INTEGRATED EFFECTS OF VERMICOMPOST AND NPS FERTILIZER ON SELECTED SOIL PHYSICOCHEMICAL PROPERTIES AND YIELD AND YIELD COMPONENTS OF ONION CROPS IN MESKAN WOREDA, EAST GURAGE ZONE, CENTRAL ETHIOPIA.

MSc. THESIS

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APRIL, 2025

WOLKITE UNIVERSITY, ETHIOPIA

Integrated Effects of Vermicompost and NPS Fertilizer on Selected Soil Physicochemical Properties and Yield and Yield Components of Onion in Meskan Woreda, Gurage Zone, Ethiopia

A Thesis Submitted to the Department of Natural Resource College of Agriculture and Natural Resource, School of Graduate Studies, Wolkite University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Agriculture (Specialization: Soil Science)

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APRIL, 2025

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WOLKITE UNIVERSITY
SCHOOL OF GRADUATE STUDIES
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As thesis research advisors, we hereby certify that we have read and evaluated the Thesis entitled. ‘’**INTEGRATED EFFECTS OF VERMICOMPOST AND NPS FERTILIZER ON SELECTED SOIL PHYSICOCHEMICAL PROPERTIES AND YIELD AND YIELD COMPONENTS OF ONION IN MESKAN WOREDA, EAST GURAGE ZONE, CENTRAL ETHIOPIA’’** prepared under our guidance by Mekonen Asefa Argaw**.** We recommend that it be submitted as fulfilling the thesis requirement of Natural Resource Management Department for defense.

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As members of the Board of Examiners of the MSc Thesis Open Defense Examination, we certify that we have read and evaluated the Thesis prepared by Mekonen Asefa and examined the candidate. We recommended that the Thesis be accepted as fulfilling the requirement for the degree of Master of Science in Soil Science.

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DEDICATION

This thesis work is dedicated to my wife Wosenyelesh Asres and my son Eyob Mekonen for their fondness and consistent care in the success of my existence.

DECLARATION

I earnestly declare that this thesis is my own work. I have followed all ethical and technical principles of scholarships in the preparation, data collection, data analysis and compilation of the thesis. And that all sources of material used this thesis have been duly acknowledged and any scholarly matter that is included in the thesis has been given recognition through citation.

This thesis has been submitted in partial fulfillments of the requirements for MSc. degree in Wolkite University and deposited at a university library to be available to borrowers under the rules of the library. I solemnly declare that this thesis is not submitted to any other learning institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHYICAL SKETCH

The author, Mekonen Asefa was born on 07 august 1985, in Butajira central Ethiopia regional state; He attended his elementary education at Butajira Primary School: secondary education at Butajira secondary school between 1993 and 2002.

After he successfully passed Ethiopian school leaving certificate examination (eslce), he joined Agarfa ATEVT Collage in 2003 and graduated with a diploma in natural resource management in 2005. Following graduation, he worked as a soil and water conservation specialist for the East Gurage Zone's Sodo and Meskan woreda agricultural office since October 2014. He also continued his education at Dilla University, where he earned a bachelor's degree in natural resource management in 2017. He also held positions as the head of the Meskan woreda youth and sport office until 2019, the sector head of the public service office until 2020, and the soil and water conservation expert for the Meskan woreda agricultural office until 2022.

The author joined Wolkite University to pursue his MSc, degree in soil science under the department of natural resource in 2023 academic years.

ACKNOWLEDGEMENTS

I would like to sincerely thank my major advisor, Abdeta Jembere (Assist.Prof.), whose ongoing and invaluable advice, motivation, and support during my study period, as well as his critical review and manuscript comments, made this study a success. Many of his insightful recommendations on conducting research and looking up scholarly articles have been really helpful to me. My major advisor, Abdeta Jembere (Assist. Prof.), in particular, shared his extensive professional knowledge with me and was helpful from the start of the proposal writing process until the end of the thesis write-up.

I am also greatly indebted to my co-advisor Solomon Kibebew (PhD), who joined me recently, for his kind treatment and unwavering support in helping me complete the study and produce this thesis in its current form.

I would also like to acknowledge the College of Agriculture and Natural Resource department for facilitating and providing me all material support to carry out the experiment. The author is also thankful to the following colleagues Shibikom Desalegn, Jemaludin Saliha, Nesru Jemal and all laboratory assistance of Wolkite University who gave me friendly advice and technical support during my research work.

I glorify my Lord for giving me both health and strength. Last, but not least, I want to express my gratitude and deepest appreciation to all my families especially my lovely wife Wosenyelesh Asres and my son Eyob Mekonen for their consistent encouragement and moral support throughout the thesis work and all- rounded support.

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LIST OF ACRONYMS AND ABBREVIATIONS

ATA	Agricultural transformation agency
av.P	Available phosphorous
av.K	Available potassium
av. S	Available sulfur
BD	Bulb density
Bd	Bulb diameter
BL	Bulb length
CEC	Cation exchange capacity
CIMMYT	Center of international maize and wheat improvement
CSA	Central statistical agency
CV	Coefficient of variation
EIAR	Ethiopian institute of agricultural research
ex.Base	Exchangeable base
ex.Ca	Exchangeable calcium
ex.Mg	Exchangeable magnesium
ex.K	Exchangeable potassium
ex.Na	Exchangeable sodium
FAO	Food and Agricultural organization
FYM	Farmyard manure
GFB	Gross field benefit
INM	Integrated nutrient management
IPCC	Intergovernmental panel on climate change
LSD	Least significant difference
MBY	Marketable bulb yield
MOARD	Ministry of agriculture and rural development
MRR	Marginal rate of return
NB	NET benefit
NPS	Nitrogen, Phosphorous and Sulfur
OC	Organic carbon
OM	Organic matter
Ph	Power of hydrogen
RCBD	Randomized complete block design
SAS	Statistical analysis software
SOM	Soil organic matter
TN	Total nitrogen
TVC	Total variable cost
UMBY	Un marketable bulb yield
USDA	United states of development agent
VC	Vermicompost

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ABSTRACT

The reduction in soil fertility caused by nutrient depletion poses a significant challenge for low-input crop production across many regions of Ethiopia. Onion (Allium cepa L.) exhibits a notable response to the application of NPS and vermicompost (VC) fertilizers. However, the optimal dosage of these fertilizers has yet to be determined in the study area. Additionally, there is limited understanding of their impact on soil properties and onion yield, primarily due to the low usage rates of both organic and mineral fertilizers by local farmers. Consequently, this study aims to examine the effects of combining vermicompost with NPS fertilizer on the physicochemical properties of the soil, as well as the yield and yield components of onion (Allium cepa L.). The research was conducted in the Dobbi Kebele of the East Gurage Zone, under irrigated conditions. The experimental design included factorial combinations of five NPS rates (0, 100, 200, 300, and 400 kg NPS ha^{-1}) and three vermicompost rates (0, 2.5, and 5 tons ha^{-1}), arranged in a randomized complete block design (RCBD) with three replications. Soil samples were analyzed for texture, bulk density, pH, total nitrogen, available phosphorus, sulfur, organic carbon, cation exchange capacity, organic matter, and exchangeable bases (calcium, magnesium, potassium, and sodium). The yield and its components were also assessed. The results from the soil analysis conducted from before and after crop harvest indicated that the application of vermicompost significantly ($p<0.05$) increased available magnesium (from 7.51 to 14.76), organic matter (from 1.5 to 6.16), while bulk density decreased (from 1.6 to 1.38) as the rate of vermicompost application increased. Furthermore, the interaction between NPS and vermicompost enhanced organic carbon (from 1.12 to 3.57), total nitrogen (from 0.15 to 0.25), available phosphorus (from 4.86 to 10.77), available sulfur (from 35.99 to 52.94),cation exchange capacity (from 37.98 to 78.68), and exchangeable potassium (from 0.55 to 1.64). These analyses were performed using SAS software version 9.4, employing analysis of variance. The study demonstrated that the application rates of NPS and VC, along with their interaction, had an impact on various phonological and yield parameters of onion crops. Specifically, factors such as neck thickness of the bulb (cm), the interaction of NPS and VC on days to maturity, and bulb length (cm) were favored, while the effect of NPS fertilizer on bulb length was found to be non-significant. Both fertilizers and their interaction influenced all selected physical and chemical properties of the soil following the harvest of onion crops. Notably, the highest marketable bulb yield (32.78 ton ha^{-1}) and total bulb yield (33.33 ton ha^{-1}) were recorded from the combination of 400 kg NPS ha^{-1} with 5 ton VC ha^{-1}. The largest bulb diameter (7 cm) and the highest average bulb weight (120 g) were also achieved with this interaction. The application of 100-400 kg NPS ha^{-1} combined with 2.5-5 ton of VC ha^{-1} resulted increases in organic carbon, total nitrogen, available potassium, available phosphorus, and cation exchange capacity compared to the control treatment. Consequently, it is concluded and recommended that the application of 5 ton VC ha^{-1} in conjunction with 400 kg of NPS ha^{-1}enhances soil physicochemical properties and onion crop yields in Meskan Woreda, East Gurage Zone. The highest marginal rate of return (MRR%) of 10855% was observed for plots receiving 100 kg NPS ha^{-1}with 2.5 ton VC Ha^{-1}, while the highest adjusted marketable bulb yield of 32.78 ton ha^{-1}, along with the greatest net benefit and benefit-to-cost ratio of 1,204,612 Birr ha^{-1} and 108.55 Birr ha^{-1}, respectively, were recorded for plots treated with 400 kg NPS ha^{-1} combined with 5 ton of vermicompost for the production of Bombay red onions in Meskan Woreda.

Key-word: vermicompost, NPS fertilizer, soil property and onion

1. INTRODUCTION

1.1 Background of the study

Nutrient depletion in Ethiopia has been exacerbated by poor soil fertility management and shifts in land use, particularly the transition from natural vegetation to agricultural land. This has led to a decline in the physical, chemical, and biological properties of the soil due to intensive and ongoing farming practices that lack effective soil fertility management. Consequently, these alterations in soil characteristics have contributed to the country's diminishing agricultural productivity and increasing food shortages. According to Habtamu (2018), the primary factors contributing to the decline in soil fertility in the nation include insufficient or absent nutrient inputs, challenges in managing crop residues, continuous cultivation practices, nutrient loss through erosion, and the absence of crop rotation strategies.

Also low soil fertility and nutrient scarcity, often resulting from a decline in soil organic matter and insufficient fertilizer application, pose significant challenges to vegetable production (Vanlauwe et al., 2010). While organic farming and chemical fertilizers are potential solutions to these issues, challenges persist with chemical fertilizers, including limited availability or supply at critical times and the high costs associated with applying the recommended amounts (Zamir et al., 2013).

Moreover, the ongoing use of chemical fertilizers poses a significant risk of environmental pollution. Conversely, the exclusive use of organic matter is limited by the availability of adequate organic inputs, low nutrient levels, and the high labor requirements for preparation and transportation (Zeinab et al., 2014). In addition to environmental issues, the increasing expense of chemical fertilizers, along with their limited accessibility for smallholder farmers, has sparked significant interest among both the scientific and agricultural communities to transition from reliance solely on chemical agriculture to an integrated nutrient management approach. This strategy incorporates both organic and inorganic nutrient sources (Singh et al. 2010).

Tesfaye (2021) emphasized that relying solely on either inorganic or organic fertilizers will not achieve sustainable productivity. Current development strategies in vegetable production focus on enhancing the productivity of cultivated land, lowering production costs, and improving input use efficiency, all while safeguarding soil, groundwater, the environment, and product quality (Singh et al. 2010). It is clear that chemical fertilizers are essential for fulfilling crop nutrient requirements and boosting production levels.

Nevertheless, the improper application of fertilizers is leading to significant economic and ecological challenges, particularly in developing nations (Sutton et al. 2011; Sun et al. 2012). Key issues arising from the excessive and indiscriminate use of synthetic fertilizers include widespread nutrient deficiencies in soils, altered soil pH, nutrient imbalances in plants, increased plant vulnerability to diseases, diminished soil organic matter, reduced populations of beneficial soil microorganisms, and heightened environmental pollution along with risks to human health (Das et al. 2015).

Consequently, the combined application of organic and inorganic nutrient sources has gained considerable importance in recent years (Prativa and Bhattarai 2011). In intensive farming systems, where nutrient turnover is significantly high, relying solely on either chemical fertilizers or organic and biological sources cannot ensure sustainable production (Javaria and Khan 2011). The synergistic application of vermicompost alongside chemical fertilizers contributes to maintaining yield stability by addressing minor deficiencies in auxiliary and micronutrients, enhancing the efficacy of related supplements, and fostering beneficial soil physical conditions (Gill and Walia, 2014).

The incorporation of organic nutrient sources enhances the physical properties and biological vitality of the soil, thereby increasing the accessibility of both applied and naturally occurring nutrients (Dick and Gregorich, 2004). A combination of chemical fertilizers and composted organic materials may prove to be a more effective, cost-efficient, and sustainable approach for agriculture and the environment (Koushal et al., 2011; Reddy and Reddy, 2011). The exclusive use of organic sources is insufficient to provide and synchronize the necessary nutrient supply for growing plants, due to the limited availability of mineral nutrients and the time required for their mineralization to make them accessible for plant uptake (Akhtar et al. 2011).The fertility and productivity of soils play a vital role in ensuring food security for the increasing global population (Johnston AE and Milford GFJ, 2012). To sustain soil productivity and manage nutrient depletion from agricultural lands, it is essential to enhance soil fertility through the application of fertilizers and effective management practices.

vermicompost is abundant in essential plant nutrients, significantly enhancing overall plant growth, promoting the development of new shoots and leaves, and improving the quality and shelf life of produce. Additionally, it helps neutralize soil conditions, mitigates heavy metal toxicity, prevents nutrient loss, and increases the efficiency of chemical fertilizers. The decline in soil respiration rates and the complete disappearance of natural decomposer communities from agroecosystems further jeopardize land sustainability and global food security (Suthar, 2009).

Onions (Allium cepa L.) can thrive in a variety of climatic conditions; however, optimal growth occurs in temperate climates that avoid extreme temperatures and excessive rainfall (Lemma, 2004). This crop is cultivated in over 130 countries globally, with China and India leading as the top producers, followed by the USA, Netherlands, Egypt, and Iran (FAOSTAT, 2014). Onion crop is unique due to its shallow, unbranched root system, making it particularly sensitive to nutrient availability and responsive to fertilizer applications.

This characteristic makes them less efficient at extracting nutrients, especially immobile nutrients like phosphorus and potassium; hence they require and often respond well to addition of fertilizers (Rizk et al., 2012). Fertilizers help to overcome the limitations of their root system and improve nutrient uptake, leading to increased yields and improved bulb quality. This characteristic necessitates higher fertilizer inputs to meet the plant's nutritional needs and enhances yield, storage quality, and shelf life.

The Central Statistical Agency (CSA, 2014) reports that the average annual onion production in Ethiopia is approximately 230,745.2 tons, cultivated across 24,375.7 hectares, with around 705,877 households engaged in its production. The future of onion cultivation appears promising due to the expansion of irrigable land (MoARD, 2005). In Ethiopia, the annual per capita vegetable consumption is 5.8 kg, with onions accounting for 1.7 kg of that total.

1.2 Statement of Problem

Nutrient depletion in Ethiopia has been exacerbated by inadequate soil fertility management and shifts in land use, particularly the transition from natural vegetation to agricultural land. This has led to a decline in the physical, chemical, and biological properties of the soil due to intensive and continuous farming practices that lack proper fertility management. From this viewpoint, the primary factors contributing to the deterioration of soil fertility in Ethiopia include insufficient or absent nutrient inputs, challenges in managing crop residues, ongoing cultivation practices, nutrient loss through erosion, and the absence of crop rotation strategies. Low soil fertility, nutrient unavailability due to acidity, and excessive agricultural input requirements are significant barriers to crop development in Ethiopia (Habtamu, 2018).

Aluminum, due to its high exchangeable content, impedes phosphorus uptake by binding it (Negese Wegene, 2019). The application of organic fertilizers can enhance soil aeration, mitigate acidity, foster increased microbial activity, boost soil organic matter, improve cation exchange capacity (CEC), and enhance phosphorus availability, ultimately leading to significant increases in crop yields. The recent combination of organic and mineral fertilizers has proven to be more effective in sustaining soil productivity (Diacono M, Montemurro F, 2015).

Organic fertilizers enhance the physical, chemical, and biological functions of soil; however, their lower nutrient concentration necessitates larger quantities for effective use. In contrast, inorganic fertilizers provide all essential nutrients for plant growth. Nevertheless, the exclusive reliance on inorganic fertilizers leads to environmental issues such as soil degradation, increased acidity, and pollution (Bhatt MK, Labanya R, Joshi HC, 2019).

