four levels of VC rates (0, 2.5, 5.0, and 7.5 t ha^{-1}) with three replications. Major crop data were collected on phenological, growth, and yield parameters.

Selected physiochemical properties of the soil were determined before planting and after crop harvest. The result revealed that experimental soil had a slight increment in total N, available P, available S, B, and percent of soil OC. Moreover, the CEC of the soil also showed that an increment indicating to some extent improves the soil fertility status of the area. The results also showed that both the main effects of NPSB fertilizer and vermicompost, and the effect of their interactions did not influence days to 50% emergence. However, the results revealed that the main effect of NPSB and vermicompost fertilizers had significantly affected the day to 75% maturity and the number of leaves per plant.

The longest days to maturity (126.7) and (127.6) were recorded by the application of 244 kg ha^{-1} blended NPSB and 7.5 t ha^{-1} VC fertilizer, respectively, and the highest number of leaves per plant (11.2) and (12.8) were recorded from 366 kg ha^{-1} NPSB and 7.5 t ha^{-1} VC fertilizer, respectively. On the other hand, the plant height and leaf length of garlic were significantly influenced by the main and interaction effect of blended NPSB and VC fertilizer. The highest plant height and leaf length of garlic (62.6cm) and (55.6 cm), respectively.

Similarly, all yield and yield-related parameters were significantly influenced by the main and interaction effects of NPSB and VC fertilizer. The highest average fresh biomass yield (65.2g), mean bulb weight (36.8g), number of cloves (30.5), biological dry yield (47.5 g), harvest indices (60.7%), marketable bulb yield (13 t ha^{-1}), total bulb yield (13.3 t ha^{-1}), and the lowest unmarketable bulb yield (0.32 t ha^{-1}) were recorded from 244 kg ha^{-1} NPSB combined with 7.5 t ha^{-1} VC fertilizer application. While the lowest phenological, growth, yield, and related parameters were recorded from the unfertilized plot (i.e., control treatment). The application of inorganic fertilizer combined with organic fertilizer on soil positively responds to the yield of garlic. Determine optimum rate of blended NPSB and VC fertilizer had a significant for increasing the productivity of garlic. The economic analysis showed the highest net benefit (3,392,556 ETB ha^{-1}) was recorded at the combined application of 244 kg ha^{-1} blended NPSB with 7.5 t ha^{-1} VC fertilizer with an acceptable high MRR.

5.2. Recommendations

The study revealed that the integrated use of 7.5 t ha^{-1} VC and 244 kg ha^{-1} blended NPSB fertilizer improves soil fertility status for sustainable garlic production and productivity in the study area. Beside lack of base line information about NPSB fertilizer experimental material used only P_2O_5 above and below 50% this is under estimated to N fertilizer blanket recommendation, so considered to balance 92 ka ha^{-1} P_2O_5 and 105 kg ha^{-1} N by adding urea. However, since the experiment was carried out only in one specific location and only for one season, it demands more studies at various agro-climatic conditions to generate more reliable results for recommendation.

6. REFERENCES

Ababulgu A. 2018. Integrated Use of NPS Blended Fertilizer and Cattle Manure for Growth, Yield and Quality of Potato (*Solanum tuberosum* L.) Under Dabo Ghibe Kebele, Seka Werada of Jimma Zone, Southwest Ethiopia. MSc Thesis submitted to Jimma University, Jimma, Ethiopia.

Abadi Tadesse. 2015. Growth and yield response of garlic (*Allium sativum* L.) varieties to nitrogen fertilizer rates at Gantaafeshum, northern Ethiopia." Ph.D diss., Haramaya University.

Abdallah, M., Dubousset, L., Meuriot, F., Etienne, P., Avice, J.C. and Ourry, A. 2010. Effect of mineral sulphur availability on nitrogen and sulphur uptake and re-mobilization during the vegetative growth of (*Brassica napus* L). *Journal of Experimental Botany*, 61(10) : 2635-2646.

Abdel-Razzak, H. and El-Sharkawy, G. 2013. Effect of Bio fertilizer and Humic Acid applications on growth, yield, quality and storability of two garlic (*Allium sativum* L.) cultivars. *Asian Journal of Crop Science*, 5(1) : 48–64.

Abera Tagesse and Alemayehu Adinew, A., 2023. Effect of nitrogen fertilizer rates on yield components, yield and quality of garlic (*Allium sativum* l.) varieties at kedidagamela district, southern Ethiopia. *International Journal of Agricultural and Natural Sciences*, 16(2) : 195-206.

Abou E., El-Shourbagy M. and Shehata S. 2012. A comparative study on the productivity of Four Egyptian garlic cultivars grown under various organic materials in comparison to conventional chemical fertilizer. *Australian Journal Basic and Applied Science,* 6(3) :4 15 -421.

Adhikari, P., Baral, B. and Shrestha, J. 2016. Maize response to time of nitrogen application and planting seasons. *Journal of Maize Research and Development*, 2(1) : 83-93.

Adhikary, P., A. Hansda, and P. Patra. 2017. Combined effect of pesticides, sulphur and boron on yield of sesame in alluvial soil of West Bengal. Bulletin of Environment, Pharmacology and Life Sciences Africa. *Advances in Agronomy*, 7(1) : 67–70.

Agegnehu, G., Nelson, P. and Bird, M. 2016. Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. *Soil and Tillage Research*, (160) : 1-13.

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

Alemayehu Tilahun Getie, Nigussie Dechassa andTamado Tana. 2015. Response of potato (*Solanum tuberosum* L.) yield and yield components to nitrogen fertilizer and planting density at Haramaya, Eastern Ethiopia. *Journal of Plant Sciences*, 3(6) : 320-328.

Alemayehu, Melkamu, and Minwyelet Jemberie. 2018. Optimum rates of NPS fertilizer application for economically profitable production of potato varieties at Koga Irrigation Scheme, Northwestern Ethiopia. *Cogent Food & Agriculture,* 4(1) : 1439663.

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

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

Ali, M., Tariq, N., Ahmed, N., Abid, M. and Rahim, A. 2013. Response of wheat (*Triticum aestivum* L.) to soil applied boron and zinc fertilizers under irrigated conditions.

Allen J. 2009. Garlic production Factsheet Garlic Production, Order Number, 97-007.