To address these challenges, an integrated nutrient management system that combines both inorganic and organic materials presents a viable strategy for sustainably and economically managing soil fertility. This approach not only improves soil fertility and productivity but also protects the environment. This method is recognized as one of the most effective practices for managing plant nutrients, maximizing the social, economic, and environmental advantages of crop production (Lim SL, 2015).

Organic inputs are frequently recommended as alternatives or in conjunction with mineral fertilizers. As a result, it is advisable for farmers to adopt a combination of organic and inorganic inputs (Alemu et al., 2016). However, the current indiscriminate use of fertilizers poses significant economic and ecological challenges, particularly in developing nations, making it increasingly difficult to manage these issues (Sutton et al., 2011; Sun et al., 2012).

The prevalent deficiency of nutrients in soils can disrupt soil pH, lead to nutrient imbalances in plants, heighten their vulnerability to diseases, diminish soil organic matter, reduce the presence of beneficial soil microorganisms, and contribute to environmental pollution and health risks for humans. These issues are primarily linked to the indiscriminate and excessive use of synthetic fertilizers (Mengistu et al., 2017). Continuous reliance on inorganic fertilizers without the addition of organic manure has frequently resulted in deficiencies of micronutrients, imbalances in soil physical and chemical properties, and unsustainable agricultural yields (Yohannes et al., 2017).

Moreover, the effectiveness of nitrogen fertilizers is often associated mainly with phosphorus (P) and potassium (K) (Nawaz et al., 2017; Rizk et al., 2012). However, there is an increasing interest among farmers in utilizing sulfur (S) fertilizers for onion cultivation. This interest is driven by two primary factors: the enhancement of yield and, more significantly, the anticipated effects of sulfur fertilizers on bulb pungency and the production of bioactive compounds (De Souza, 2015). The health benefits of onions are well-recognized, particularly in their role in protecting against cancer, hypertension, diabetes, and infections (Ben-Noun, 2018; Ren et al., 2016).

Onions are more susceptible to nutrient deficiencies than many other vegetables due to their shallow and unbranched root systems, which makes them highly responsive to fertilizer applications. Nitrogen (N), potassium (K), phosphorus (P), and sulfur (S) are classified as primary macronutrients because plants absorb them in larger quantities from the soil compared to other essential nutrients. While many smallholder farmers in Ethiopia recognize the importance of fertilizers, they often struggle to apply them at the recommended rates and times due to high costs, lack of credit, delivery delays, and inconsistent returns (Garg et al., 2006).

1.3 Objectives

1.3.1 General objectives

The objective of the study was aimed to examine the combined impact of vermicompost and NPS (nitrogen, phosphorus, and sulfur) fertilizer on specific physicochemical properties of the soil, as well as on the yield and yield components of onions in the study area.

1.3.2 Specific Objectives

- To investigate the impact of vermicompost and NPS (Nitrogen, Phosphorus pent oxide, and Sulfur) fertilizer on selected physicochemical characteristics of the soil.
- To assess the influence of vermicompost and NPS (Nitrogen, Phosphorus pent oxide, and Sulfur) fertilizer on the yield of onion crops.

1.3.3 Research Questions

- What impact does vermicompost have on specific physicochemical properties of soil and the yield of onions?
- Is there a synergistic effect of combining vermicompost with NPS fertilizer on the physicochemical properties of soil and onion yield?

1.3.4 Significance of the study

The research aims to establish foundational data regarding the impact of vermicompost and NPS fertilizer on the physicochemical properties of soil, as well as on the yield and yield components of onion crops. Therefore, it is essential to recognize the significant benefits of combining organic and inorganic nutrient sources. Beyond merely providing nutrients, organic materials enhance the physical structure and biological vitality of the soil, thereby increasing the availability of both applied and naturally occurring nutrients. The combination of chemical fertilizers with composted organic matter can prove to be more effective, cost-efficient, and sustainable for agriculture and the environment (Reddy, 2011; Koushal et al., 2011).

Onion (Allium cepa L.) is a significant bulbous crop that belongs to the Alliaceae family. Both the green leaves and the immature and mature bulbs are consumed raw or utilized in various vegetable dishes. Additionally, onions are integral to the preparation of soups, sauces, and pickles and they serve as a flavor enhancer in numerous recipes. Often referred to as the "Queen of the Kitchen," onions are esteemed for their distinctive flavor, aroma, and taste, as well as the medicinal benefits associated with their flavor compounds (Griffiths et al., 2002). They are a good source of protein, calcium, phosphorus, and carbohydrates (Bhattacharjee et al., 2013). The characteristic pungency of onions is attributed to the volatile oil allyl propyl disulfide, an organic compound that is high in sulfur.

2. LITRATURE REVIEW

2.1 Concept and Definition

2.1.1 Soil Fertility Status in Ethiopia

Soil erosion poses a global threat, negatively impacting the productivity of natural ecosystems as well as agricultural, forestry, and rangeland systems (Perkins et al., 2013; Lemenih, 2014; Van Leeuwen et al., 2015). Consequently, the significant changes in soil quality due to accelerated erosion have led to reduced agricultural output and land abandonment.

In tropical and subtropical regions, food production heavily depends on the availability of soil nutrients and overall soil fertility. This reliance makes soil fertility a critical factor for farmers in Sub-Saharan Africa, particularly in Ethiopia, where agriculture is fundamental to the nation's economy (Sheldrick et al., 2003). Unfortunately, soil fertility is experiencing a decline, driven by rapid population growth, shifts in agricultural practices, lack of crop rotation, and inadequate soil conservation and land management strategies.

Alterations in agricultural practices also affect the chemical, physical, and biological characteristics of the soil, significantly contributing to soil degradation, primarily through the decline in soil fertility caused by insufficient nutrient inputs (Getachew et al., 2014). It is evident that soil fertility diminishes when the nutrients extracted from the soil through harvests exceed the nutrients returned to the system from both natural and human sources (Gruhn et al., 2000). This situation is particularly prevalent in areas with low natural soil fertility, limited replenishment of extracted nutrients, and high erosion rates, especially in mountainous regions, posing a serious threat to both current and future food production (Gachimbi et al., 2005; Harris and Consulting, 2014).

Soil fertility depletion represents a significant environmental issue impacting agricultural output and the livelihoods of farmers in Ethiopia. According to Belete et al. (2018), approximately 106,000 km^2, or 9.6% of the nation's total area, is incapable of supporting crop yields. The potential for soil productivity in Ethiopia has come under scrutiny due to the decline in soil organic matter, which is attributed to low productivity levels, excessive tillage practices, and competing demands for biomass (Hurni et al., 2010).

2.2 The Requirements of Organic Fertilizer

2.2.1 Vermicompost

According to Suthar (2007) and Nogales et al. (2005), vermicomposting is a biotechnological technique for composting a range of organic waste. Bhat et al. (2018) and Chattopadhyay (2012) claim that vermicompost is a very advantageous byproduct of trash that is improved by specific earth worm species. Vermicomposting is a process that combines bio-oxidative methods with the stabilization of organic materials, similar to traditional composting.

However, it uniquely involves the interactions between earthworms and microorganisms. Microorganisms play a crucial role by producing enzymes that facilitate the biochemical breakdown of organic matter, while earthworms enhance the microbial population by fragmenting and consuming fresh organic materials. Additionally, earthworms interact with various soil organisms, influencing different microflora and microfauna communities (Lores et al., 2006).

The end product of this process is a finely textured, peat-like material characterized by a low carbon-to-nitrogen ratio, high porosity, excellent aeration, effective drainage, substantial water retention, and active microbial life. This material results from the non-thermophilic biodegradation of organic substances through the collaborative efforts of earthworms and their associated microbes (Edwards and Burrows, 1988; 2000b; Arancon et al., 2004).

Earthworms function as mechanical mixers, breaking down organic substrates and modifying their physical and chemical properties, which increases the surface area available for microbial decomposition (Dominguez, 2004). According to Chaou et al. (2013), vermicompost enhances soil microbial activity, maintains optimal soil temperatures, and improves both the physical and chemical conditions of the soil. This is achieved by ensuring a balanced composition of soil particles, which contributes to better porosity and water infiltration, ultimately enhancing nutrient content and promoting plant growth.

The gut of earthworms is crucial for the processing of soil and organic materials (Drake and Horn, 2007). The activities of endosymbiotic microorganisms and the enzymes present in the earthworm's gut, such as cellulase, protease, chitinase, and phosphatase, facilitate the conversion of ingested soil and organic matter into valuable products that provide essential nutrients and contribute to the microbial biomass (Zhang et al., 2000). The most significant species in this context include Eisenia fetida, Eisenia andrei, Dendrobaena veneta, Lumbricus rubellus, Perionyx excavatus, and Eudrilus eugeniae.

Eisenia fetida is the most favored species of worm, primarily due to its superior reproductive capacity. This species consumes organic matter more rapidly than other worm varieties, facilitating quicker production of fertilizer. Its adaptability also surpasses that of other species. The vermicompost produced by Eisenia fetida contains a higher concentration of organic matter (Dominguez & Edwards, 2011).

The temperature of the production environment plays a crucial role in the worms' vital functions. This is largely because they possess an open circulatory system, which causes their body temperature to fluctuate with the surrounding environment. While they can survive at temperatures around 7-8 °C, their activity is significantly restricted, and exposure to temperatures below 0 °C can lead to mortality.

Although optimal temperatures can vary among species, it is generally recommended that the ambient temperature remain between 15-25 °C to ensure maximum vitality (Rostami et al., 2009a). Certain specialized worm species are fed organic waste from both animal and plant sources, and the process of transforming this organic material into a valuable fertilizer through their digestive systems is known as "vermicomposting." The final product is referred to as "bio humus" or "vermicompost" (Karaçal and Tüfenkçi, 2010). Chemically, vermicompost offers more beneficial effects compared to compost produced through thermophilic methods and the use of synthetic fertilizers (Kiyasudeen et al., 2015).

The chemical makeup of vermicompost products can differ significantly. This variation is influenced by several factors, including the type of substrate material utilized (such as waste from various animals, urban refuse, and plant debris), the breakdown process affected by environmental temperature, moisture levels during production, and the species of worm employed. Livestock manure is the most commonly used animal waste in vermicompost production. Research indicates that the pH levels of samples from various vermicompost materials range from 5.8 to 8.65 (Barlas et al., 2018; Jouquet et al., 2011; Mehrizi et al., 2015; Jabeen & Ahmad, 2016; Göçmez, 2013).

2.2.1.1 The Role of Vermicompost on Soil Microbial Activity

Vermicompost plays a vital role in enhancing soil microbial activities, which is crucial for nutrient cycling, plant growth and soil health. Vermicomposting is a worm-mediated biodegradation process using live epigeic worms such as Eisenia fetida. Worms play an important role in the process of nutrient dissolution and bioremediation by enhancing the population of beneficial bacteria (Goswami, L.; Gorai, P.S.; Mandal, N.C. 2021). The digestive system of worms contains many beneficial microorganisms, nitrogen-fixing bacteria, and enzymes (Wang, F.; Zhang, W.; Miao, L.; Ji, T.; Wang, Y.; Zhang, H.; Ding, Y.; Zhu, W. 2021). Although microorganisms are actually responsible for the biochemical degradation of organic matter, worms decompose and condition the substrate, increasing the surface area for microorganism activity (Aira, M.; Domínguez, J. 2009).

Worms mineralize organic matter through intestinal transit, digest it in the foregut and midgut, and then excrete it through the hindgut, interacting directly with microorganisms (Dume, B.; Hanc, A.; Svehla, P.; Michal, P.; Chane, A.D.; Nigussie, A. 2022). A diversified bacterial community in the gut accelerates the breakdown and mineralization of organic matter and even the accumulation of P and K (Yürürdurmaz, C. 2022). Microorganisms involved in the vermicomposting process degrade complex organic compounds (e.g., lignin, cellulose, hemicellulose) into simpler forms and produce a variety of extracellular hydrolytic enzymes such as cellulase, protease, urease, phosphatase, lipase, and β-glucosidase (da Silva, L.F *et al.*;2023). which are responsible for the transformation of nutrients, such as this enzyme helps in organic matter decomposition,nutrient mineralization (N,P,K release) and detoxification of pollutants.

2.3 Nutrient Composition of vermicompost

Vermicomposting is a mesophilic process that occurs more rapidly than traditional composting, as organic material is processed through the digestive system of earthworms. This process leads to significant transformations, resulting in earthworm castings, also known as worm manure, which are abundant in microbial activity. These castings are characterized by their excellent nutrient retention, the presence of plant growth regulators, and other substances produced by microorganisms, such as humates. Additionally, they possess properties that repel pests and root knot nematodes (Nagavallemma et al., 2004; Asha Aalok et al., 2008; Grappelli et al., 1987; Shiwei and Fu-Zhen, 1991; Arancon et al., 2005b, 2006, 2003; Atiyeh et al., 2002).

Research indicates that worm castings can contain up to five times the amount of plant-available nutrients compared to standard potting soil mixes. A chemical analysis conducted by Ferreras et al. (2006) revealed that these castings have five times the available nitrogen, seven times the available potash, and 1.5 times more calcium than what is typically found in 15 cm of quality topsoil. Furthermore, the nutrient longevity in worm castings is up to six times greater than that of other potting mixes.

Research indicates that phosphorus is transformed into a form accessible to plants as it passes through the digestive system of worms (Ferreras et al., 2006). Phosphorus is often regarded as a critical limiting factor for plant growth. Consequently, any method that significantly enhances phosphorus availability through plants and organic matter is vital for agricultural practices. Most commercially available potting soil mixes tend to be sterile and lack a microbial population. The presence of both nutrients and microbial organisms is crucial for cultivating healthy and productive plants. Vermicompost not only introduces beneficial microbial organisms and nutrients with enduring effects but also improves the structure of existing soil and enhances its water retention capacity.

2.4 Effects of vermicompost on soil physicochemical properties

It was noted that the application of vermicompost at a rate of 20 tons per hectare to agricultural soil over two consecutive years led to a significant enhancement in soil porosity and aggregate stability (Ferreras, L., Gomez, E., et al., 2006). Furthermore, a notable increase in the number of large, elongated soil macropores was observed following a single application of vermicompost, which provided a nitrogen equivalent of 200 kg per hectare to a cornfield (Marinari et al., 2000).

Vermicompost also appears to have considerable impacts on the physical characteristics of soil. In a similar vein, significant reductions in soil bulk density, along with notable increases in soil pH and total organic carbon, were recorded after the application of vermicompost at a rate equivalent to 60 kg per hectare of nitrogen over two consecutive growing seasons. These alterations in soil properties enhance the availability of air and water, thereby promoting seedling emergence and root development (Gopinath et al., 2008). The composition of vermicompost typically includes 1.5% to 2.2% nitrogen, 1.8% to 2.2% phosphorus, and 1.0% to 1.5% potassium, with organic carbon levels ranging from 9.15 to 17.98, in addition to various micronutrients.

The prolonged application of inorganic fertilizers without the incorporation of organic amendments leads to environmental degradation and adversely affects the physicochemical properties of soil. In contrast, organic fertilizers not only provide essential organic matter and nutrients but also enhance microbial activity, increase biodiversity, and expand the microbial population within the soil. They influence soil structure, nutrient cycling, and various other physicochemical characteristics (Albiach et al., 2000). Insufficient levels of organic matter can result in diminished soil fertility and productivity. Organic matter plays a crucial role in crop growth and yield, both by directly supplying nutrients and by indirectly improving soil physical properties such as aggregate stability and porosity. The use of organic amendments is a widely accepted practice for enhancing soil fertility (Graham, Haynes, and Meyer 2002).

Recently, vermicompost has gained attention as a means to boost soil organic matter content and, consequently, soil fertility. This natural eco-manure is produced through the breakdown of organic matter facilitated by the interaction of microorganisms and earthworms (Hu et al., 2004). It contains readily available nutrients for plants, including magnesium, calcium, phosphorus, potassium, and nitrate. Vermicompost has the potential to improve soil productivity in continuous cropping systems (Zhang, Xu, and Liu 2010). It can be utilized as a soil amendment to enhance soil fertility by increasing nutrient levels, cation exchange capacity, and organic matter content, thereby improving soil structure (Srivastava et al., 2011).