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

Anonymous. 2009. Earthworms vermicompost a powerful crop nutrient over the conventional compost and protective soil conditioner against the destructive chemical fertilizers for food safety and security. Journal *Agriculture and Environment. Science,* (5) : 01-55.

Ansari, A. and Hanief, A. 2015. Microbial degradation of organic waste through vermicompost.*International Journal of Sustainable Agricultural Research*, 2(2) : 45-54.

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

Aslam, Z., Ahmad, A., Bellitürk, K., Iqbal, N., Idrees, M., Rehman, W., Akbar, G., Tariq, M., Raza, M., Riasat, S. and Rehman, S. 2020. Effects of vermicompost, vermi-tea and chemical fertilizer on morpho-physiological characteristics of tomato (*Solanum lycopersicum*) in Suleymanpasa District, Tekirdag of Turkey. *Pure and Applied Biology (PAB)*, 9(3) : 1920-1931.

Assefa Abraha Gebrekiros, Solomon Habtu Mesgina, and Yirga Weldu Abrha. 2015. Effect of inorganic and organic fertilizers on the growth and yield of garlic crop (*Allium sativum* L.) in Northern Ethiopia. *Journal of agricultural Science*, 7(4) : 80.

ATA (Agricultural Transformation Agency). 2016. Soil fertility status and fertilizer recommendation Atlas of Southern National, Nationality and People Regional State, Ethiopia

Ayalew Abay. 2016. Assessment of soil fertility status of different types of soils in selected areas of Southern Ethiopia. *Journal of Natural Sciences Research* 6(1) : 2224-3186.

Ayalew Asrat, Daniel Tadesse, Zenebe G. Medhin, Solomon Fantaw, 2015. Evaluation of garlic (*Allium sativum* L.) varieties for bulb yield and growth at dabat, northwestern Ethiopia. *Open Access Library Journal*, 2(1) : 1-5.

Ayed, C., Mezghani, N., Rhimi, A. and Mohandes Dridi, B. 2019. Morphological evaluation of Tunisian garlic (*Allium sativum* L.) landraces for growth and yield traits. *Journal of Horticulture and Post-harvest Research*, 2(1) : 43-52.

Bagali A., Patil H., Chimmad V., Patil P. and Patil R. 2012. Effect of inorganics and organics on growth and yield of onion (*Allium cepa* L.). *Karnataka Jouranl of Agricultural Science*, 25 (1) : 112-115.

Bekunda, B., Sanginga, N. and Woomer, P. 2010. Restoring soil fertility in sub-Sahara

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

Betewulign, Eshetu and Solomon Tulu, 2014. Evaluating the role of nitrogen and phosphorous on the growth performance of garlic (*Allium sativum* L.). *Asian journal of agricultural Research,* 8(4) : 211-217.

Bewuket Gashew, Kebede Woldetsadik and Ketema Belete. 2017. Effects of organic and inorganic NP fertilizers on the performance of garlic (*Allium sativum* L.), varieties at Koga, *Northwestern Ethiopia. Journal of Biology Agriculture and Healthcare,* 7(7) : 2224-3208.

Bewuket Gashaw. 2021. Evaluation of Different Rates of NPS on Growth and Yield Performances of Garlic (*Allium sativum* L.) in Cheha District, Gurage Zone, Ethiopia, *International Journal of Agronomy*, Article ID 7742386, 2021(5). https://doi.org/10.1155/2021/7742386

Bezabih Emana, Afari V., Amsalu Ayana, Balemi T. and Milkessa Temesgen. 2015. Characterization and Assessment of Vegetable Production and Marketing Systems in the Humid Tropics of Ethiopia. *Quarterly Journal of International Agriculture,* 54(2) : 163-187.

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

Biramo Geremew. 2018. The role of integrated nutrient management system for improving crop yield and enhancing soil fertility under Small holder farmers in Sub-Saharan Africa: A review article. *Modern Concepts and Developments in Agronomy*, (2) : 1-9.

Bizuayehu Desta, Netsanet Tena and Getachew Amare. 2021. Growth and bulb yield of garlic as influenced by clove size, *Hindawi the Scientific World Journal*, (1) : 7. https://doi.org/10.1155/2021/7351873.

Bouyoucos, G. 1965. Hydrometer method improved for making particle size analyses of soils 1. *Agronomy journal*, 54(5) : 464-465.

Carl Rosen. 2011. Vegetable crop management department of soil, water and climate conservation. *European Journal of Nutrition,* 44(2) : 85-94

Chillot Y. and Hassan R. 2010. Social costs and incentives for optimal control of soil nutrient depletion in the central highland of Ethiopia. *Agricsys*, (103) : 153-60.

Choudhary, Bhagwan Singh, A. Soni and S. Khaswan. 2013. Growth, yield and quality of garlic (*Allium sativum* L.) as influenced by different nutrient management practices. *Annals of Agricultural Research,* 34:3.

CIMMYT (International Maize and Wheat Improvement Center). 1988. From Agronomic Data to Farmers Recommendations Economics Training Manual, Completely Revised Edition, Mexico.combinations of poultry manure and urea on growth, yield and economics of garlic (*Allium sativum* L.). *Journal of Agriculture and Natural Resources*, 3(1) : 253–264

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

CSA (Central Statistical Agency). 2021. Agricultural Sample Survey Report on area and production of crops. Addis Ababa, Ethiopia: CSA.

CVR (Crop Variety Register). 2009. Ministry of agriculture and rural development animal and plant health regulatory Directorate, (12) : 135-136

Damse, D., Bhalekar, M. and Pawar, P. 2016. Effect of integrated nutrient management on growth and yield of Aloe barbadensis. *Indian Journal of Agricultural Sciences*, 86(1) : 91–95.

Dargie Mirete. 2015. Influence of mineral N and phosphorus fertilizer rates on growth, yield components and bulb yield of onion (*Allium cepa*) at Kobo, Northern Ethiopia.(Doctoral dissertation, Haramaya University).

Debnath and Ghosh. 2011. Response of Boron and Zinc Fertilization to Productivity of Rice in Piedmont Soil of Arunachal Pradesh. *International Journal of Agriculture, Environment and Biotechnology,* 8(4) : 907-914

Dewis, J. and Freitas P. 1970. Physical and chemical methods of soil and analysis FAO Bulletin Number, (10) : 275.