The depletion of soil organic matter significantly contributes to the decline of ecosystem resilience and the deterioration of ecosystem services (Feller et al., 2012). Consequently, numerous studies have suggested the use of vermicompost as a sustainable alternative for achieving economically viable crop production while minimizing environmental pollution. Furthermore, organic fertilization has been demonstrated to mitigate plant diseases, particularly those induced by soil-borne pathogens, enhance microbial biomass and activity, increase soil organic matter levels, and bolster soil resistance to erosion (Thiele-Bruhnetal, 2012).

Soil organic matter is essential for the sustainability of agricultural production due to its numerous beneficial attributes, including positive impacts on soil quality, cation exchange capacity, water retention, and the ability to sequester pollutants (Liu et al. 2006). Vermicompost has been shown to improve the physical properties of soil by enhancing air and water permeability, as well as increasing total porosity and aggregate stability by reducing penetration resistance and bulk density (Aksakal, Sarı, and Angin 2016). Additionally, vermicompost enhances soil fertility, boosts nutrient availability for plants, and improves the soil's capacity to retain moisture (Radillo et al., 2013).

2.5 Effects of Vermicompost on Soil Physical Properties

The presence of earthworms in the soil enhances its porosity and facilitates better water infiltration. The activities of earthworms, which include feeding, burrowing, and casting, significantly alter the physical, chemical, and biological characteristics of both organic matter and soil. As previously mentioned, the nutrient composition of vermicompost is generally superior to that of traditional compost. Indeed, vermicompost can enhance soil fertility through physical, chemical, and biological means (Lim, S. L., Wu, T. Y., Lim, P. N., & Shak, K. P. (2015).

Soils enriched with vermicompost exhibit improved aeration, increased porosity, reduced bulk density, and enhanced water retention capabilities. The castings produced by earthworms are rich in humus, which promotes the aggregation of soil particles, leading to improved porosity. This, in turn, enhances both aeration and the soil's capacity to hold water. Consequently, soils treated with vermicompost are better equipped to improve soil structure and maintain higher moisture levels.

2.6 Effects of Vermicompost on Soil Chemical Properties

Soil chemical properties have greatly improved, such as electrical conductivity, pH, nutrient and organic matter status leading to improved plant growth and yield due to vermicompost application, (Kumari, *et al*., 2019). Moreover, earthworms secrete several hormones, enzymes and vitamins during casting that promote the activity of other beneficial microbes in the soil, thereby improving soil health.

In addition, humic acid in humus provides binding sites for a variety of plant nutrients, i.e., potassium, iron, calcium, sulphur and phosphorus. Jeyabal, G.,& Kuppuswamy. (2001) have reported increased growth of rice stalks and improvement in soil fertility status following vermicompost application.

As discussed earlier, earthworm casts are chemically and biologically rich, hence, soils imbedded with vermicompost have a higher rate of plant growth hormones and humic acid, less root pathogens or soil borne diseases, higher microbial activity and population and exhibit higher cation exchange capacity [Atiyeh, *et al.,* 2002), Arancon, *et al.*, 2003), Postma, *et al.*,. (2003), Perner, *et al.*, 2006).and overall improvement in plant growth and yield Bellitürk, *et al.*, (2020).

2.7 Effect of organic and inorganic fertilizer application on soil properties

Soil fertility decline is one of the constraints to food production in Sub-Saharan region. Low soil fertility in the region caused inherently low soil nutrient content and loss of nutrient through erosion and crop harvests (Ugboh and Ulebor, 2011). Soil fertility and crop yields are lower in developing countries because loss of nutrients from farm lands exceeds inflows (Vanlauwe *et al.*, 2015). Application of inorganic fertilizers together with organic manures were increased the total N content of soil than when used individually (Moe *et al.*, 2019). Application of organic fertilizer not only increases the nutrient content of soils, but also improves the physical and biological condition of soils.

Improvement in soil properties especially soil bulk density and soil structure enhance crop root development and distribution which enable soil C and N cycles. A well-developed root system may play a dominant role in soil C and N and may have relatively greater influence on soil organic C and N levels than the aboveground plant biomass (Norby and Cotrufo, 1998 cycles; Gale *et al.,* 2000; Puget and Drinkwater, 2001). Girma and Zeleke (2017), revealed that combined application of organic and inorganic fertilizers improved productivity of crop as well as soil nutrient content thus improve soil fertility status.

2.8 Nutrient requirements of onion

The cultivated onion (Allium cepa L.) is an important crop, with world production of about 88.48 million metric tonnes for the year 2013–2014 (FAOSTAT, 2017). The medicinal and health benefits of onion are due to the presence of flavonoids; anthocyanins, fructo-oligosaccharides, and organosulphur compounds (Goldman, 2011).There are different production systems where onion seeds are sown in the field or where seedlings are transplanted after nursery culture or where seed bulbs are planted into the field. Fertilization strategies for onions that are directly sown, transplanted after nursery culture or grown from seed bulbs are same. Nutrient management involves using crop nutrients as efficiently as possible to improve productivity while protecting the environment.

The key principle behind nutrient management is balancing soil nutrient inputs with crop requirements. When applied in proper quantities and at the right times, added nutrients help to achieve optimum crop yields; applying too little will limit yield and applying too much does not make economic sense and can harm the environment. Nutrients that are not effectively utilized by crops can potentially leach into groundwater or enter nearby waters by surface runoff. Too much nitrogen or phosphorus for example can impair water quality. Fertilizer requirements of a crop vary with fertility status of the soil, availability of soil moisture, variety of the crop, purpose for which the crop is grown, etc.

The major factors determining the level of soil fertility are organic matter content, availability of macro and micro- nutrients, soil reaction and physical soil characteristics such as texture, structure, depth and nature of the soil profile (Tisdale, Nelson, Beaton, & Halvin, 1995). Soil microbial communities carry out key ecosystem services that are vital for life on our planet, including cycling of carbon (C) and other nutrients and sustaining plant growth (Jansson & Hofmockel, 2018).

Rhizosphere microorganisms promote plant growth and protect plants from pathogen attack by a range of mechanisms (Lugtenberg & Kamilova, 2009; Raaijmakers, Paulitz, Steinberg, Alabouvette, & Moenne-Loccoz, 2009). These involve biofertilisation, stimulation of root growth, rhizore mediation, control of abiotic stress, and disease control. Many beneficial functions carried out by the soil micro biome are currently threatened due to changing climate and precipitation patterns, soil degradation and poor land management practices (Amundson *et al.,* 2015).

Onion requires intensive supply of plant available nitrogen (N), phosphorus (P) and potassium (K) to attain maximum yield of bulbs because the plants have a shallow, sparsely branched root system. Inefficient use of fertilizers may result in considerable residuals of these plant nutrients in soil following harvest (Brewster, 2008). Especially Sulfur plays a crucial role in pungency and health value of onion, particularly in plants like onions. It's essential for the production of sulfur-containing compounds, which contribute to the unique flavors and pungent smells of these vegetables. Sulfur also has health benefits, acting as a component in key proteins and contributing to various metabolic processes.

2.9 Effects of vermicompost on yield and quality of onion

Onion (Allium cepa L.) is one of the important bulb crop belongs to family Alliaceae. The green leaves, immature and mature bulbs are eaten raw or used in preparation of vegetables. Onion is also used in preparing soups, sauces, pickles and for flavouring food. It is commonly known as Queen of the Kitchen, because of its highly valued flavor, aroma and unique taste and the medicinal properties of its flavour compound (Griffiths *et al.* 2002). Onion is rich in protein, calcium, phosphorus and carbohydrates (Bhattacharjee *et al.,* 2013).

The pungency present in onion is due to volatile oil allyl propyl disulphide‘organic compound that is rich in Sulfur. Overall, excessive amounts of inorganic fertilizers are applied to onion in order to achieve a higher bulb yield (Shedeed, *et al.,* 2014). In view of this fact, a systematic investigation of the effect of inorganic N and locally available and affordable vermicompost is paramount importance for improving yield (Kokobe *et al.,* 2013; Tana and Wolde 2015; Yohannes *et al.,* 2017).

The bottleneck problem for high production and productivity is lack of adaptable high yielding varieties, lack of proper soil fertility management practice and other agronomic practices, diseases and insects etc. The problem of farmers throughout the country is that they have little knowledge on the optimum amount of NPS fertilization and advantage of incorporating organic fertilizer, especially vermicompost, with inorganic fertilizer for the production of bulb, as well as seed of onion (Nikus and Fikre, 2010).

However, chemical fertilizers generate several deleterious effects on the environment and human health. The synthetic fertilizers are rapidly lost by leaching in drainage water; this causes dangerous environmental pollution (Aisha *et al.,* 2007; Hernandez *et al.,* 2010). As well as, soil fertility is associated with nutrient mineralization in organic matter and release to soil solution in available form for plant absorption.

Mineralization is the result of normal biological cycles within the soil, it can be stimulated by adding appropriate amount of quality compost and biofertilizers (Paulin and Peter, 2008; Guimaraes *et al.,* 2013). Application of organic fertilizers and/or biofertilizers to the soils promoted nutrients availability, plant uptake, increased crop yield and quality (Shaheen *et al.,* 2007; Shedeed *et al.,* 2014).

Compost is an aerobically decomposed organic material derived from plants and animal residues by mesophilic and thermophilic microorganisms (Martens, 2000). Vermicompost is a product of organic matter degradation through interactions between earthworms and microorganisms (Arancon *et al.,* 2008). Compost and vermicompost are not only the sources of organic matter and nutrient, but also improve microbial population, physical, biological and chemical properties of the soil, as well as produce vigorous plants (Manivannan *et al.,* 2009; Mavaddati *et al.,* 2010; Shehata and El-Helaly, 2010).

Many researchers studied the role of organic fertilizers as a stimulant of plant growth and yield of onion (Rizk *et al.,* 2002; Ahmed, 2004; Shaheen *et al.,* 2007), improving bulb quality and its storability (Geries *et al.,* 2012; Kandil, *et al.,* 2013; AlFraihat, 2016).

2.10 Combined effect of vermicompost and NPS fertilizer on soil physicochemical properties and onion yield

The use of inorganic fertilizer to maintain cropping was found to increase yield just for exactly couple of years, however, on a long run, it has not be effective and prompts soil degradation (Satyanarayana *et al.,* 2002). The combined use of vermicompost and chemical fertilizers help in keeping up yield stability through correction of minimal lacks of auxiliary and micronutrients, improving effectiveness of connected supplements and providing favorable soil physical conditions (Gill and Walia, 2014).

Onion is commonly used as flavorings or as vegetables in stews and salads. It is one of the richest sources of flavonoids in the human diet which has been associated with a reduced risk of cancer, heart disease and diabetes. Globally, the area under onion production is increasing due to its high profitability per unit area and ease of production FAO (2011). In Ethiopia, onions grow in different agro-climatic regions mainly due to considerably increasing its importance in the daily diet of Ethiopians. It is also one of the most essential condiments, vegetable and cash crops in Ethiopia (Sara *et al.,* 2015).

Onion production in Ethiopia is affected by different factors among which unbalanced fertilizer application, inappropriate fertilizer rate or lack of proper soil fertility management practices, limited awareness of growers on soil fertility management are the major ones (Gebretsadik and Dechassa 2016; Negasi *et al.,* 2017). Continuous use of inorganic fertilizers and inappropriate soil fertility management practices are among the major factors limiting productivity of onion in Northwestern zone of Tigray (Yohannes *et al.,* 2017). Farmers in the zone mostly use blanket recommendation of 200 kg ha^{-1} DAP and 150 kg ha^{-1} Urea for onion production. They rarely use organic manure for onion production on small scale in gardens and near their homestead (Yohannes *et al.*, 2017).

Decomposition of organic materials would provide additional nutrients to the growing medium, which may lead to higher uptake of nutrient by the crop and subsequently high yield (Shaheen *et al.,* 2007). Moreover, in Tahtay Koraro district of northwestern zone of tigray, there were no studies about combined application of organic and inorganic N on growth and yield of onion (Yohannes *et al.*, 2017).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The research was carried out in the Dobbi kebele of Meskan Woreda, situated in the East Gurage Zone of central Ethiopia, during the year 2023-2024 under irrigated conditions. This location is approximately 140 kilometers from Addis Ababa and 7 kilometers from Butajira, the capital of the East Gurage Zone. The coordinates of the study site are 0380 020‘29.988’’ E and 0800 09‘12.832’’ N, with an elevation of 2146 meters above sea level. The primary crops cultivated in this area include maize (Zea mays L.) and teff (Eragrostis tef (Zucc.) Trotter), along with wheat (Triticum aestivum) and common bean (Phaseolus vulgaris L.). The soil in this area is primarily classified as clay loam.

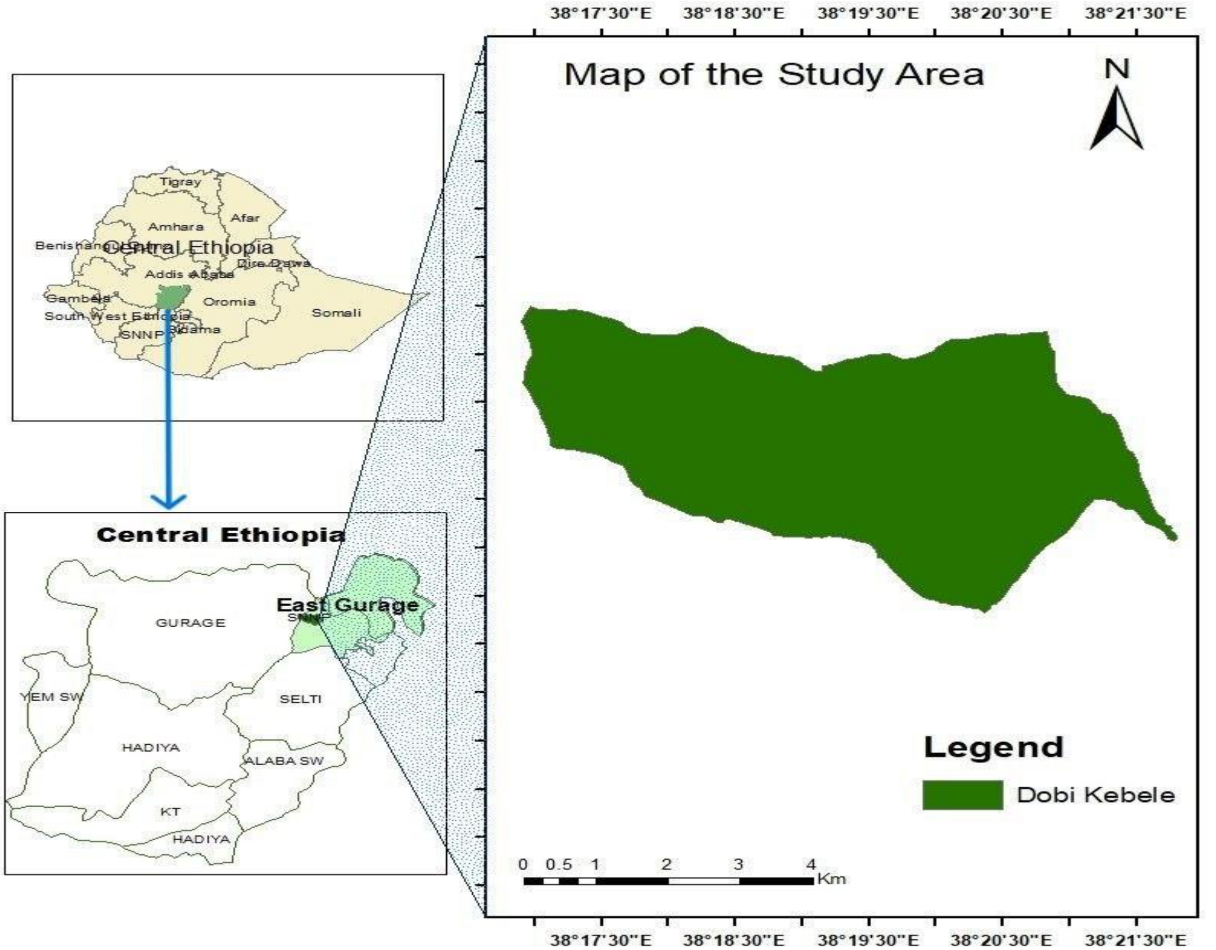

Figure 1.Location map of study area

3.2 Climate and Topography

The climatic conditions in Meskan Woreda, located in the Eastern Guraghe zone, are categorized into two agro-climatic zones: Dega, which accounts for 24%, and Weynadega, comprising 76%. And the research was conducted under the Weynadega agro climatic zone. The altitude in this area varies from 1,700 to 3,200 meters above sea level (m.a.s.l) (MWFNRM, 2010). The annual rainfall ranges from 960 to 1,200 mm. The area experiences bimodal rainfall, with a short rainy season occurring from March to April, while the primary rainy season lasts from June to September. Temperatures fluctuate, with a mean annual maximum of 26°C and a mean annual minimum of 10.3°C across different elevations. These conditions are conducive to the cultivation of a diverse array of crops, particularly onions, which thrive at altitudes ranging from 700-2,200 m.a.s.l.

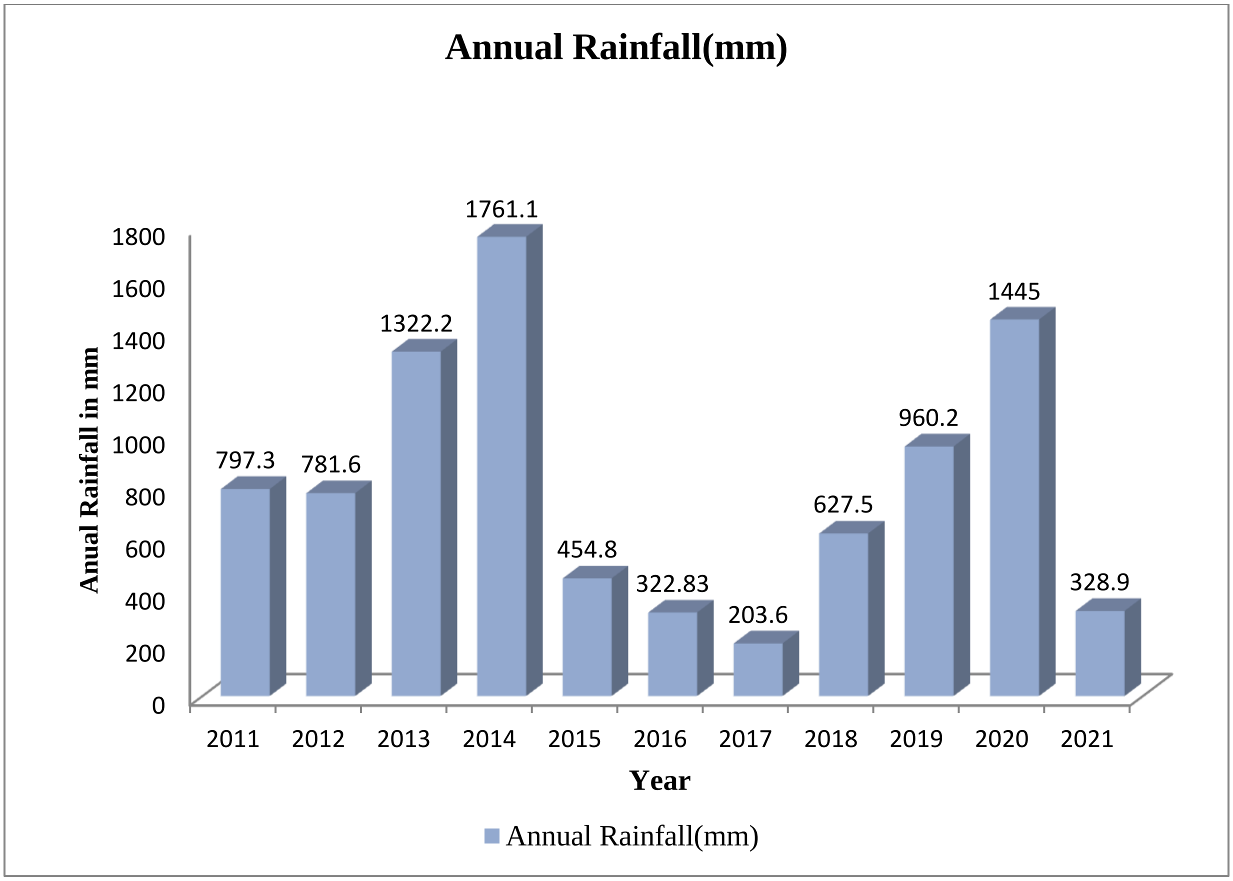

Figure 2.Annual Rain Fall (mm) of Butajira station (2011-2021)

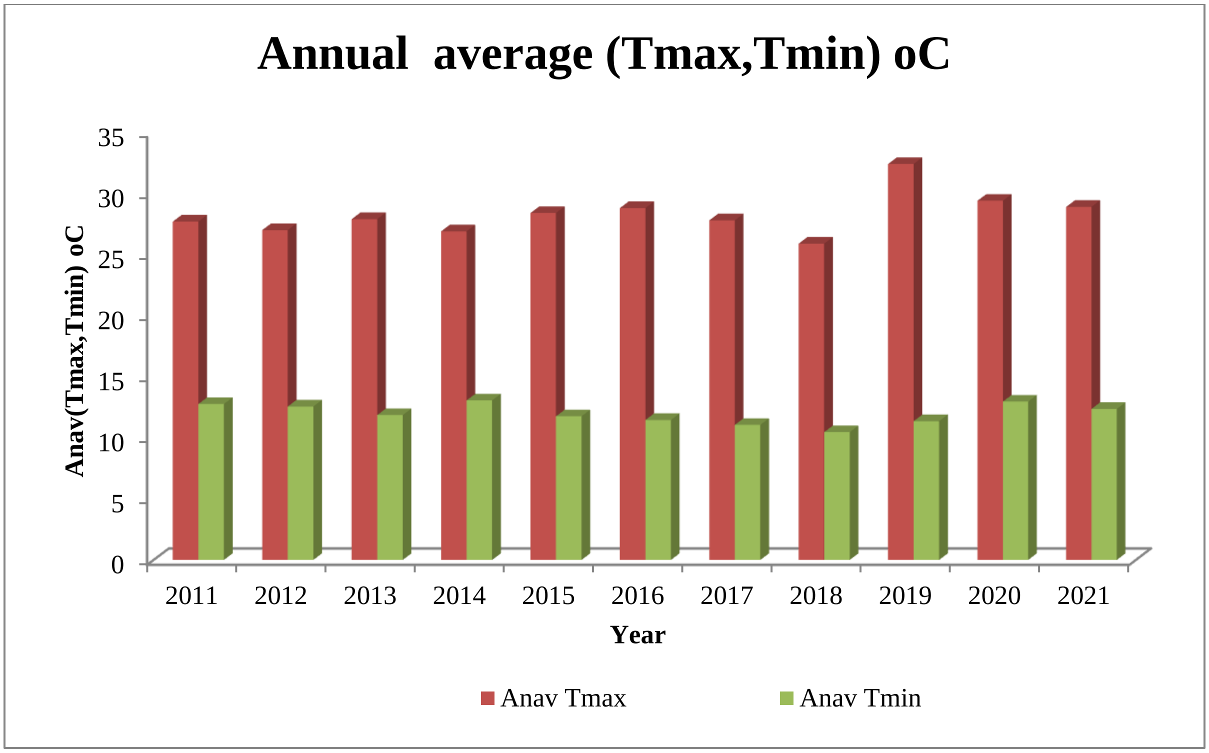

Figure 3.Annual Mean Temperature (^{o}C) of Butajira station (2011-2021)

3.3 Plant Material

The Bombay red onion variety served as the test material for this study. Seeds of the Bombay red variety were sourced from private producers. This variety demonstrated advantages over commercial hybrid onion cultivars, showing an increase in marketable bulb weight by 12.5% and bulb yield by 9%. It is capable of thriving at altitudes ranging from 700 to 2200 meters above sea level and has a growth period of 110 to 120 days. Bombay Red is among the most prevalent and widely utilized onion varieties in Ethiopia. Additionally, it possesses several bulb and seed quality characteristics that surpass those of commercial onion varieties (Wassu et al., 2017). A comprehensive description of this variety can be found in Table 1.

Table 1.Description of the agronomic traits of the enhanced Bombay red onion variety utilized in the experiment.

Characteristics	**Improved Bombay red onion variety**
Adaptation area	Medium to high altitude central Ethiopia from 1700-2200m.a.s.l
Spacing (cm)	50*30*10(double row)
Spacing between plant(cm)	10
Average bulb maturity	120 days
Fertilizer rate in kg ha^{-1}	(72-N,184-P_2O5 & 28-S) $kgha^{-1}$
Marketable bulb weight (g)	94
Marketable bulb yield (t ha^{-1})	32.78
Total bulb yield (t ha^{-1})	33.33
Year of release	2025

3.4 Experimental Design and Treatment

The experiment was carried out by controlling the experimental variables, specifically the treatments involving vermicompost and NPS fertilizers. Since there was two treatments it consisted of a 3 × 5 factorial arrangement of NPS fertilizers, with application rates of 0, 100, 200, 300, and 400 kg NPS per hectare, based on a recommended base of 5 tons per hectare. This was combined with varying rates of vermicompost (0, 2.5, and 5 tons per hectare) as suggested by Joshi et al. (2013), and these rates were partially substituted for inorganic fertilizers, particularly NPS at 100-400 kg/ha, as indicated by Diriba et al. (2013).

Vermicompost was applied to the designated plots one week prior to sowing to ensure nutrient availability. Each treatment was replicated three times and The treatments were randomly distributed according to the randomized complete block design (RCBD) because it give precise result and can be corrected again if there is a missed data. Onion bulbs were planted in double rows using irrigation water, with furrow spacing maintained at 50 cm, double row spacing at 30 cm, and plant spacing at 10 cm, as per EARO (2004).

Table 2 Treatment combination in factorial arrangement

Treatments	Fertilizers combination
1	0 ton ha^{-1} vermicompost + 0 kg ha^{-1} NPS
2	0 ton ha^{-1} vermicompost +100 kg ha^{-1} NPS
3	0 ton ha^{-1} vermicompost + 200 kg ha^{-1} NPS
4	0 ton ha^{-1} vermicompost + 300 kg ha^{-1} NPS
5	0 ton ha^{-1} vermicompost + 400 kg ha^{-1} NPS
6	2.5 ton ha^{-1} vermicompost + 0 kg ha^{-1} NPS
7	2.5 ton ha^{-1} vermicompost + 100 kg ha^{-1} NPS
8	2.5 ton ha^{-1} vermicompost + 200 kg ha^{-1} NPS
9	2.5 ton ha^{-1} vermicompost + 300 kg ha^{-1} NPS
10	2.5 ton ha^{-1} vermicompost + 400 kg ha^{-1} NPS
11	5 ton ha^{-1} vermicompost + 0 kg ha^{-1} NPS
12	5 ton ha^{-1} vermicompost + 100 kg ha^{-1} NPS
13	5 ton ha^{-1} vermicompost + 200 kg ha^{-1} NPS
14	5 ton ha^{-1} vermicompost + 300 kg ha^{-1} NPS
15	5 ton ha^{-1} vermicompost + 400 kg ha^{-1} NPS

3.5 Agronomic practice

The experimental land was cultivated using an ox for ploughing and subsequently harrowed. Fine seedbeds were manually prepared and leveled, with rows established across each plot. The spacing between plots and blocks was maintained at 1 meter each. The onion variety utilized in this experiment was "Bombay Red," which is predominantly cultivated in the Meskan Woreda. Initially, onion seedlings were grown in a nursery, for which the nursery soil was ploughed 2 to 3 times. Seeds were sown in a well-prepared nursery bed, and all recommended seedling management practices were implemented as outlined by Lemma Dessalegn and Shimeles Aklilu (2003).

Once the seedlings reached the 3 to 4 leaf stage or attained a height of 12 to 15 cm, healthy and uniform seedlings were transplanted into the well-prepared experimental field. The planting of onion seedlings was conducted using a ridge planting system, with spacing between water furrows, rows, and plants set at 50 cm, 30 cm, and 10 cm, respectively, in accordance with the recommendations of Lemma and Shimeles Aklilu (2003). A distance of 1 meter was maintained between plots and replications to facilitate agronomic practices. Each experimental plot measured 6 m^2 and contained six double rows, with 20 plants in each row, totaling 240 plants per plot.

The respective amounts of nitrogen (N), phosphorus pentoxide (P_2O_5), and sulfur (S) were applied to the experimental plants as a basal application during transplanting. Following the blanket recommendation for NPS fertilizer (100 kg NPS ha-1) (EthioSIS, 2014), fertilizer preparations for each plot were made for 100%, 75%, 50%, 25%, and 0% NPS ha^{-1}. Additionally, vermicompost was prepared based on the respective rates of 5 tons ha^{-1}, 2.5 tons ha^{-1}, and 0 tons ha^{-1}, and was applied one week prior to transplanting as a basal application.

3.6 Soil Sample collection and Sampling preparation

Soil samples were collected in the field for each plot of the treatments after the harvest. Following standard procedures for soil sampling and preparation, as outlined by Paetz and Wilke (2005), composite samples were collected and thoroughly mixed to accurately represent the field conditions. Random sampling was performed using an auger in a zigzag pattern across the entire experimental area. A total of 45 soil samples were collected from the topsoil layer, reaching a depth of 20 cm, and combined in a bucket to form a representative sample. The soil was then crushed into small particles and mixed thoroughly. From this mixture, composite samples weighing 1 kg were placed into plastic bags from three sub samples each. Duplicate samples were prepared for the analysis of physicochemical properties.

3.7 Soil analysis

3.7.1 Physical analysis

The soils were subjected to air drying and subsequently passed through a 2 mm sieve. The particle size distribution was assessed using the hydrometer method (Day, 1965), and soil textural classes were categorized according to the proportions of sand, silt, and clay, utilizing the

USDA soil textural triangle as outlined by Rowell (1994). Bulk density was measured employing the core method as detailed by Jamison et al. (1950).

3.7.2 Soil chemical analysis

The chemical analysis of the soil samples included measurements of soil pH, total nitrogen, available phosphorus, organic matter, cation exchange capacity, available sulfur, organic carbon, and exchangeable potassium. Soil pH was assessed using a 1:2.5 (weight/volume) suspension of soil to water, with a glass electrode connected to a digital pH meter (McLean, 1982). The total nitrogen content was measured using the Kjeldahl method as outlined by Jackson (1958). Available phosphorus was extracted with 0.5 M NaHCO3 and quantified using a light spectrophotometer, following the procedures established by Olsen et al. (1954).

Cation exchange capacity (CEC) was evaluated through the ammonium acetate method utilizing 1N NH4OAc (Black, 1965). Available sulfur in the soils was extracted using the Mehlich-III multinutrient extraction method (Melich, 1984) and analyzed with an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) at the appropriate wavelength range. Organic carbon content was determined via the wet combustion or dichromate oxidation methods (Walkley and Black, 1934), and soil organic matter was calculated by multiplying the organic carbon content by 1.724. Exchangeable potassium was assessed using a flame photometer after extraction with 0.5 ammonium acetate, as per Hesse (1971). The chemical composition of the vermicompost was analyzed using similar procedures as those applied to the soil samples.

3.8 Data Collection

Soil samples were collected from each treatment to assess the physicochemical characteristics of the soil. Additionally, data on yield parameters were gathered from the time of planting through to harvesting, including post-harvest phenological metrics. The recorded parameters included: Days to emergence, Days to bulb maturity; Yield metrics: Bulb weight (g), Bulb length (cm), Bulb diameter (cm), Marketable bulb yield (ton ha-^{1}), Unmarketable bulb yield (ton ha^{-1}), and Total bulb yield (ton ha^{-1}).

3.9 Yield and yield components

3.9.1 Bulb weight

The average weights of ten randomly chosen bulbs from each plot were measured, and the weight of each bulb was documented, leading to the calculation of the overall average bulb weight.

3.9.2 Bulb length

The bulbs selected for weight measurement were also utilized to assess bulb length. The lengths of ten randomly chosen bulbs were measured from the base to the tip in centimeters using a caliper, and the average value was documented.

3.9.3 Bulb diameter

The bulbs employed for measuring bulb length were also utilized to assess bulb diameter. The average size of the bulb was determined by measuring the diameters in centimeters at the midpoint of ten randomly chosen bulbs with a caliper, and the mean bulb diameter was recorded.

3.9.4 Marketable bulb yield

Bulbs that exhibited no signs of mechanical damage, disease, or insect pest infestations, and were consistent in color while ranging from medium to large sizes (20 - 160 g), were deemed suitable for the market. The weights of these bulbs were calculated based on the net plot area of each section, measured in kilograms using a scale balance, and reported as tons per hectare (Lemma and Shimeles, 2003).

3.9.5 Unmarketable bulb yield

Bulbs that were either undersized or oversized (weighing less than 20g or more than 160g), as well as those that were misshapen, decayed, discolored, diseased, or exhibiting physiological defects, were deemed unmarketable, as stated by Lemma and Shimeles (2003). The weight of these bulbs collected from the net plot area of each plot was measured in kilograms using a scale balance and reported in tons per hectare.