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

Diriba Shifereaw, Nigussie, Dechassa, Kebede Woldetsadik, Getachew Tabor. and J., Sharma1. 2014. Bulb quality of garlic (*Allium sativum* L.) As influenced by the application of inorganic fertilizers. *African Journal Agriculture Research,* 9(8) : 778-790.

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

DZARC (DebreZeit Agricultural Research Center). 2000. DebreZeit Agricultural Research Center Annual research report, 1999/2000.

DZARC (DebreZeit Agricultural Research Center). 2019. DebreZeit Agricultural Research Center Annual research report, 2019.

DzARC (Debre-Ziet Agricultural Research Center). 2006. Garlic Production and Management. Debre-Ziet Agricultural Research Center, Leaflet (Amharic Version), Debre-Ziet, Ethiopia.

EIAR (Ethiopian Institute of Agricultural Research). 2007. Guideline of crop production technologies Available: www.eiar.gov.et/fruits and vegetables in Ethiopia, Addis Ababa.

Epstein E. and Bloom A. 2005. Mineral nutrition of plants: Principles and perspectives, 2nd edition. Sunderlands, MA: Sinauer Associates

Espino, H., Hernández, F., Hernández, O., Bautista, D., Ávila, A., Muñoz, F., Montero, L., Benítez, S., Valdez, L., Torres, T. and Parga, M. 2012. Agronomic and biotechnological strategies for breeding cultivated garlic in Mexico. In *Genetic Diversity in Plants*. IntechOpen.

EWPCO (Enor Woreda Plan Commissions Office). 2020. Enor woreda plan commissions office annual report, 2020 (unpublished).

Falodun, E., Ehigiator and R. Egharevba. 2013. Growth and yield of onion as influenced by organic and inorganic fertilizer in edo rainforest of Nigeria. *Journal of Tropical Agriculture, Food, Environment, and Extension*, 12 (3) : 15-24.

Fanaei, H., Narouirad, M., Farzanjo, M. and Ghasemi, M. 2014. Evaluation of Yield and Some Agronomical Traits in Garlic Genotypes (*Allium sativum* L). *Annual Research and Review in Biology*, 4 (22) : 3386-3391.

FAOSTAT (Food and Agriculture Organization Statistics), 2023. Garlic production and quantity (tons) for Ethiopia http://www.factfish.com/statistic/garlic/.

Farooqui, M., Naruka, I., Rathore, S., Singh, P. and Shaktawat, R. 2009. Effect of nitrogen and sulfur levels on growth and yield of garlic (*Allium sativum* L.). *Asian Journal of Food Agriculture and Industry,* (2) : 18–23.

Fatma A., Rizk, A., Shaheen, E., Abd El-Samad and T. El-Labban. 2014. Response of onion plants to organic fertilizer and foliar spraying of some micro-nutrients

under sandy soil conditions. *Journal of applied sciences research,* January 2014. fertility status and fertilizer recommendation, EthioSIS, report.

Fikreyohannes Gedamu, Kebede W/Tsadik, Nigussie Dechassa and Tiwari, A. 2008 Effect of clove size and plant density on the bulb yield and yield components of Ethiopian garlic (*Allium sativum* L.). *Pantnagar Journal of Research*, 6(2) : 234-238.

Gateri, M., Nyankanga, R., Ambuko, J. and Muriuki, A. 2018. Growth, yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and time of topdressing. *International Journal of Plant and Soil Science,* (3) : 1–13.

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

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

Getachew Amare and Temesgen Mamo. 2020. Effects of nitrogen and NPS fertilizer rates on fresh yield of garlic (*Allium sativum* L.) at Debre Berhan, Ethiopia. *Journal of Agriculture and Crops*, (6) : 113–118.

Getachew Tabor, Yosef Alemu, Selamawit Ketema, Mohammed Yesuf and Gashawbeza Ayalew. 2016. Vegetable Crops Research in Ethiopia: Achievements and Future Prospects. *Agricultural Research for Ethiopian Renaissance*.

Getaneh, Tadila and Nigusse Dechassa. 2011. Effect of manure and nitrogen rates on yield and yield components of garlic (*Allium sativum* L.) at Haramaya, Eastern Ethiopia. Ph.D diss., Haramaya University, 2011.

Gezachew Abate and Yenegete, A. 2006. Effect of compost supplemented with NP fertilizers on soil property, NP-uptake and yield of potato (*Solanum tuberosum* L.) in West Gojjam, North Western Ethiopia.

Gezu, Getachew Debela. 2015. Fertility Mapping of Soils of Bako Tibe District, West Shewa Zone of Oromia National Regional State, Ethiopia. Ph.D diss., Haramaya University.

Gizachew Atinafu, , Fasil Tadesse, Asfaw, Yenenesh Asfaw and Getachew Tabor. 2021. Morphological characterization and evaluation of garlic (*Allium sativum* L.) accessions collected from Northern Highlands of Ethiopia. *Advances in Crop Science and Technology*, 9(7) : 4. https://doi.org/10.4172/2329- 8863.1000474.

Gomez K. and A. Gomez. 1984. Statistical Procedures of *Agricultural Research 2nd edition*\John Willey and Sons, New York, pp: 680.

Gopinath, K., Saha, S., Mina, B., Pande, H., Kumar, N., Srivastava, A. and Gupta, H. 2009. Yield potential of garden Pea (*Pisumsativum* L.) varieties and soil properties under organic and integrated nutrient management systems. *Archives of Agronomy and Soil Science*, (55) : 157-167.

Gupta N., Banafar R. and Asati K. 2005. Influence of macro and micro nutrients on keeping quality of onion National Seminar on Agro technology, Quality, Processing and Export of Spices, 78.

Hamza M. 2008. Understanding soil analysis data. Department of Agriculture and Food,Western Australia. Report, 327.

Hargreaves J., Adl M. and Warman P. 2008. Review of the use of composted municipal solid waste in agriculture Nova Scotia, Canada. A*griculture Ecosystems and Environment, (*123) : 1-14.

Hunde, N. F. 2017. Opportunity, problems and production status of vegetables in Ethiopia: a review.Ethiopian *Institute of Agricultural Research, Assosa Research Center, Assosa, Ethiopia,* 4(2) : 172.

Ipek, M., Ahmet I. Philipp and Simon W. 2008. Molecular Characterization of Kastamonu Garlic: An Economically Important Garlic Clone in Turkey. *Scientia Horticulture,*115(2) : 203–8. https://doi.org/10.1016/j.scienta.2007.09.001

Irfan, A., Nawaz, A., Ullah, E., Hassan, L., Raza, A., Zuhra, N. and Iqbal, I. 2021. Assessing growth and yield of two maize cultivars under different levels of Vermicompost Application. Journal of Agriculture Environment and Food Security, (2): 1-8.

Israel Zewide, Ali Mohammed and Solomon Tulu. 2012. Effect of different rates of nitrogen and phosphorous on yield and yield components of potato (*Solanum tuberosum* L.) at Masha District, Southwestern Ethiopia. *International Journal of Soil Science*, 7(4) : 146-156.

James, B. 2008. Onions and Other Vegetable *Alliums* (2nd ed.). *Horticulture Research International*, pp. 448.

Jasso-Chaverria C., Hochmuth G., Hochmuth R. and Sargent S. 2005. Fruit yield, size, and color responses of two greenhouse cucumber types to nitrogen fertilization in Perlite soil less culture. *Horticulture Technology*, 15(3**)** : 565-571.

Jones Clain, Kathrin and Olson Rutz Courtney. 2011. Pariera dinkins nutrient uptake timing by crops to assist with fertilizing decisions department of land resources and environmental science, Montana State University, Bozeman.

Jones, J.B. 2003. *Agronomic Handbook: Management of crops, soils, and their fertility*. CRC Press LLC, Boca Raton, FL, USA. pp.482.

Juszczuk, I. and Ostaszewska, M. 2011. Respiratory activity, energy and redox status in sulphur deficient bean plants. *Environmental and Experimental Botany*, (74) : 245-254.

Karltun, E., lemenih, M. and Tolera, M. 2013. Comparing farmers' perception of soil fertility change with soil properties and crop performance in beseku, Ethiopia. *Land degradation & development*, 24(3):228-235.

Kassa Melese. 2015. On opportunities and Potential in Ethiopia for Production of Fruits and vegetable. Haramaya University. *International Journal of African and Asian Studies*, 15.

Kathuku, A., Kimani, S., Okalebo, J., Othieno, C. and Vanlauwe, B. 2011. The Effects of integration of organic and inorganic sources of nutrient on maize yield in central Kenya. In Innovations as Key to the Green Revolution in Africa (1st edition). London New York: Springer Dordrecht Heidelberg, (1) : 265–270

Khandakhav, S., M. Rahman, M.. Uddin, S. Khan and K. Quddus. 2004. Effect of lime and potassium on potato yield in acid soil. *Journal of Pakistan Biological Science,* 7(3):380-383.

Kokobe Wolde Yohannes, Derbew Belew and Adugna Debela. 2013. Effect of Farmyard Manure and Nitrogen Fertilizer Rates on Growth, Yield and Yield Components of Onion (Allium cepa L.) at Jimma, Southwest Ethiopia. *Asian Journal of Plant Sciences,* 12(6) : 228-234

Kumar S., Bhowmik D., Chiranjib Tiwari P. and Kharel R. 2010. *Alliumn sativum* and its health benefits *Journal of Chemistry Pharmacology Resource,* 2(1) : 135-146.

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

Landon J. 1991. Booker tropical soil manual. A handbook for soil survey and agricultural.

Lanzotti V., Scala F. and Bonanomi G. 2014. Compounds from *Allium* species with cytotoxic and antimicrobial activity. *Phytochemistry Reviews*, (13) : 769-791.

Mahajan, A., Gupta, R. and Sharma, R. 2008. Vermicompost and sustainable agriculture. *In book: Research Trends in Agriculture Sciences,* pp.73-88

Manaig Elena M. 2016. Vermicomposting Efficiency and Quality of Vermicompost with Different Bedding Materials and Worm Food Sources as Substrate. *Research Journal of Agriculture and Forestry Sciences,* 4(1) : 1-13.

Manish, K., Pandit, M., Telwala, Y., Nautiyal, D., Koh, L. and Tiwari, S. 2017. Elevational plant species richness patterns and their drivers across non-endemics, endemics and growth forms in the Eastern Himalaya. *Journal of Plant Research*, 130(5) : 829-844.

Manna, D. 2014. Growth, yield and bulb quality of onion (*Allium cepa* L.) in response to foliar application of boron and zinc manure and nitrogen fertilizer rates on growth, yields and qualities of onion (*Allium cepa. L*.) at Jimma Zone Ethiopia. *Asian Journal of Plant Sciences*, 11(1) : 1682-3974.

Marsic, N.K., Necemer, M., Veberic, R., ULRIH, N.P. and Skrt, M., 2019. Effect of cultivar and fertilization on garlic yield and allicin content in bulbs at harvestand during storage. *Turkish Journal of Agriculture and Forestry*, 43(4) : 414-429.

Masrie Biruk, Nigussie Dechassa, Tamado Tana, Yibekal Alemayehu, and Bekele Abebie, 2015. The effects of combined application of cattle manure and NP fertilizers on yield and nutrient uptake of potato in North-Eastern Ethiopia. *Journal of Science and Sustainable Development*, 3(1) : 1-23.

Mbithi M., Mwanarusi S. and Mwangi M. 2015. Effect of different rates of vermicompost on growth and yield of beetroot (*Beta vulgaris* L.), *Egerton Journal of Science and Technology,* (15) : 30-43.

Mehdi Ra, Hossein A.A and Mehdi G. 2012. Effect of vermicompost and municipal solid waste compost on growth and yield of canola under drought stress conditions. *International Journal of Agriculture Resource,* 2(4) : 395-402.

Melaku Fisseha. 2010. Response of onion (*Allium cep var. cepa*) to combined application of farmyard manure and Inorganic Nitrogen and Phosphorous Fertilizer at Alage, Ethiopia. M.Sc. Thesis submitted to the school of graduate studies, Haramaya University

Melaku Tefera, Tesfaye Balemi and Weyessa Garedew. 2017. Effect of NP fertilizer and poultry manure rates on bulb yield and yield components of garlic (*Allium sativum* L.) on vertisol at Ambo. *East African Journal of Sciences,* 13(2) : 159-168

MOANR (Minister of Agriculture and Natural Resource). 2016. Vegetable, fruit and root crops production manual Addis Ababa, Ethiopia 51-54.