3.9.6 Total bulb yield

The overall yield of onions was calculated by summing both marketable and unmarketable bulb yields, and it is expressed in tons per hectare.

3.10 Partial Budget Analysis

The economic analysis was conducted following the methodology outlined in CIMMYT (1988), which utilized the current market prices for inputs at the time of planting and for outputs at the time of harvesting. All costs and benefits were calculated on a per-hectare basis in Eth-Birr. The partial budget analysis employed the average marketable onion yield for each treatment as a key concept.

The economic benefits associated with various treatments were assessed to estimate the net returns, as well as the costs of NPS, vermicompost, and the revenue generated from the total onion bulbs utilized for further economic evaluation. Additionally, the market prices for NPS, vermicompost, marketable bulbs, and labor costs were obtained through market assessments conducted during the observation period.

Gross average marketable onion bulb yield (kg ha-1) (AvY) represents the average yield for each treatment. Adjusted yield (AjY) refers to the average yield reduced by 10% to account for the fact that experimental yields typically exceed those that farmers can realistically achieve with the same treatments. Consequently, for economic calculations, farmers' yields are adjusted to be 10% lower than the research findings (CIMMYT, 1988). The formula for adjustable marketable bulb yield is: Average yield - (Average yield - 0.1).

Gross field benefit (GFB) is determined by multiplying the field or farm gate price that farmers receive for onions by the adjustable marketable bulb yield. The equation for GFB is: Adjustable marketable bulb yield * field/farm gate price for onions.

Total variable cost (TVC) encompasses the expenses related to fertilizers and their application at varying dosages for the experiment. The costs associated with other inputs and production practices, such as labor, land preparation, planting, earthing up, weeding, and harvesting, were considered consistent or negligible across treatments.

Net Income (NI) or Net Benefit (NB) is calculated as the remaining amount after deducting total variable costs for inputs (TVC) from total revenue (TR). The formula for NB is: TR – TVC.

The marginal rate of return (MRR) measures the increase in returns resulting from additional input. MRR (%) is calculated as the change in net benefit (ΔNB) multiplied by 100, divided by the change in total variable cost (ΔTVC). The marginal rate of return (MRR %) is thus derived by dividing the change in net benefit by the change in total variable cost.

3.11 Statistical Analysis

The data go through statistical analysis utilizing SAS software version 9.4. Analyses of variance (ANOVA) were conducted according to the GLM procedure at a significance level of 5%. In instances where the ANOVA indicated a significant difference, mean separations were carried out using the least significant difference (LSD) test at a probability level of 5% (Gomez and Gomez, 1984). Additionally, correlation analyses were executed to identify the linear relationships between selected physicochemical properties of the soil and the yield components of onion.

4. Result and Discussion

4.1 The Physicochemical Characteristics of Soil Prior to Planting in the Study Area

The physicochemical characteristics of soil significantly influence numerous functions, such as fertility, drainage, water retention, and overall soil health. Gaining insight into these characteristics is essential for evaluating the soil's potential for agricultural applications, environmental conservation, and effective land management strategies. In the context of the study area, the soil has been traditionally suited for the continuous cultivation of annual crops during the main growing season, as well as for irrigated vegetable production.

This agricultural practice was conducted without the implementation of suitable land management techniques and optimal production potential. There was an absence of proper ploughing, timely follow-up, and the application of recommended amounts of organic vermicompost and inorganic NPS fertilizers, which are essential for enhancing soil nutrient quality, health, and crop yield. Consequently, the results of the soil's physicochemical parameters were predominantly low, with the exception of bulk density. This was evident from the laboratory analysis of soil physicochemical parameters conducted prior to planting in the study area. Below are some key physicochemical properties of the soil.

4.1.1 Physical properties of soil

The key physical properties of soil include texture, structure, porosity, water retention capacity, and bulk density. These characteristics are crucial for understanding soil health, agricultural efficiency, and environmental stewardship. Soil physical properties influence its behavior and functionality, particularly concerning water movement, root development, and nutrient accessibility. In the studied area, the soil was classified as clay loam, with a particle size distribution of 34.4% sand, 36.8% silt, and 28.8% clay. The bulk density was measured at 1.46 g/cm^3, and the total porosity of the soil was recorded at 45% in the control plot. However, all measured physical properties of the soil were found to be within a low range. Consequently, it is essential to utilize alternative organic and inorganic fertilizer sources to enhance the physical properties of the soil.

4.1.2 Chemical properties of soil

The chemical properties of the soil prior to harvesting included soil pH, total nitrogen (TN), organic carbon (OC), available phosphorus (AvP), available sulfur (AvS), cation exchange capacity (CEC), and exchangeable bases (ex. Base). The soil pH was measured at 5.4%, with TN at 0.15%, OC at 1.12%, AvP at 4.86 ppm, AvS at 19.8 ppm, and CEC at 37.98 cmol(+) kg-1. The levels of exchangeable bases were recorded as follows: calcium (Ca) at 21.69 cmol(+) kg-1, magnesium (Mg) at 10.49 cmol(+) kg-1, sodium (Na) at 0.45 cmol(+) kg-1, and potassium (K) at 0.31 cmol(+) kg-1, all noted in the control plot. It is important to highlight that the majority of the soil's chemical properties were found to be in a low range, with the exception of exchangeable calcium and magnesium. Consequently, it is essential to incorporate alternative organic and inorganic fertilizer sources to enhance the soil's chemical characteristics.

Table 3 Selected soil physicochemical characteristics of the experimental site before planting

Parameters	Values
Bulk density (g cm^{-3})	1.46
Soil textural class	Clay loam
Total porosity (Ø) (%)	45
p^H	5.4
Total nitrogen (%)	0.15
Organic carbon (%)	1.12
Available phosphorus (ppm)	4.86
Available sulfur (ppm)	19.8
Exchangeable Base (meq kg^{-1})	
Na	0.45
Ca	21.69
Mg	10..49
K	0.31
CEC	37.98

4.2 Impact of vermicompost and NPS fertilizer on the physicochemical properties of soil following harvest Physical properties of soil

4.2.1 Soil physical properties

4.2.1.1 Particle size distribution

The analysis of specific physicochemical properties of the soil reveals a particle size distribution comprising sand (34.4%), silt (36.4%), and clay (28.8%). According to the USDA textural soil classification scheme (1987), the soil at the experimental site can be classified as clay loam (figure 4). This classification influences the soil's capacity to retain and drain water, as well as its ability to hold nutrients.

Soil texture is a fundamental physical property that is relatively unaffected by management practices, and it plays a crucial role in determining nutrient availability, organic matter content, air circulation, and water retention in the soil (Murphy, 1968). The inherent characteristic of soil texture indicates its suitability for crop cultivation and other applications. Rieke and Joke (2005) noted that Bombay red onion achieves high yields in sandy loam to silt loam textured soils, although it can also thrive in clay loam soils.

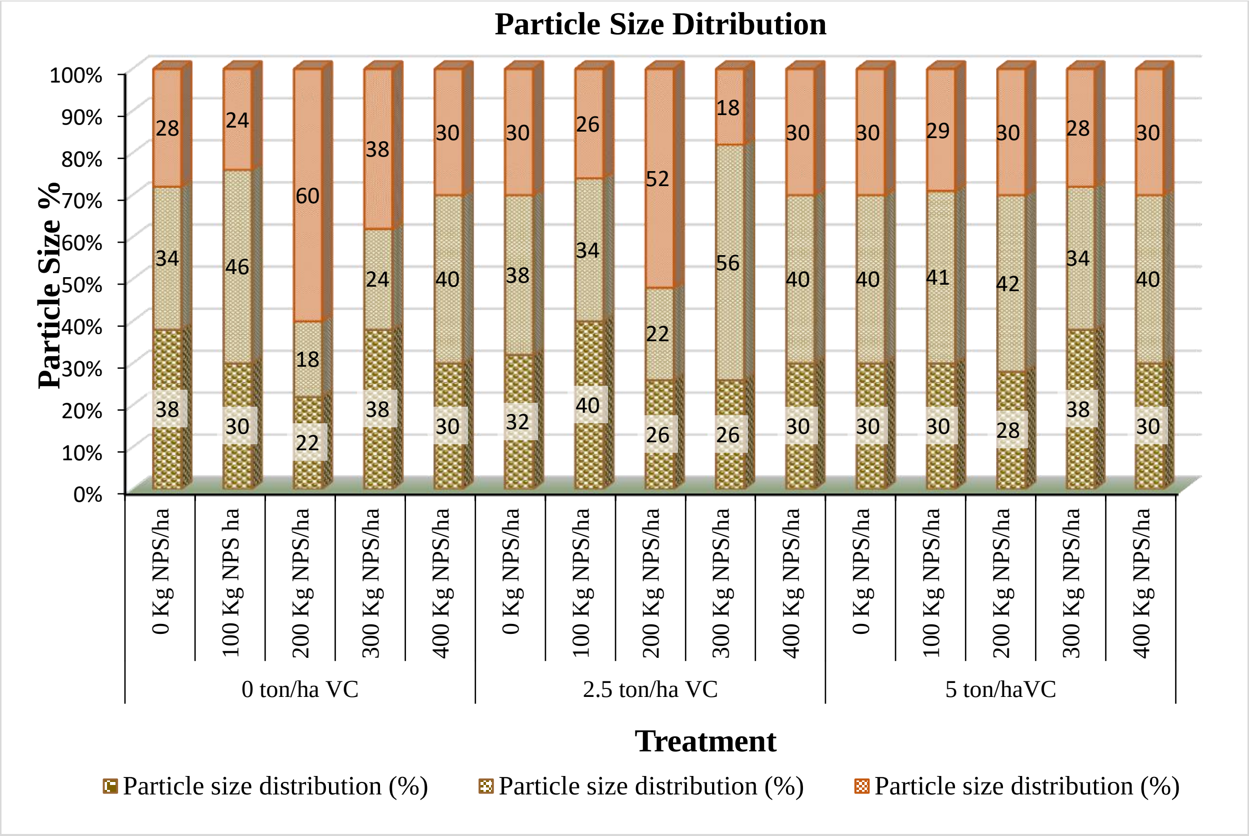

Figure 4.**Graph of particle size distribution (sand, silt and clay) in%**

4.2.1.2 Bulk Density

Bulk density is a crucial physical characteristic that can influence the root development of plants. The combination of vermicompost and inorganic NPS fertilizers had a significant impact ($p<0.01$) on both the bulk density and the available water holding capacity of the soil (see Appendix 1). A notable reduction in soil bulk density was recorded with the application of treatments involving 5 ton ha^{-1} of vermicompost and 400 kg ha^{-1} of NPS fertilizer (refer to Table 3). In support of this, Tesfaye et al. (2019) identified an inverse correlation between bulk density and organic matter derived from industrial waste.

Ibrahim et al. (2015) and Azimzadeh (2015) similarly found that the use of NPS and organic fertilizers led to a significant reduction in soil bulk density. The lowest bulk density recorded was 1.38 g cm^{-3} in the plot treated with 5 ton ha^{-1} of vermicompost and 400 kg ha^{-1} of NPS fertilizer, while the control plot exhibited the highest bulk density at 1.46 g cm^{-3}.

These findings suggest that the combined application of NPS and higher rates of vermicompost positively influenced soil bulk density. In contrast, increasing the rates of NPS alone did not significantly affect soil bulk density when compared to the varying amounts of vermicompost. Specifically, the treatment with 0 ton ha^{-1} of vermicompost and 200, 300, and 400 kg ha^{-1} of inorganic NPS resulted in bulk densities of 1.44, 1.45, and 1.46 g cm^{-3}, respectively. Conversely, the application of 2.5 and 5 tons ha^{-1} of vermicompost without any inorganic NPS fertilizer yielded bulk densities of 1.40, 1.41, and 1.42 g cm^{-3}. This indicates a direct correlation between vermicompost and organic carbon levels, suggesting that the addition of vermicompost enhances soil organic carbon content by making it more accessible for plant uptake.

This aligns with the findings of Gudadhe et al. (2015), who reported a reduction in soil bulk density following the continuous application of farmyard manure (FYM). In contrast, my observations indicated that the application of mineral fertilizers did not influence bulk density, primarily due to a decline in organic carbon (OC) levels. This phenomenon occurs because bulk density, defined as the mass of a material per unit volume including voids, is typically not directly influenced by chemical fertilizers. Instead, it is affected by how these fertilizers alter soil characteristics, such as compaction and organic matter content.

4.2.1.3 Total Porosity

The simultaneous use of vermicompost and NPS chemical fertilizer in the study area demonstrates a consistent increase in total porosity with the escalation of treatment levels following crop harvest. However, it is important to note that these changes are not statistically significant. Observations from the study site indicate that the application of both organic and inorganic fertilizers can enhance this parameter, necessitating further replicable research. The highest total porosity recorded was 48% with the application of 5 ton ha^{-1} of vermicompost and 200 kg per hectare of NPS, while the control plot exhibited the lowest total porosity at 45% (Table 3). It was calculated by one minus bulk density to the particle density times by 100.

The increase in total porosity resulting from vermicompost application may facilitate root development, improve soil drainage, and enhance air circulation within the soil, ultimately leading to a rise in soil organic matter content. Conversely, a decrease in porosity correlates with a reduction in organic matter and an increase in bulk density. The augmentation of organic matter in the soil not only serves as a reservoir of plant nutrients but also influences the physical, chemical, and biological characteristics of the soil, playing a crucial role in the establishment and maintenance of soil fertility (Fageria, 2009).

Table 4.Physical characteristics of the experimental soil following the harvest of the Bombay red onion crop, as affected by the application of vermicompost and NPS fertilizers.

Vermicompost (ton/ha)	**NPS** (kg/ ha)	**BD** g/cm^3	**Porosity** Ø (%)
VC 0 ton ha^{-1}	NPS 0 kg /ha	1.456	45
	NPS 100 kg/ ha	1.43	46.3
	NPS 200 kg/ha	1.386	48
	NPS 300 kg/ha	1.44	46
	NPS 400 kg/ha	1.4	47.17
VC 2.5 ton ha^{-1}	NPS 0 kg/ha	1.43	46.03
	NPS 100 kg/ha	1.44	46
	NPS 200 kg/ha	1.4	47.17
	NPS 300 kg/ha	1.43	46.03
	NPS 400 kg/ha	1.44	46
VC 5 ton ha^{-1}	NPS 0 kg/ha	1.39	48
	NPS 100 kg/ha	1.45	45.3
	NPS 200 kg/ha	1.45	45.3
	NPS 300 kg/ha	1.43	46.03
	NPS 400 kg/ha	1.42	46.5
LSD (%)		1772	0.8722
CV (%)		0.702855	1.949980

Key.*BD = bulk density*

Table 5 Chemical characteristics of the experimental soil following the harvest of Bombay red onion crops, as affected by the application of vermicompost and NPS fertilizers.

Treatment		Prameter						
VC(ton ha^{-1})	NPS (kg ha^{-1})	PH (%)	Av P (ppm)	Av S (ppm)	Total N (%)	OC (%)	CEC(cmo(+) kg^{-1} soil)	Ex base meq/100g
0	0	5.4	4.86	35.99	0.1527	0.65	37.98	30.46
	100	6.08	5.77	49.99	0.11	1.19	50.38	49.21
	200	6.04	7.59	34.84	0.17	1.11	28.4	28.23
	300	5.86	8.045	8.3	0.09	1.31	29.94	29.07
	400	5.7	10.31	52.45	0.06	0.65	78.6	74.31
2.5	0	5.92	6.686	43.14	0.18	2.07	27.1	11.56
	100	5.83	7.136	10.58	0.11	1.54	29.76	27.06
	200	5.79	8.5	45.73	0.13	0.97	39.4	31.29
	300	5.78	9.86	52.94	0.13	1.15	71.5	68.36
	400	5.92	10.77	48.53	0.27	3.57	41	39.18
5	0	5.82	6.227	14.1	0.12	2.65	25.76	23.95
	100	5.82	6.68	52.42	0.072	0.85	78.68	71.87
	200	5.73	8.95	48.01	0.23	3.08	34.82	29.86
	300	5.82	9.86	18.68	0.13	1.7	31.9	24.43
	400	5.94	10.77	47.5	0.23	2.71	30.7	29.64
LSD (5%)		0.1772	0.0098	0.5899	0.0023	0.0254	0.0951	0.0821
CV		4.048021	0.160773	2.026707	4.048021	2.092543	11.99943	0.284617

Means that share the same letter(s) in the columns are not significantly different from one another at the 5% significance level. LSD refers to the Least Significant Difference at the 5% level. The abbreviations used are as follows: AvP for available phosphorus, AvS for available sulfur, TN for total nitrogen, OC for organic carbon, AvK for available potassium, and CEC for cation exchange capacity.