Mohamed Amin, Shiberu Tadele and Thangavel Selvaraj. 2014. White rot (*Scelerotium cipivorum Berk*)-an aggressive pest of onion and garlic in Ethiopia: an overview. *Journal of Agricultural Biotechnology and Sustainable Development,* 6(1) : 6-15.

Mohammad R. Asgharipour and Mohammad Javad Arshad, 2012. Effect of planting date and plant density on yield and yield components of garlic In farmin, Advance s in environmental biology, 6(3):583-586, 2012, ISSN 1995-0756.

Mohammadi, G.R., Ajirloo, A.R., Ghobadi, M.E. and Najaphy, A. 2013. Effects of non-chemical and chemical fertilizers on potato (*Solanum tuberosum* L.) yield and quality. *Journal of Medicinal Plants Research*, 7(1): 36-42.

Mondal, M., Akter, M.B., Rahman, M.H. and Puteh, A.B., 2016. Influence of micronutrients and manures on growth and yield of garlic (*Allium sativum* L.) in sandy loam soil. *International Journal of Plant and Soil Science*, 13(4) : 1-8.

Mucheru-Muna, M.W., Ada, M.A., Mugwe, J.N., Mairura, F.S., Mugi-Ngenga, E., Zingore, S.and Mutegi, J.K. 2021. Socioeconomic predictors, soil fertility knowledge domains and strategies for sustainable maize intensification in Embu County. *Kenya Heliyon,* 7(2): 06345.

N'Dayegamiye, A., Nyiraneza, J., Giroux, M., Grenier, M. and Drapeau, A. 2013. Manure and paper mill sludge application effects on potato yield, nitrogen efficiency and disease incidence. *Agronomy*, 3(1) : 43-58.

Najar, I.A. and Khan, A.B. 2013. Effect of vermicompost on growth and productivity of tomato (Lycopersicon esculentum) under field conditions. *Acta Biol Malaysiana*, 2(1) : 12-21.

Nasreen, S., Haque, M.M., Hossain, M.A. and Farid, A.T.M. 2007. Nutrient uptake and yield of onion as influenced by nitrogen and sulphur fertilization. *Bangladesh Journal of Agricultural Research,* 32(3) : 413-420.

Nebret Tadese. 2012. Effect of nitrogen and sulfur application on yield components and yield of common bean (*phaseolus vulgaris* L.) in Eastern Ethiopia. *Academic Research Journal of Agricultural Science and Research,* 5(2) : 77-89.

Ngullie, E., Singh, V.B., Singh, A.K. and Singh, H. 2011. Fertilizing for Sustainable Onion Production Systems. *Better Crops Vegetable Scienc*e, 95:32-34.

Nigatu Muluneh. 2016. Assessment of Onion production practices and effects of N:P_2O_5 :S fertilizers rates on yield and yield components of onion (*Allium cepa*

L.). MSc. Thesis presented to the School of Graduate Studies of Bahir Dar University College of Agriculture and Environmental Sciences Bahir Dar, Ethiopia.

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

Nigussie Abebe, Kuyper, W. and Neergaard, A. 2015. Agricultural waste utilization strategies and demand for urban waste compost: Evidence from smallholder farmers in Ethiopia. *Waste Management*, (44) : 82-93.

Pathma, J. and N. Sakthivel, 2012. Microbial diversity of Vermicompost bacteria that exhibit useful agricultural traits and waste management potential. *SpringerPlus*, (1) : 1-19

Patidar, M., Shaktawat, R.P.S. and Naruka, I.S. 2017. Effect of sulphur and vermicompost on growth, yield and quality of garlic (*Allium sativum* L.). *Journal of Krishi Vigyan*, 5(2) : 54-56.

Pessarakli, M. ed., 2001. *Handbook of plant and crop physiology* (No. 22137). New York: Marcel Dekker.

Potarzycki, J. and Grzebisz, W. 2009. Effect of zinc foliar application on grain yield of maize and its yielding component. *Plant, soil and environment*, 55(12) : 519-527.

Pramanik PGK, Ghosh P. K. and Banik. P. 2007. Changes in organic-C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants *Journal of Bio resource Technology* (98) : 2485-2494.

Ramandeep, K. B., S. Rakesh, and K. Jashanjot. 2015. Effect of organic sources of nutrients on yield and quality of onion (*Allium cepa*L.). *Indian Journal of Ecology* 42 (1) : 266–7.

Rameshwar, H.Y. and Anteneh Argaw, 2016. Manurial value of khat waste vermicompost from Awday, Harar town, Ethiopia. *International Journal of Recycling of Organic Waste in Agriculture*, (5) : 105-111.

Rebekić, A., Lončarić, Z., Petrović, S. and Marić, S., 2015. Pearson's or Spearman's correlation coefficient-which one to use. *Poljoprivreda*, 21(2) : 47-54.

Rizk, F. A., A. M. Shaheen, E. H. Abd El-Samad, and O. M. Sawan. 2014. Effect of different Nitrogen plus phosphorus and sulphur fertilizer levels on growth, yield

and quality of onion (*AIlium cep*a L.). *Journal of Applied Science Research,* 8(7): 3353-3361.

Rodriguez, R. A., Miglierina, A. M., Ayastuy, M. E., Lobartini, J. C., Van Konijnenburg, A., Dagna, N., Greco, N., Egea, C. and Fernández, J. A. 2012. The effect of different organic fertilization on garlic (*Allium sativum* L.) in Bahía Blanca Region, *Argentine Acta Hort,* (933) : 187– 194.

Rop K., Karuku G. N., Mbui D., Njomo N. and Michira I. 2019. Evaluating the effects of Formulated Nano-NPK Slow Release Fertilizer Composite on the Performance and Yield of Maize, Kale and Capsicum. *Annals of Agricultural Sciences*, 1-11.

Rowell, D.L. 1994. Soil science: Method and applications. Addison, Wesley, England: Longman Scientific and Technical, Longman Group UK Limited, 350p

SAS. 2011. Statistical Analysis Systems SAS/STAT users guide Version 9.3 Cary NC: SAS Institute Inc. USA.

Scherer, H.W., Pacyna, S., Spoth, K.R. and Schulz, M. 2008. Low levels of ferredoxin, ATP and leghemoglobin contribute to limited N2 fixation of peas (*Pisum sativum* L.) and alfalfa (*Medicago sativa* L.) under S deficiency conditions. *Biology and fertility of Soils*, 44(7): 909-916.

Serbessa, H., Mekonnen, T., and Abi, M. 2023. Opportunities and Challenges of Urban Farming in Ethiopia: Evidence from Vegetable Producers in Addis Ababa. *Journal of Developing Country Studies*, 7(2) : 1-16.

Sevak, K., Patel, N., Bhadhauria, H. and Wankhade V. 2012. Effect of Integrated Nutrient Management on growth and yield of garlic (*Allium sativum* L.). *Advance research journal of crop improvement*, *3*(2): 164-166.

Shafeek M R., Aisha H., Ali Asmaa, Mahmoud R., Magda M., Hafez A. and Fatma. 2015. Improving growth and productivity of garlic plants (*Allium sativum* L.) as affected by the addition of organic manure and humic acid levels in sandy soil conditions, Vegetable Research Department, National Research Center, Cairo, Egypt. http://www.ijcmas.com Accessed on 2 March 2016.

Shaheen, A., Fatma, M. A., Rizk and Singer, S.M. 2007. Growing onion plants without chemical fertilization. *Research Journal of Agriculture and Biological Science,* 3(2): 95-104.

Shege Getu Yayeh, Melkamu Alemayehu, Amare Haileslassie and Yigzaw Dessalegn. 2021. Assessment of small holder farmer's garlic (*Allium sativum* L.) production

practices under irrigated farming system in the Highlands of Ethiopia. *African Journal of agricultural Research*, 17(19) : 1172-1179

Shege Getu Yayeh. 2015. Assessment of Garlic Production Practices and Effects of Different Rates of NPS Fertilizer on Yield and Yield Components of Garlic (*Allium sativum* L) Under Irrigated Farming System in Yilmana Densa District, Amhara Region, Ethiopia. MSc. Thesis submitted to Bahir Dar University, Bahir Dar, Ethiopia.

Shege, G., Melkamu, A., Amare, H. and Yigzaw, D. 2017. Economic and Agronomic optimum rate of NPS fertilizer for irrigated garlic (*Allium sativum* L) Production in high lands of Ethiopia Department of horticulture Debre Markose University. *Burie campus*.

Shibabaw, Agegnehu, Getachew Alemayehu, Enyew Adgo, Folkard Asch and Bernhard Freyer. 2018. Effects of organic manure and crop rotation system on potato (*Solanum tuberosum* L.) tuber yield in the highlands of Awi Zone. *Ethiopian Journal of Science and Technology* 11 (1): 1-18.

Shrestha, J., Chaudhary, A. and Pokhrel, D. 2018. Application of nitrogen fertilizer in maize in Southern Asia a review. *Peruvian Journal of Agronomy*, 2(2): 22-26.

Silva, A.R.D., Cecon, P.R., Dias, C.T.D.S., Puiatti, M., Finger, F.L. and Carneiro, A.P.S. 2014. Morphological phenotypic dispersion of garlic cultivars by cluster analysis and multidimensional scaling. *Scientia Agricola*, 71: 38-43.

Singh NI, Chauhan JS. 2009. Response of French bean (*Phaseolus Vulgaris* L.) to organic manures and inorganic fertilizer on growth and yield parameters under irrigated condition. *Natural Science,* 7(5):1-3.

Sitaula, H. P., Dhakal, R., Bhattarai, C., Aryal, A., & Bhandari, D. 2020. Effects of different combinations of poultry manure and urea on growth, yield and economics of garlic (*Allium sativum* L.). *Journal of Agriculture and Natural Resources*, 3(1): 253–264. https://doi.org/10.3126/janr.v3i1.27179

Surindra S. 2009. Impact of vermicompost and composted farmyard manure on growth and yield of garlic (*Allium sativum* L.)Field crop. *Institutional Journal of Plant Production*. 3(1): 27-28.

Suthar S. and Singh S. 2008. Feasibility of vermicompost in bio stabilization sludge from a distillery industry The Science of Total Environment (393) : 237-243.

Suthar, S. 2009. Impact of vermicompost and composted farmyard manure on growth and yield of garlic (*Allium sativum* L.) Field crop. *Institutional Journal of Plant Production,* 3(1): 27–38.

Tadesse Abadi, 2015. Growth and yield response of garlic (*Allium sativum* L.). Varieties to nitrogen fertilizer rates at Ganta Afeshum, Northern Ethiopia MSc. thesis Haramaya University Ethiopia.

Tadila, G. and Nigusie, D. 2018. Effect of manure and nitrogen rates on growth and yield of garlic (*Allium sativum* L.) at Haramaya, Eastern Ethiopia. *Journal of Horticulture and Forestry*, 10(9) : 135-142.

Tamiru, Fikru, and Fikreyohannes Gedamu. 2019. Response of garlic (*Allium sativum* L.) growth and bulb yield to application of vermicompost and mineral nitrogen fertilizers in Haramaya district, eastern Ethiopia. *East African Journal of Sciences* 13(2): 159-168.

Tegbaru, B. 2016. The role of DSM in transforming agriculture: The case of Ethiopian Soil Information System (EthioSIS). In *7th Global DSM Workshop,* (Vol. 27).

Tekalign Tsegaw, Abdissa, Y. and Pant, L.M., 2012. Growth, bulb yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and phosphorus fertilization on vertisol. II: Bulb quality and storability. *African Journal of Agricultural Research*, 7(45) : 5980-5985.

Tekalign, M., and I. Haque. 1991. Phosphorus status of some Ethiopian soils III. Evaluation of soil test methods for available phosphorus. *Tropical Agriculture, (*68) : 51–6.

Teshale, Mulu, and Negasi Tekeste. 2021. Growth and yield response of garlic (l.) to intra row spacing and variety at selekeleka, Northern Ethiopia. *The Open Biotechnology Journal,* 15 (1).

Tolanur, S.I. and Badanur, V.P. 2003. Effects of integrated use of organic manure, green manure and fertilizer nitrogen on sustaining productivity of rabisorghumchickpea system and fertility of a vertisol. *Indian Journal of Soil Sciences,* 51(1): 41-44.

Tsai, C.W., Chen, H.W., Sheen, L.Y. and Lii, C.K., 2012. Garlic: Health benefits and actions. *BioMedicine*, 2(1):17-29.