4.2.2 Soil Chemical Properties

4.2.2.1 Soil Reaction (pH)

Soil pH plays a crucial role in various essential processes, such as the activity of soil microorganisms and the accessibility of nutrients for plants. The analysis of variance revealed that there were no significant differences in soil pH values resulting from the interaction of varying levels of vermicompost and NPS fertilizer applications. This suggests that the soil pH across all experimental plots ranged the lowest to the highest from 5.4 to 6.08 (refer to Table 4), indicating that the combined use of vermicompost and NPS fertilizer did not have a significant impact on soil pH.

This could be attributed to a one-year fertilizer field trial and the flooding that occurred in the region a year prior to the experiment's initiation. The pH levels recorded in the plot with the highest treatment combination fell within the range indicative of slightly acidic soil, as noted by Tekalign (1991). Likewise, Tesfaye et al. (2020) found that the application of vermicompost and NPS fertilizer did not have a significant effect on soil pH.

Vermicompost which is the final product of the process of decomposing organic matter, is less pollutant and rich in nitrogen than organic matter before the decomposition process, as well as rich in water-soluble nutrients. The presence of earthworms in the soil affects the physical properties of the soil as it changes the movement of Water and enhances porosity in it. The organic vermicompost contains a number of enzymes that enhance the activities of microbial organisms and thus increase the microbial biomass in the soil (Hatti,S.S., Londonkar, R.L., Patil, S.B., Gangawane, A.K. and Patil, C.S. 2010).

There are foods and household waste that worms prefer and do not cause them harm, such as cardboard and all kinds of leaves free of dyes, which are considered the basic bedding for worms and are a source of carbon, as well as dry and green tree leaves, the rice straw and kitchen waste are considered suitable feed materials for worms because the vermicompost production process took place in a short period of time, and the C / N ratio decreased and the nutrient content increased compared to the material content. This improvement in properties makes vermicompost an ideal product for increasing soil fertility (da Silva, *et al.,* 2023).

4.2.2.2 Organic carbon

The interaction between vermicompost and NPS had a highly significant effect ($p<0.01$) on the soil organic carbon levels (see Appendix 1). The maximum soil organic carbon content recorded was 3.57%, achieved through the application of 5 ton $ha^{-1}$of vermicompost combined with 400 kg of NPS ha^{-1}, while the control group exhibited the lowest level at 1.12%. As the rate of vermicompost increased from 2.5 to 5 ton ha^{-1} alongside 300 kg of NPS per hectare, a significant increase in soil organic carbon was observed, particularly with the combination of 400 kg of NPS per hectare (refer to Table 4).

The rise in soil organic carbon associated with higher vermicompost application rates in conjunction with NPS fertilizer may be attributed to the increased organic matter contributed by vermicompost through the direct addition of organic materials and improved root development. Therefore, as the quantity of vermicompost applied increases, it likely leads to a corresponding enhancement in soil organic carbon content. This finding aligns with the research conducted by Tilahun et al. (2013), which demonstrated that soil organic matter levels immediately following onion harvest significantly responded to the application of farmyard manure, with the highest carbon content (8.7%) recorded at the maximum application rate of 15 ton ha^{-1}.

In a similar vein, Mukta et al. (2015) found that the application of vermicompost at a rate of 10 ton ha^{-1}, combined with 50% chemical fertilizers, enhanced the nutrient profile of post-harvest soil and preserved higher levels of organic carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, and boron compared to the control group.

The findings of this research suggest that the integrated use of vermicompost and NPS fertilizers can support long-term soil productivity, which is essential for sustainable onion cultivation. Soil carbon is recognized not only as a primary reservoir for atmospheric CO2 but also as a critical component of soil quality that influences soil fertility, crop yield, hydrology, drainage, greenhouse gas emissions, and various other ecological functions (Pacala et al., 2004). Enhancing soil carbon levels is vital for maintaining soil quality and productivity (Post and Kwon, 2000).

4.2.2.3 Total nitrogen

The total nitrogen, a crucial nutrient that influences crop yield, ranged from 0.15% to 0.27% following the application of various amendment rates (Table 4). Nitrogen plays a vital role as a component of enzymes, vitamins, chlorophyll, and other cellular structures, all of which are necessary for the growth and development of crops (Singh et al., 2018). The interaction between vermicompost and NPS had a highly significant effect ($p<0.01$) on the nitrogen levels in the soil (Appendix 1). The application of both vermicompost and inorganic NPS fertilizer resulted in greater total nitrogen content in the soil compared to the control group. The highest nitrogen level observed was 0.27% in plots treated with 400 kg NPS ha^{-1} alongside 5 ton of vermicompost ha^{-1}, while the control group recorded the lowest at 0.15%.

The increase in total nitrogen with higher rates of vermicompost combined with inorganic NPS fertilizer may be attributed to the enhanced nitrogen production in the soil due to vermicompost compared to the control plots. Additionally, the higher concentrations of soil organic carbon and nitrogen in vermicompost likely provided a more substantial nitrogen source for mineralization (Arancon et al., 2006).

Nethra et al. (1999) observed an increase in nitrogen levels in the soil following the application of vermicompost. Similarly, Mukta et al. (2015) found that applying vermicompost at a rate of 10 ton ha^{-1}, in conjunction with 50% of the recommended chemical fertilizers, enhanced the nutrient profile of the postharvest soil and preserved higher levels of organic carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, and boron compared to the control group. Furthermore, the combination of vermicompost and mineral nitrogen led to greater total nitrogen content than both the control and the application of 100% mineral nitrogen, as reported by Yohannes et al. (2017).).

4.2.2.4 Available phosphorus

In a manner akin to OC and TN, the interaction between vermicompost and NPS fertilizer ($p<0.05$) demonstrated a significant effect on the levels of available phosphorus (see Appendix 1). Sahlemedhin (2002) categorized phosphorus availability into four ratings: very low (0-3), low (4-7), medium (8-11), and high (>11). The highest concentration of available phosphorus (10.77 ppm) was recorded with the application of 5 ton of vermicompost ha^{-1} in conjunction with 400 kg of NPS ha^{-1}. The combination of 2.5 ton of vermicompost ha^{-1} with 400 kg of NPS per hectare did not show a significant difference compared to the combination of 5 ton of vermicompost ha^{-1} with 300 kg of NPS ha^{-1} (refer to Table 4).

The enhancement of available phosphorus in the soil is attributed to the incorporation of vermicompost, which not only adds phosphorus directly but also facilitates the solubilization of native phosphorus through the release of various organic acids during the decomposition of organic matter (Srinivasulu et al., 2000). Similar findings were reported by Jamir et al. (2013), who observed an increase in available phosphorus levels resulting from the combined use of organic manures and chemical fertilizers.

Tilahun et al. (2013) noted that the combined application of 15 tons of farmyard manure (FYM) and 100 kg of P2O5 ha^{-1} raised the available phosphorus from 11.9 ppm to 38.1 ppm. Additionally, soils treated with vermicompost at a rate of 15 ton ha^{-1} exhibited significantly higher phosphorus levels compared to control plots. Phosphorus (P) is recognized as a crucial element in agriculture, second only to nitrogen, as insufficient available phosphorus in soils restricts the growth of both cultivated and wild plants (Foth and Ellis, 1997).

While the low levels of phosphorus may indicate a fixation issue, Solomon et al. (2002) noted that phosphorus availability in many Ethiopian soils has been decreasing due to fixation influenced by both low and high pH levels. To enhance the bioavailability of phosphorus in these soils, adjusting the soil pH raising it in acidic soils and lowering it in alkaline soils represents the most effective management strategy to reduce phosphorus fixation.

Phosphorus availability in soil is significantly influenced by soil pH, with optimal availability generally occurring within the pH range of 6.0 to 7.0. At pH levels outside this range, phosphorus can become less available due to various chemical reactions and interactions with soil components. In low pH acidic soils (pH below 5.5), phosphorus can bind strongly with aluminum (Al) and iron (Fe) oxides and hydroxides, forming relatively insoluble compounds. This process, known as fixation, reduces the amount of phosphorus available for plant uptake. And in High pH alkaline soils (pH above 7.5), phosphorus can react with calcium (Ca) to form calcium phosphates, which are also less soluble and less readily available to plants. The forms of P greatly influence its availability in the soil and subsequently influence productivity (W. Ahmed, H. Jing, L. Kaillou *et al.,* 2019).

4.2.2.5 Available sulfur

The statistical analysis of variance conducted on the gathered data indicated that the interaction between NPS fertilizers and vermicompost significantly affected the availability of sulfur ($p<0.05$) (Appendix 1). Specifically, the highest sulfur content, measuring 52.94 mg kg^{-1}, was observed in plots treated with 300 kg NPS ha^{-1} in conjunction with 5 ton of vermicompost ha^{-1}. This was closely followed by the combination of 400 kg NPS ha^{-1} with 5 tons of vermicompost ha^{-1}.

Furthermore, plots that received 400 kg NPS ha^{-1} along with 5 tons of vermicompost ha^{-1} did not exhibit a significant difference compared to those that received 400 kg NPS ha^{-1} combined with 2.5 ton of vermicompost ha^{-1}. This finding highlights the role of inorganic NPS fertilizer in enhancing sulfur content in the soil (Table 4). The current study aligns with the research conducted by Abd El-Kader et al. (2007), which suggested that the increase in vegetative growth and dry weight of plant organs may be attributed to the direct impact of sulfur on soil properties, leading to reduced pH levels and improved availability of other essential nutrients, enhanced plant metabolism, increased photosynthetic rates, and higher levels of free amino acids..

A comparable outcome was observed by Shege et al. (2017), who indicated that, the application of 300 kg NPS ha^{-1} of fertilizer resulted in the highest above-ground dry biomass, thereby enhancing the growth and development of garlic. Additionally, Sumit et al. (2014) reported that a combination of 50% vermicompost nitrogen, 25% urea nitrogen, phosphate-solubilizing bacteria (PSB), and Azotobacter led to an increase in available sulfur content compared to the control plot.

4.2.2.6 Cation exchange capacity

The analysis of variance revealed a significant impact of vermicompost and NPS fertilizer ($p<0.05$) on CEC (see Appendix 1). The highest cation exchange capacity (CEC) of 78.68 cmol kg^{-1} soil was achieved through the combined application of 2.5 ton of vermicompost ha^{-1} with 400 kg of NPS ha^{-1}. There were no significant differences observed in plots treated with 2.5 and 5 ton of vermicompost ha^{-1} in conjunction with 300 kg and 400 kg of NPS ha^{-1}. In contrast, the lowest CEC recorded was 25.76 cmol kg^{-1} soil for the 5 tons ha^{-1} treatment alone, while the control plot showed a CEC of 37.69 cmol kg^{-1} soil (refer to Table 4). Vermicompost, being an organic amendment, increases soil organic matter, which directly impacts CEC. NPS fertilizers, while primarily providing nutrients, can also affect CEC indirectly by altering soil pH and nutrient availability, which in turn influence the CEC.

The observed increase in CEC in the plots treated with the combination of vermicompost and NPS can primarily be attributed to the presence of humic substances in the vermicompost (Mahmoud and Ibrahim 2009). Supporting this finding, Tolanur (2002) noted that the application of organic manure alongside inorganic fertilizers significantly enhanced cation exchange capacity, as well as the availability of phosphorus and potassium, and organic carbon. This aligns with the results of Vasanthi and Kumarasamy (1999), who also reported a significant increase in CEC in soils treated with a combination of vermicompost and NPK.

Saikh et al. (1998) indicated that the enhancement of cation exchange capacity (CEC) is linked to the increase in soil organic carbon, which is significantly influenced by the type and quantity of mineral and organic colloids in the soil. Consequently, CEC assessments are typically included in the comprehensive evaluation of a soil's potential fertility and its likely response to fertilizer applications (Landon, 1991). The application of vermicompost as an organic amendment, combined with NPS fertilizer, notably improved the CEC status of the soil.

The CEC quantifies the extent of accessible negative charge per unit weight of soil, reflecting the number of cations that a specific soil sample can retain in an exchangeable form. This measurement plays a crucial role in buffering against fluctuations in pH, nutrient availability, calcium concentrations, and changes in soil structure. Therefore, CEC is a key factor influencing soil structure stability, nutrient accessibility for plant growth, soil pH, and the soil's response to fertilizers and other soil amendments. A low CEC indicates that the soil is less resistant to alterations in its chemical composition (Thomas and Hargrove, 1984).

4.2.2.7 Exchangeable Base

The analysis of variance revealed a significant impact of vermicompost and NPS fertilizer ($p<0.05$) on the base cations, as illustrated in Figure 5. The phrase "exchangeable bases" or "total exchangeable bases" denotes the cumulative concentration of the bases calcium, magnesium, potassium, and sodium in their exchangeable forms.

4.2.2.7.1 Soil Exchangeable calcium

The application of either vermicompost alone or in combination with NPS fertilizer has been shown to enhance soil fertility. The highest level of exchangeable calcium, measuring 60.93 cmol kg^{-1}, was observed with the application of 5 ton ha^{-1} of vermicompost alongside 100 kg of NPS per hectare (Figure 5). In contrast, the lowest exchangeable calcium level recorded was 6.05 cmol kg^{-1} with the application of only 2.5 ton ha^{-1}, while the control plot exhibited a level of 21.96 cmol kg^{-1}. This increased exchangeable calcium content from the combination of NPS fertilizer and vermicompost may be due to the release of calcium ions resulting from the dissolution and mineralization processes of the vermicompost (Mengistu et al., 2017).

4.2.2.7.2 Soil Exchangeable magnesium

Compared to the control group, the application of NPS fertilizer, whether combined or applied individually with vermicompost, resulted in an increase in soil exchangeable magnesium (Ex.Mg). The rise in soil Ex.Mg can be attributed to the application of vermicompost, which showed a 50% increase over the control. This effect is likely due to the high Ex.Mg content found in theapplication of 400 kg ha^{-1} alone, which measured 14.76 cmol (+) kg^{-1} at a rate of 400 kg NPS ha^{-1} (as illustrated in Figure 4). In contrast, the lowest Ex.Mg value of 3.99 cmol (+) kg^{-1} was observed with the application of 5 tons ha^{-1} of vermicompost alone, while the control exhibited a value of 7.6 cmol (+) kg^{-1}. The presence of these base cations enhances the organic matter content in the soil as a result of NPS fertilizer application.

4.2.2.7.3 Soil Exchangeable sodium

The variance analysis revealed that the highest level of exchangeable sodium, measuring 2.42 cmol (+) kg^{-1}, was observed exclusively in the treatment with 400 kg NPS ha^{-1}. Additionally, a value of 2 cmol (+) kg^{-1} was noted for the combination of 2.5 tons ha^{-1} of vermicompost and 400 kg NPS ha^{-1} (see figure 4). Conversely, the lowest exchangeable sodium values of 0.45 and 0.33 cmol (+) kg-1 were recorded in the control plot and with the application of 2.5 tons ha^{-1} of vermicompost combined with 200 kg NPS ha^{-1} of fertilizer. Both amendments, namely NPS fertilizer and vermicompost, significantly influenced exchangeable sodium levels, whether applied individually or together. This effect is attributed to the soil microorganisms present in vermicompost, which have the ability to solubilize exchangeable sodium and facilitate its leaching from the root zone, thereby reducing its availability in the soil, as noted by Justyna (2019).

Furthermore, vermicomposting has the potential to enhance the bacterial community and the functionality of soil bacteria, which subsequently improves soil structure by releasing exopolysaccharides, forming organic-mineral complexes, and binding soil particles into aggregates. Consequently, vermicompost can mitigate alkalization by increasing the formation of macro aggregates in alkaline soils (Demir et al., 2020). Additionally, the presence of humic acid in vermicompost is crucial for structural stabilization, enhancing nutrient availability, and improving the chemical, biological, and physical properties of the soil. Thus, the application of vermicompost can lead to improved soil structure, increased nutrient availability, enhanced water retention capacity, and greater microbial activity in alkaline soils (Rady et al., 2016).

4.2.2.7.4 Soil Exchangeable potassium

Due to the lack of significant responses to potassium application in the central and northern regions of the country, there is a limited understanding of potassium dynamics in Ethiopian soils (Karmakar S, et al., 2009). The exchangeable potassium levels at the experimental site varied from 0.31 to 1.64 cmol+kg^{-1}, which are classified as low to high according to FAO ratings (2006) following the application of vermicompost and NPS fertilizers (Figure 5).