Uzma A, Sayed H, Syed Z. 2016. Interactive effect of phosphorus and zinc on the growth, yield and nutrient uptake of garlic (*Allium sativum* L.) variety Gulabi. *Asian Journal Agricultural Food,* 04.

Van Reeuwijk, L. P. 2002. Procedures for soil analysis. 3rd ed. International Soil Reference and Information Centre (ISRIC), Wageningen, The Netherlands.

Vanaclocha B., Cañigueral S., Fitoterapia and Vademécum de prescripción. 2019. 5a *edition* Barcelona: Elsevier 37p.

Verma S., Choudhary M. R., Yadav B. L. and Jakhar M. L. 2012. Effect of vermicompost and sulphur on growth, yield and quality of garlic var, G41. *Journal of Spices and Aromatic Crops,*22 (1): 20–23.

Verma S., Choudhary MR, Yadav BL and Jakhar ML. 2013. Influence of vermicompost and Sulphur on growth and yield of garlic (*Allium sativum* L.) under semiarid climate. Department of Horticulture, S.K.N. College of Agriculture. Rajasthan, India. *Journal of Spices and Aromatic Crops* 22(1):20-23.

Vongdala, N., Tran, H. D., Xuan, T. D., Teschke, R., and Khanh, T. D. 2019. Heavy metal accumulation in water, soil, and plants of municipal solid waste landfill in Vientiane, Laos. *International journal of environmental research and public health*, 16(1): 22.

Walag, A.M.P., Ahmed, O., Jeevanandam, J., Akram, M., Ephraim-Emmanuel, B.C., Egbuna, C., Semwal, P., Iqbal, M., Hassan, S. and Uba, J.O. 2020. Health benefits of organosulfur compounds. *Functional foods and nutraceutical s: bioactive components, formulations and innovations*, pp.445-472

Wang, Y and Lambers H. 2020. Root released organic anions in response to low phosphorus availability: Recent progress, challenges and future perspectives. *Plant Soil*, (447) : 135- 156.

Westerfield Robert. 2015. Reviewed of Garlic Production for the Gardener. The University of Georgia, the U.S.A. www.extension.uga.edu/publications. Accessed on 02 March 2016.

Wondimu T. 2009. The effect of combination of farmyard manure and inorganic nitrogen on onion yield and soil fertility. An MSc Thesis Presented to the school of graduate studies of Mekelle University P 38.

Yadav Durgesh Singh, Bhavna Jaiswal, Meenu Gautam, and Madhoolika Agrawal. 2020. "Soil acidification and its impact on plants." *Plant responses to soil pollution*, (53) : 1-26.

Yadav RN, Bairwa HL and Gurjar MK. 2017. Response of garlic (*Allium sativum* L.) to organic manures and fertilize. *International Journal of Current Microbiology and Applied Sciences* 6(10):4860-486.

Yayeh, Shege Getu, Melkamu Alemayehu, Amare Haileslassie, and Yigzaw Dessalegn. 2017. Economic and agronomic optimum rates of NPS fertilizer for irrigated garlic (*Allium sativum* L) production in the highlands of Ethiopia. *Cogent Food and Agriculture* 3 (1) (2017): 1333666.

Yemane Kahsay, Fasigaw Belay and Alemat Embaye. 2016. Enhancing onion production and productivity through introduction of seed production techniques in central zone of Tigray region, Ethiopia. *Academia Journal of Agricultural Research*.

Yohannes Kokobe, Derbew Belew, and Adugna Debela. 2013. Effect of farmyard manure and nitrogen fertilizer rates on growth, yield and yield components of onion (*Allium cepa* L.) at Jimma, southwest Ethiopia. 228-234.

Youssef, N. 2013. Growth and bulbing of garlic as influenced by low temperature and storage period treatments. *World Rural Observations*, 5(2): 47-57.

Zaman M.S., Hashem M.A., Jahiruddin M., Rahim M.A. 2011. Effect of nitrogen for yield maximization of garlic in old Brahmaputra Flood Plain Soil. *Bangladesh Journal of Agricultural Research,* 36(2): 357-367.

Zeru, Tesfaye, Temesgen Awoke, Teshome Assefa, Biniyam Tesfaye. 2023. Spicy Shiro flour and Berbere powder (an ethnic, indigenous food of Ethiopia). *Journal of Ethnic Foods*, 10(1) : 28.

Zhou, Y., Wang, D., Zhu, J., Liu, Q. and Fan, M.X. 2005. The role of sulfur fertilizers in balanced fertilization. In: L.J. De Kok and E. Schnug (eds.), *Proceedings of the 1st7 Sino-German Workshop on Aspects of Sulphur Nutrition of Plants,* 23 – 27. May 2004 in Shenyang, China Landbauforschung Volkenrode, (283):171-176.

7. APPENDIX

Appendix Table 1. Soil Physiochemical Properties and Characteristics of Vermicompost Before Planting

Parameters	Soil	Vermicompost
	Value	Value
pH (H_2O)	6.2	7.4
OC (%)	0.5	11
TN(%)	0.04	0.91
Av.P(ppm)	8.66	35
Av.S(ppm)	17.83	21.6
Av.B(ppm)	0.084	1.53
CEC(cmol(+) kg^{-1}	22	45
Soil particle size		
Sand (%)	20	
Silt (%)	48	
Clay (%)	32	
Textural class	Silty clay	

Appendix Table 2. Mean squares of ANOVA for Selected Chemical Properties of Soil after Harvest

		Mean Squares						
Source of Variation	D.F	OC	TN	AP	AS	AB	CEC	pH
Replication	2	0.07^{ns}	0.0005^{ns}	0.82^{ns}	1.21^{ns}	0.015^{ns}	0.345^{ns}	0.28^{ns}
NPSB	3	1.05^{**}	0.009^{**}	33.74^{**}	281.6^{**}	0.263^{**}	52.66^{**}	0.54^{*}
VC	3	11.6^{**}	0.019^{**}	20.23^{**}	500.7^{**}	56.03^{**}	89.15^{**}	3.22^{**}
NPSB*VC	9	0.19^{**}	0.0006^{ns}	0.539^{ns}	31.82^{**}	0.048^{**}	21.7^{**}	0.156^{ns}
Error	30	0.0575	0.00045	0.754	2.92	0.0160	1.282	0.174

*Where, OC, organic carbon (%), TN, total nitrogen (%); AP, available phosphorous (ppm); AS, available sulfur (ppm), AB, available boron (ppm),CEC; cation exchange capacity (cmol(+) kg^{-1}); pH (1:2.5 soil to H_2O), potential of hydrogen in water suspension; **highly significant at $P < 0.01$; *significant at $P < 0.05$;*

Appendix Table 3. Mean squares of ANOVA for Phenological and growth parameters of garlic as influenced by NPSB and VC fertilizer

		Mean Square				
Source of Variation	D.F	DE	PH	LEL	NLPP	DM
Replication	2	0.75000^{ns}	14.7484^{ns}	56.394815**	0.91341^{ns}	6.0833^{ns}
NPSB rate	3	0.14^{ns}	550.9524**	519.319**	4.77624**	170.687**
VC rate	3	0.1388^{ns}	1255.2856**	998.868**	55.78851**	239.687**
NPSB*VC	9	0.12037^{ns}	48.932**	38.7557**	1.09657^{ns}	56.85416^{ns}
Error	30	0.26111111	12.446797	5.579892	0.7585924	29.350000

Where, D.F= Degree of freedom, DE= Day to 50% emergency, PH = Plant height, LEL= Leaf length, NLPP= Number of leaf per plant, DM= Day to 75% maturity, NPSB= Nitrogen, Phosphorous, Sulfur and Boron respectively, VC= Vermicompost, ns,,** indicates non significant, significant and highly significant differences at 5% and 1% probability level respectively.*

Appendix Table 4. Mean squares of ANOVA for average fresh biomass yield, mean clove weight, clove number per bulb and biological dry yield of garlic as influenced by NPSB and VC

		Mean Square			
Source of Variation	D.F	AFBY	MBW	NC	BDY
Replication	2	6.725*	7.527727^{ns}	1.074^{ns}	2713.02**
NPSB rate	3	824.584**	422.5970**	167.763**	69650.52**
VC rate	3	542.600764**	312.94**	177.527**	34921.35**
NPSB*VC	9	47.100949**	32.293587**	26.5586058**	1285.71**
Error	30	222.3	2.577049	1.919193	249.1319

Where, AFBY = Average fresh biomass yield, MBW= Mean clove weight, NC= Number of clove per bulb and BDY= Biological dry yield, ns,, ** indicates non significant, significant and highly significant differences at 5% and 1% probability level respectively.*

Appendix Table 5. Mean squares of ANOVA for harvest index(%), marketable bulb yield (t ha^{-1}), unmarketable bulb yield and total bulb yield of garlic as influenced by NPSB and VC.

		Mean squares			
Source of Variation	D.F	HI	MBY	UMBY	TBY
Replication	2	8.98^{ns}	2.73812**	0.00328^{ns}	2.82703**
NPSB	3	442.07***	66.05187**	0.266918**	58.72130**
VC	3	346.5***	25.41243**	0.263596**	21.35348**
NPSB*VC	9	45.43**	3.05965**	0.040126**	2.74575**
Error	30	387.6	0.1719028	0.00832792	0.2351446

Where, HI= Harvest index, MBY= Marketable bulb yield (t ha^{-1}), UMBY= Unmarketable bulb yield and TBY= Total bulb yield, ns,,** indicates non- significant, significant and highly significant differences at 5% and 1% probability level respectively.*

Appendix Table 6. Interpretive values or Ratings for Selected Soil Properties

Ratings								
Soil Parameters	Very low	Low	Medium	High	Very high			Sources
Soil OC (%)	< 0.5	0.5-1.5	1.5-3.0	> 3.0	_			Tekalign (1991)
Total N (%)	< 0.05	0.05-0.12	0.12-0.25	> 0.25	_			Tekalign (1991)
Available P (mg kg^{-1})	< 5	5-9	10-17	18-25	> 25			Cottenie (1980)
CEC (cmol(+) kg^{-1})	< 5	5-15	15-25	25-40	> 40			Landon (1991)
Available B (ppm)	< 0.2	0.3–1.0	1.1–2.0	2.1–4.0	> 4.1			Jones (2003)
Available S (mg kg^{-1})	0.1-0.6	0.7-2	2.1-5	5.1-250	> 250			Jones (2003)
Ratings of soil pH (H_2O)								
Ratings	VSA	SA	MA	SlA	N	MAlk	SAlk	Tekalign (1991)
pH (1:2.5 H2O	<4.5	4.5-5.2	5.3-5.9	6.0-6.6	6.7-7.3	7.4-8.0	>8.0	

Where, VSA= Very strongly acid, SA= Strongly acid, MA= Moderately acid, SA= Slightly acid, MA= Moderately alkaline, SAlk= Strongly alkaline.

Appendix Table 7. Ten years of monthly temperature and rainfall of the area Emdibir sub-station meteorological data

2013-2022 Meteorological data (10 years)				Meteorological data of 2022			
	RF (mm)	Temperature (o c)		Month	RF (mm)	Max.Temp	Min.Temp
		Minimum	Maximum				
2013	1330.2	10.2	22.5	Jan	23.1	26.0	8.5
2014	997.6	10.3	22.8	Feb	16.1	27.0	10.4
2015	1321.1	11.7	22.6	Mar	119.4	26.2	12.6
2016	1298.6	10.35	22.51	Apr	200.2	26.0	12.3
2017	1141.3	10.6	23.1	May	134.2	24.7	12.7
2018	1264.3	10.4	22.7	Jun	191.0	23.0	12.9
2019	1367.2	10.7	22.6	Jul	372.4	21.0	13.1
2020	1480.8	11.4	22.4	Aug	260.9	21.3	13.2
2021	1515.3	10.4	22.5	Sep	163.2	22.3	12.0
2022	1595.5	12.9	22.2	Oct	64.9	24.4	9.0
				Nov	24.9	25.3	7.7
				Dec	25.2	25.5	6.2

Source: Ethiopian Meteorological Agency, Emdibir Sub Station

Some pictures during field and laboratory works



Appendix Figure 1. Preparation of experimental field layout



Appendix Figure 2. Planting garlic seed



Appendix Figure 3. Vegetative growth performance of garlic











Appendix Figure 4. Different yield data measuring