The highest exchangeable potassium value of 1.64 cmol+kg^{-1} was observed with the application of 5 tons per hectare of vermicompost combined with 400 kg ha^{-1} of NPS fertilizer, while the lowest value of 0.31 cmol+kg^{-1} was noted in the control treatment (Figure 5). The increase in exchangeable potassium compared to the control may be attributed to potassium released from the applied vermicompost into the soil. The rise in soil exchangeable potassium levels with varying doses of vermicompost is likely due to the high potassium content present in vermicompost. Supporting this, Ibrahim et al. (2015) reported an increase in exchangeable potassium with higher doses of vermicompost.

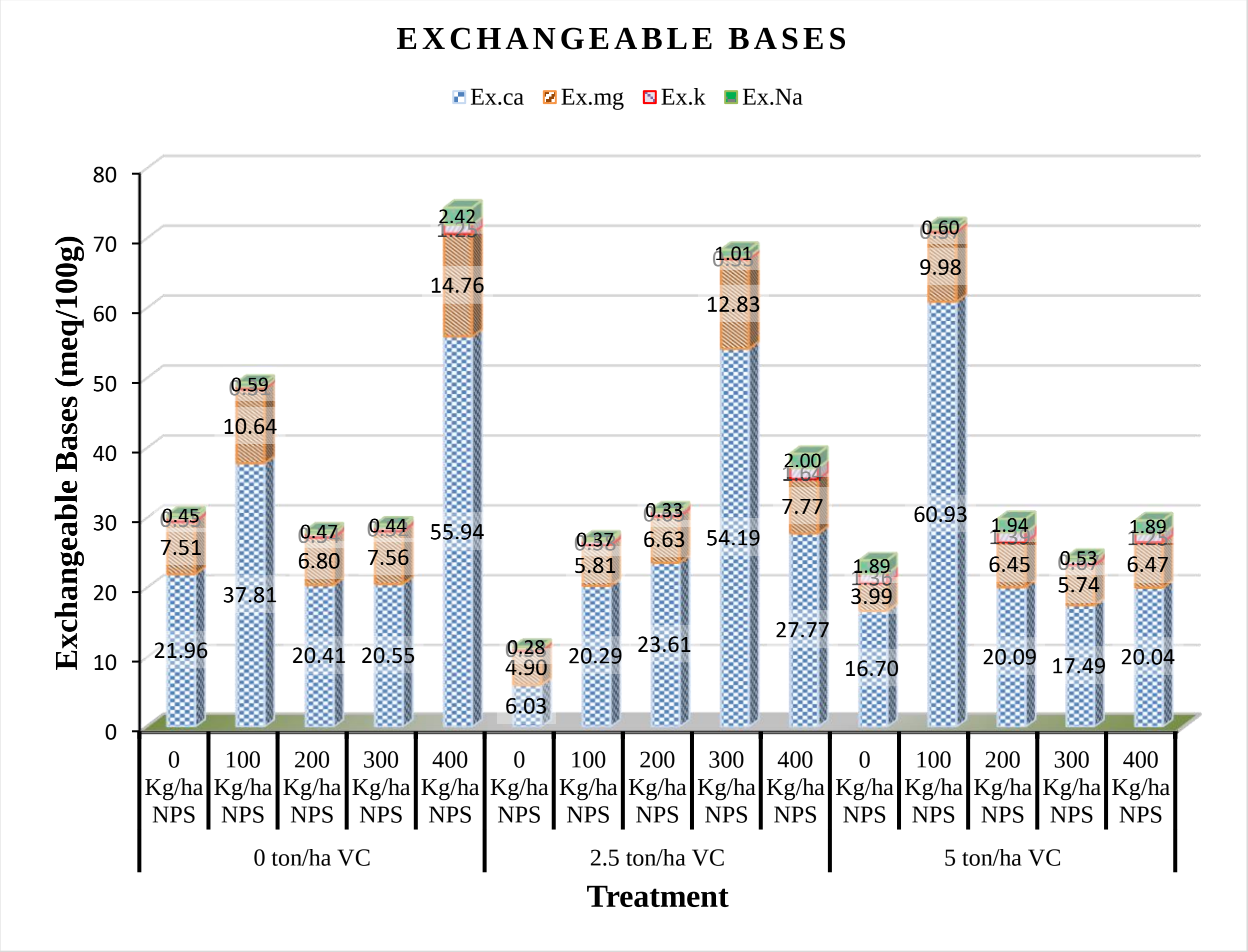

Figure 5.Graph of Exchangeable base in meq/100g.

4.3 Yield and Yield component Analysis

4.3.1 Bulb Length

The length of the bulbs was significantly influenced ($p<0.01$) by the interaction between vermicompost and NPS fertilizer, as indicated in Appendix 2. Increasing the application of vermicompost from 0 to 2.5 and 5 ton ha^{-1} resulted in a corresponding increase in the bulb length of Bombay red onion. The maximum bulb length of 7 cm was observed in plants treated with 5 ton of vermicompost ha^{-1}, while the minimum bulb length of 1.83 cm was noted in plants that did not receive any fertilizer (Figure 6).

The observed increase in bulb length at elevated vermicompost (VC) rates of 5 ton ha^{-1} may be due to a decrease in the limitations imposed by growth factors such as nutrients and moisture. This enhancement in vermicompost availability promotes vigorous foliage development, allowing the bulbs to accumulate more assimilates for storage, ultimately leading to an increase in bulb length. According to Gonzalez et al. (2001), the application of inorganic fertilizers and organic manure provides all necessary nutrients during the growth phase, resulting in improved measurements of various growth parameters. Additionally, Pande and Mundra (1971) noted that the application of nitrogen significantly enhanced the bulb length of summer onions.

4.3.2 Bulb Diameter

The interaction between NPS fertilizer and vermicompost significantly influenced the bulb diameter of Bombay red onion ($p<0.05$) (Appendix 2). The largest bulb diameter, measuring 7 cm, was observed with the combined application of 400 kg NPS ha^{-1} and 5 tons of vermicompost per hectare. Conversely, the smallest bulb diameter recorded was 2 cm in non-fertilized plots, which is 145% smaller than the maximum observed diameter (Figure 6).

This increase in bulb diameter supports the theory that vermicompost acts as a soil activator, conditioner, and enhancer of soil fertility, providing essential plant nutrients, vitamins, enzymes, growth hormones, and beneficial microorganisms (Anonymous, 2006). According to Pramanik et al. (2007), humic acids released from vermicompost improve nutrient absorption by plants by enhancing the permeability of root cell membranes and promoting root development.

Supporting these findings, Yohannis et al. (2017) noted that increasing the application of vermicompost from 2.5 ton ha^{-1} to 5 ton ha^{-1}, along with raising inorganic nitrogen from 25% to 50%, resulted in a 32.9% increase in bulb diameter. Additionally, Melkamu (2018) observed a positive trend in both the length and diameter of onion bulbs with higher concentrations of phosphorus and sulfur, particularly at elevated nitrogen levels.

Yoldas et al. (2011), Akoun (2005), and Jayathilake et al. (2003) indicated that combining organic and inorganic fertilizers can enhance the diameter of onion bulbs. Additionally, Nasreen et al. (2007) observed a significant increase in onion bulb diameter with the application of mineral nitrogen, reaching up to 120 kg per hectare. Kumar et al. (1998) also documented an increase in bulb diameter resulting from the application of 120 kg per hectare nitrogen levels.

4.3.3 Mean Bulb Weight

Mean bulb weight is a crucial factor in enhancing onion yield. The analysis of variance revealed that the interaction between NPS fertilizer and vermicompost had a significant effect ($p<0.01$) on the mean bulb weight of the improved onion variety (see Appendix 2). The highest mean bulb weight recorded was 120g, achieved through the combined application of 5 tons per hectare of vermicompost with 400 kg per hectare of NPS fertilizer, which showed a highly significant difference compared to the control plots. Conversely, the control plots yielded the lowest mean bulb weight of 18.33 g. additionally, plots treated with 100, 200, 300,and 400 kg of NPS per hectare, along with combinations of 2.5 and 5 tons of vermicompost ha^{-1}, exhibited significant differences among themselves (refer to Figure 6).

The superior bulb weight observed at higher rates of NPS and vermicompost may be attributed to enhanced translocation of photosynthesis from the leaves to the bulbs, resulting in increased bulb weight and diameter (Singh et al., 1997). The greater availability of nutrients and the production of growth-promoting substances likely facilitated faster cell elongation and multiplication, thereby enlarging the bulb size. The mineralization of vermicompost contributes to the accumulation of soil nutrients, which subsequently improves nutrient availability for the growing crop. Furthermore, vermicompost is known to contain various plant growth hormones, enzymes, beneficial bacteria, and mycorrhizae (Gupta et al., 1977).

This observation aligns with the findings of Yohannes et al. (2017), who noted that the integrated application of 5 tons ha^{-1} of vermicompost and 34.75 kg of nitrogen fertilizers resulted in a 144.63% increase in onion bulb weight compared to plots without fertilizer. Similarly, Naseeruddin et al. (2016) reported that the combined use of 5 ton ha^{-1} of vermicompost and 50 kg of nitrogen ha^{-1} led to a 144.62% increase in bulb weight over untreated plots and a 75% increase compared to those fertilized with 100 kg of nitrogen per hectare.

Nasreen and Hossain (2004) found that the weight of individual onion bulbs increased by 150% compared to the control group when organic manure was applied at a rate of 10 tons ha^{-1}. This enhancement can be attributed to the benefits of farmyard manure, which improves soil structure, increases moisture retention, enhances fertility, and positively influences the density and quality of onion bulbs (Randall et al., 1999). Additionally, Alemu et al. (2014) reported that the combined application of nitrogen and vermicompost, at rates of 23 kg N ha^{-1} and 5 tons of vermicompost ha^{-1}, significantly raised the average number of garlic cloves by 4.33% compared to the control.

4.3.4 Marketable Bulb Yield

The variance analysis revealed that the interaction between NPS fertilizer and vermicompost had a significant effect ($p<0.01$) on the yield of marketable bulbs (see Appendix 2). The highest yield, measuring 32.78 tons per hectare, was observed in plants receiving a combination of 400 kg of NPS ha^{-1} and 5 ton of vermicompost ha^{-1}. Conversely, the lowest marketable bulb yield, at 2.78 ton ha^{-1}, was noted in plots that did not receive any fertilizer treatment (refer to Figure 6).

The nutrients released from vermicompost likely contributed to the overall marketable bulb yield, in conjunction with the nutrients provided by inorganic NPS fertilizer. This could explain the elevated marketable bulb yield observed in the treatment with the highest recorded results. Therefore, the combination of organic vermicompost and inorganic NPS fertilizers may yield superior marketable bulb outputs compared to the use of inorganic NPS fertilizer alone.

The highest marketable yield of onions (32.78 ton ha^{-1}) was achieved with the application of 5 ton ha^{-1}of vermicompost combined with 400 kg ha^{-1} NPS fertilizers. In contrast, the lowest marketable yield (2.78 ton ha^{-1}) was noted in plots that did not receive any fertilizer. Similarly, Alemu et al. (2014) reported that the marketable yield of garlic increased by 10% when the application rate of vermicompost was raised from 0 to 5 ton ha^{-1}.

The relationship between bulb weight and yield with varying rates of VC and NPS fertilizers typically follows a response curve, often with an initial increase in both parameters, followed by a plateauing or even a decline at higher rates. In other words, applying a moderate amount of fertilizer will lead to significant increases in bulb weight and yield, but exceeding a certain threshold may not result in further gains and could even lead to negative effects. At a certain point, the increase in bulb weight and yield will start to level off.

This is because the plants may have reached their optimal level of nutrient uptake, and any further increase in fertilizer application may not be effectively utilized. In some cases, exceeding the optimal fertilizer rate can actually lead to a decrease in bulb weight and yield. This can be due to factors like nutrient toxicity, imbalances, or stress caused by excess fertilizer. In some cases, exceeding the optimal fertilizer rate can actually lead to a decrease in bulb weight and yield. This can be due to factors like nutrient toxicity, imbalances, or stress caused by excess fertilizer.

4.3.5 Total BulbYield

The variance analysis indicated that the total yield of the improved Bombay red onion variety was significantly affected ($p<0.01$) by the interaction between NPS fertilizer and vermicompost (Appendix 2). In line with the marketable bulb yield, the combination of 400 kg NPS ha^{-1} and 5 ton of vermicompost ha^{-1} resulted in the highest total bulb yield of 33.33 ton ha^{-1}, which is approximately 119% greater than the lowest yield of 2.78 ton ha^{-1}observed in the control plot that received no fertilizer.

The increase in yield may be attributed to vermicompost supplying adequate nutrients and minimizing nutrient competition, thereby enhancing bulb size and contributing to improved marketable yield. These findings align with Asefa (2017), who noted that the yield and related parameters of garlic were enhanced through the combined use of NPS and cattle manure fertilizers.

Additionally, Kumar (2017) found that the application of 5 tons of FYM per hectare along with 2.5 ton of vermicompost ha^{-1} and a fertilizer mix of PK + S + Zn (100:50:100:20:10 kg ha^{-1}) resulted in significantly higher bulb yields compared to other treatments, including the control. Similarly, Ngullie et al. (2011) reported that the highest yield was achieved with a 50% combination of vermicompost and 50% RDF N. Yohannes et al. (2017) also found that the maximum total bulb yield was obtained with 5 tons of vermicompost per hectare combined with 50% RDF N (35.25 ton ha^{-1}), followed by 5 ton of vermicompost ha^{-1} with 75% RDF N (32.31 ton ha^{-1}), while the control yielded the lowest at 19.91 ton ha^{-1}.

The use of 100% organic nutrient sources, including farmyard manure (FYM), vermicompost, neem seed cake, Azotobacter, phosphate-solubilizing bacteria (PSB), and trap crops, resulted in the highest onion yield and significantly enhanced soil fertility compared to both the control group and the application of 100% recommended doses (RD) of NPK (Priynka et al., 2018). In a similar vein, Alemu et al. (2016) found that applying vermicompost at rates between 0 to 5 ton ha^{-1} led to a notable 9.57% increase in the total bulb yield of garlic. Additionally, Nasreen et al. (2007) reported that the highest onion yield was achieved with a combined application of 120 kg of nitrogen and 40 kg of sulfur ha^{-1}, along with a standard dose of 40 kg of phosphorus, 75 kg of potassium, 5 kg of zinc ha^{-1}, and 5 tons of cow dung ha^{-1}.

In the present study, the total bulb yield of Bombay red onion increased as the rate of NPS fertilizer dose from 300 kg to 400 kg ha^{-1}, with the highest recorded yield being 33.33 tons ha^{-1} and minimal variation among the plots. This finding aligns with Kilgori et al. (2007), who reported a significant increase in garlic bulb yield with nitrogen applications of 0, 60, and 120 kg ha^{-1}. However, higher nitrogen doses of 180 and 240 kg ha^{-1} were found to decrease bulb yield. Excessive application of fertilizers or nutrients can be detrimental, as it may hinder nutrient uptake and adversely affect crop growth and yield (Lee and Lee, 2014).

Table 6 Interaction effects of vermicompost and NPS fertilizers on bulb diameter, bulb length, mean bulb weight, marketable bulb yield and total bulb yield of Bombay red onion

Treatment		Parameter				
VC(t ha-1)	NPS (kg ha-1)	Bulb diameter (cm)	Bulb length (cm)	Mean bulb weight(g)	Marketable bulb yield(t ha-1)	Total bulb yield (t ha-1)
0	0	2	1.5	18.33	2.783	5.55
	100	4	4	48.33	9.45	11.17
	200	5	5	70	14.45	14.45
	300	6.5	6.5	85	17.217	17.78
	400	7	7	88.33	24.45	25
2.5	0	5	5	60	6.117	9.45
	100	6	6	71.67	16.117	16.667
	200	6	5	79.33	18.83	21.667
	300	6.5	6.5	87	24.45	25
	400	7	7	95	26.117	27.78
5	0	7	7	83.33	20.55	23.883
	100	6	6	73.33	20.55	21.667
	200	7	7	96.67	25	26.117
	300	7	7	90	28.88	29.45
	400	7	7	116.67	32.78	33.33
LSD (5%)			0.2313	4.5657	26.772	9.3612

Means with the same letter(s) in the columns arenot significantly different at 5% level Of significance,LSD=Least significant difference at 5% level.

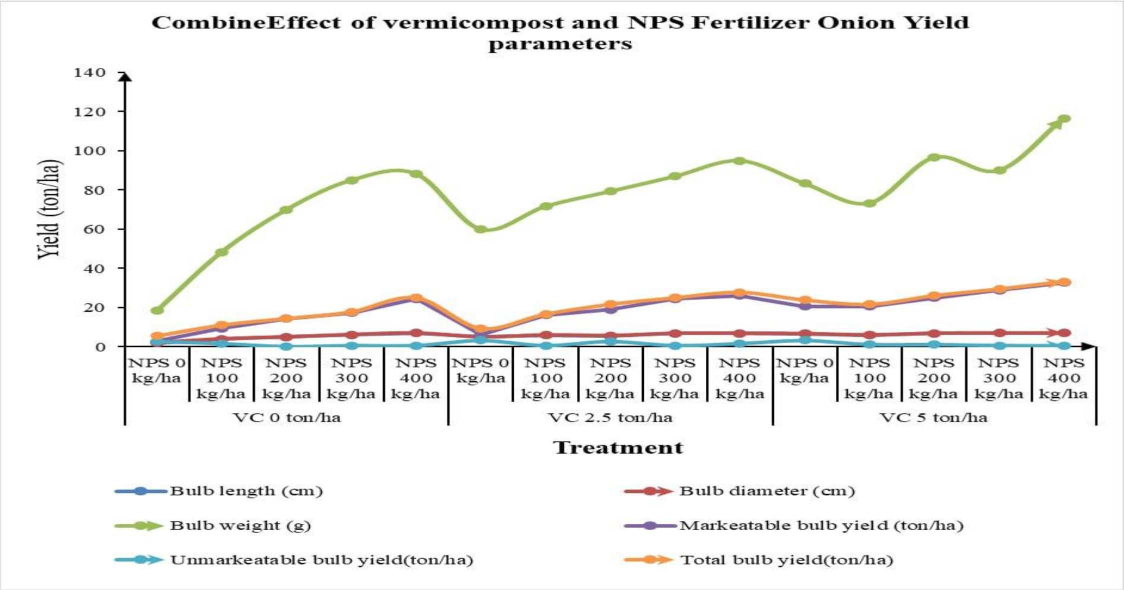

Figure 6 Graph of onion bulb key parameters

4.4 Simple correlation analysis among the selected parameters

A Pearson correlation analysis was conducted to assess the correlation coefficient between specific physicochemical properties of soil and the yield components of onions. The results indicated a strong positive correlation between onion yield and its components with soil characteristics, specifically bulb diameter and pH, with a correlation coefficient of r = 0.6563, has positive correlation this indicated that the value of pH goes to optimum range it favors the increment of bulb diameter, also bulb diameter and AvP (r = <.0001),has positive correlation, this yield parameter demands the nutrients that increase its size as we increase the phosphorus bearing fertilizers bulb diameter was increased, and bulb diameter and AvS (r = 0.8637), has strong relationship and positive correlation as it was described above onion was sulfur demand crop because it increases the spices content of onion and provides quality product since we use sulfur containing fertilizers it increases the diameter of bulb, and bulb diameter and TN (r = 0.5547), has strong relationship and positive correlation as we add The simultaneous use of organic and inorganic fertilizers enhances soil nutrients, thereby improving soil properties that contribute to an increase in bulb diameter. Additionally, bulb diameter shows a positive correlation with organic carbon (OC) (r = 0.0015). This parameter, similar to total nitrogen (TN), indicates that as the carbon content in the soil rises, the nutrient levels also increase, which in turn promotes the growth of bulb diameter, similarly, bulb diameter and CEC (r = 0.3755), has positive correlation this indicated that CEC of the soil mean the capacity of negative ions present in the exchangeable sites that is in the plant uptake form so this was as CEC increases the diameter of onion bulb also increases and bulb diameter and ex.K (r = 0.2735), also has positive correlations this implies that the base cations in the exchangeable site increases the bulb diameter. Similarly the yield parameter BW and pH, (r = 0.5839) has positive correlation this is the same with that of bulb diameter as we improve the soil properties by applying the amendments it increases the weight of onion bulb, and BW and avP (r = <.0001), has positive correlation this indicate that the phosphorus was in the available form it provides nutrient for bulb development, also BW and avS, (r = 0.7511), has positive correlation this was the same with that of the above discussion as onion was sulfur lover crop it favors the increment in bulb weight, next BW and TN, (r = 0.0606), and BW with OC(r = 0.0001), A positive correlation exists between these two parameters, indicating that an increase in soil carbon content enhances the nutrient status of the soil, which in turn improves bulb weight. Additionally, there is a strong positive correlation between BW and CEC, as well as ex.K (r = 0.9619) and (r = 0.7543). The presence of these anions and base cations in their exchangeable forms contributes to the increase in bulb weight. Another yield parameter, MBY, shows a positive correlation with pH (r = 0.2511); when soil pH is slightly acidic to neutral, it favors an increase in the marketable yield of onions. This relationship is also observed between MBY and avP (r = <.0001), where the application of soil amendments reduces phosphorus fixation, thereby enhancing the quality and yield of marketable bulbs. Furthermore, MBY exhibits a strong positive correlation with avS (r = 0.5961), as the addition of sulfur-containing fertilizers improves spice conditions and boosts marketable yields. The correlation between MBY and TN (r = 0.1505) is also positive, as the incorporation of organic and inorganic fertilizers enhances the soil's production capacity by supplying essential nutrients. Similarly, MBY correlates positively with OC (r = 0.0017), indicating that like TN, OC can contribute to optimal marketable yields. Additionally, MBY shows a positive correlation with CEC and ex.K (r = 0.2554) and (r = 0.1777), as these ions in their exchangeable forms support optimal marketable bulb yields of onions (Table 5). The findings from the correlation analysis reveal substantial relationships among the variables studied. The results indicate that as the application rate of soil amendments, including vermicompost and inorganic NPS fertilizers, increases, there is a positive correlation between most limiting and critical soil nutrients and yield parameters. This enhancement in nutrient availability contributes to improved soil fertility, production capacity, and physicochemical properties.

Table 7.correlation analysis for soil parameter with yield parameter

	sand	**silt**	**clay**	**PH**	**BD**	**AvP**	**avS**	**TN**	**OC**	**CEC**	**AvK**	**ExNa**	**Exk**	**Exca**	**Exmg**	**Exbase**
BL	-0.26 0.0812	0.15 0.321	-0.01 0.9381	0.01 0.9236	-0.49 0.0006	0.77 <.0001	-0.03 0.8306	0.09 0.5489	0.47 0.0012	0.14 0.3722	0.51 0.0004	0.56 <.0001	0.51 0.0004	0.16 0.2812	0.07 0.6344	0.17 0.2576
Bdiam	-0.26 0.0814	0.17 0.2647	-0.03 0.8497	0.07 0.6563	-0.48 0.0008	0.78 <.0001	-0.03 0.8637	0.09 0.5547	0.46 0.0015	0.14 0.3755	0.52 0.0002	0.56 <.0001	0.51 0.0003	0.16 0.2915	0.07 0.6602	0.17 0.2735
BW	-0.21 0.1642	0.08 0.5929	0.03 0.8591	0.08 0.5839	-0.49 0.0006	0.83 <.0001	0.05 0.7511	0.28 0.0606	0.54 0.0001	0.01 0.9619	0.39 0.008	0.58 <.0001	0.57 <.0001	0.05 0.7667	-0.01 0.9386	0.05 0.7543
MBY	-0.21 0.1646	-0.01 0.9613	0.11 0.4722	-0.17 0.2511	-0.56 <.0001	0.81 <.0001	0.08 0.5961	0.22 0.1505	0.45 0.0017	0.17 0.2554	0.39 0.0075	0.63 <.0001	0.57 <.0001	0.22 0.1418	0.13 0.3896	0.20 0.1777
UMBY	0.02 0.8869	-0.23 0.1343	0.20 0.1992	0.32 0.0315	0.13 0.3837	-0.41 0.0049	0.01 0.9353	0.08 0.5871	0.12 0.4367	-0.20 0.186	-0.18 0.2383	-0.08 0.6151	0.02 0.8819	-0.28 0.0619	-0.32 0.0324	-0.25 0.0962
TBY	-0.24 0.1072	0.00 0.9763	0.11 0.4543	0.09 0.5769	-0.57 <.0001	0.84 <.0001	0.12 0.4353	0.24 0.1083	0.49 0.0007	0.15 0.3291	0.44 0.0023	0.64 <.0001	0.63 <.0001	0.18 0.228	0.07 0.6516	0.16 0.2864

Key: *BL= bulb length, Bdiameter =bulb diameter, BW = bulb weight, MBY = marketable bulb yield, UMBY = unmarketable bulb yield, TBY = total bulb yield, pH= soil reaction, BD = bulk density, AvP = available phosphorous, AvS = available sulfur, TN =total nitrogen, OC = organic carbon, CEC =cation exchange capacity, AvK =available potassium, ExNa =exchangeable sodium, Exk = exchangeable potassium, Exca = exchangeable calcium, Exmg = exchangeable magnesium and Exbase = exchangeable base.*

4.5 Partial Budget Analysis

The variable costs associated with this experiment encompass the expenses for NPS fertilizer and vermicompost. However, certain costs, such as those for seeds, chemical sprays, irrigation, weeding, and harvesting, remained consistent across the treatments, while the cost of fertilizer application exhibited only minor differences among them. Additionally, both the total variable costs and the net benefits were computed. During the harvesting season, the market price for Bombay red onion bulbs was 45 Birr per kilogram, while the costs for NPS fertilizer and vermicompost during the planting season were 36.97 Birr per kilogram and 10 Birr per kilogram, respectively.

The highest adjusted marketable bulb yield recorded was 29.45 ton ha^{-1}, achieved with the application of 400 kg of NPS fertilizer ha^{-1}in conjunction with 5 ton of vermicompost ha^{-1}. This treatment yielded the greatest net benefit of 1,204,612 Birr ha^{-1} and a benefit-to-cost ratio of 10.99. Following this, a yield of 25.995 ton ha^{-1} was obtained from plants that received 300 kg of NPS fertilizer ha^{-1} along with 5 ton of vermicompost ha^{-1}, resulting in a net benefit of 1,052,834 Birr ha^{-1} and a benefit-to-cost ratio of 10. The lowest adjusted marketable bulb yield was 2.505 ton ha^{-1}, with a net benefit of 56,875 Birr ha^{-1} and a benefit-to-cost ratio of 2.02, observed in plants that did not receive any fertilizer.

The highest marginal rate of return (MRR%) recorded was 10855% (or 108.55), which was observed in plots treated with 100 kg ha^{-1} of NPS fertilizer combined with 2.5 tons ha^{-1} of vermicompost. Conversely, the lowest MRR of -2036% (-203.6) was noted for plants that received only 2.5 ton ha^{-1} of vermicompost. The second and third highest MRRs were 7824% (78.24) and 7203% (72.03), corresponding to the application of 400 kg ha^{-1} and 100 kg ha^{-1} of NPS fertilizer, respectively. Overall, the MRR for the production of Bombay red onion using various rates of NPS and vermicompost fertilizers exceeded -2036%, with the exception of the treatment involving only 2.5 ton ha^{-1} of vermicompost. This indicates that the production of the Bombay red onion variety, when utilizing all fertilizer rates, achieved a minimum acceptable rate of return, as defined by CIMMYT (1988), which considers a minimum acceptable MRR to be 100%.

The premise is that when a grower invests 1 Birr in the cultivation of Bombay red bulbs, there exists the potential to earn an additional 1 Birr from the sale of the product. The marginal rate of return is defined as the marginal net benefit (Stephen and Nicky, 2007). However, the optimal treatment recommendations are not solely determined by the highest marginal rate of return; instead, they should be based on the minimum acceptable marginal rate of return in conjunction with the maximum net benefit that producers can achieve through the adoption of the technology (CIMMYT, 1988). The application of fertilizer should ideally yield the highest net returns with a minimum benefit-cost ratio of 2:1, although a higher ratio is preferable. A frequent error is to focus exclusively on the benefit-cost ratio while neglecting the absolute net return (Fixen et al., 2014).

One of the primary goals of using fertilizers is to enhance yield production (Badr et al., 2012). This indicates that the best treatment recommendations should consider not only the marginal rate of return but also the absolute net return, benefit-cost ratio, and yield. Consequently, a preliminary recommendation was made to apply 100 kg ha^{-1} of NPS fertilizer in conjunction with 2.5 ton ha^{-1} of vermicompost for the production of Bombay red onions in Meskan woreda. This recommendation is based on the fact that the combined application of organic and inorganic fertilizers at these specified rates resulted in the highest adjusted marketable bulb yield of 29.45 ton ha^{-1}, along with the highest net benefit of 1,204,612 Birr ha^{-1} and a benefit-cost ratio of 10.99.

Table 8.Summary of economic analysis of application of vermicompost and NPS for onion production

Treatment combination		Adj MBY ton/ha	GFB ETB/ha	TVC Birr	NB ETB/ha	BCR	MRR	MRR (%)
VC 0 ton/ha	NPS 0 kg/ha	2.505	112725	0	56875	2.02	0	0
	NPS 100 kg/ha	8.505	382725	3697	323178	6.43	72.03	7203
	NPS 200 kg/ha	13.005	585225	7394	521981	9.25	53.77	5377
	NPS 300 kg/ha	15.495	697275	11091	630334	10.42	29.31	2931
	NPS 400 kg/ha	22.005	990225	14788	919587	14.02	78.24	7824
VC 2.5 ton/ha	NPS 0 kg/ha	5.505	247725	25000	166875	3.06	-203.6	-2036
	NPS 100 kg/ha	14.505	652725	28697	568178	7.72	108.55	10855
	NPS 200 kg/ha	16.995	764775	32394	676531	8.67	29.31	2931
	NPS 300 kg/ha	22.005	990225	36091	898284	10.77	59.98	5998
	NPS 400 kg/ha	23.505	1057725	39788	962087	11.06	17.26	1726
VC 5 ton/ha	NPS 0 kg/ha	18.495	832275	50000	726425	7.86	-63.74	-6374
	NPS 100 kg/ha	18.495	832275	53697	722728	7.6	-1	-1
	NPS 200 kg/ha	22.5	990000	57394	876756	8.74	41.66	4166
	NPS 300 kg/ha	25.995	1169775	61091	1052834	10	47.63	4763
	NPS 400 kg/ha	29.45	1325250	64788	1204612	10.99	41.05	4105

Key: *AdjMBY =adjusted marketable bulb yield, GFB = gross field benefit, TVC = total variable cost, =NB = net benefit, BCR = benefit cost ratio and MRR = marginal rate of return*

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The findings of this study depicted that vermicompost and NPS fertilizer used together can improve the physicochemical properties of soil by increasing microbial activity, soil structure, and nutrient availability. For onion crops, this integration leads to increased yield, increased bulb development, and improved crop resilience. This attributes to the fact that the combined use these fertilizers offer a balanced and sustainable way to grow onions, enhancing both short-term yields and long-term soil health.

The bulk density measurements for the examined surface soil fell within an acceptable range for vegetable cultivation, including onions. The analysis revealed that the soil exhibited a moderately acidic reaction, with a pH of 5.4, which is outside the optimal pH range for the effective availability of essential nutrients for onion growth. Additionally, the fertility levels of the soils in the study area, as indicated by total nitrogen, organic carbon, available phosphorus, and available sulfur, were found to be low.

Results from the field experiment demonstrated that the combined application of vermicompost and NPS fertilizers enhanced the nutrient profile of the soil, while also reducing bulk density by 1.38g cm^3 below that of the control due to varying rates of organic amendments. The higher pH associated with vermicompost contributed to a relative increase in soil pH 6.08% compared to the control. Furthermore, the application of both organic and inorganic fertilizers at a rate of 400 kg NPS ha^{-1} along with 5 ton of vermicompost ha^{-1} led to an increase in organic matter, total nitrogen 0.27%, available phosphorus 10.77ppm., available sulfur 52.94ppm, exchangeable base 74.37meq/100g, and cation exchange capacity (CEC) 78.68 $cmol^+$ kg^{-1}compared to the control.

The maximum marketable bulb yield of 32.78 ton ha^{-1} and the total bulb yield of 33.33 ton ha^{-1} were achieved in plots treated with 400 kg of NPS fertilizer ha^{-1} and 5 ton of vermicompost ha^{-1}. Additionally, the largest bulb diameter and the highest average bulb weight were observed in these same plots compared to the control treatment. Consequently, this study aimed to assess the impact of the combined use of vermicompost and inorganic NPS fertilizer on the physical and chemical properties of the soil, as well as on the bulb yield and yield components of onion, promoting sustainable nutrient management practices that are environmentally friendly.

The combined use of vermicompost and NPS fertilizers offers a cost-effective and sustainable approach for farmers, particularly in areas with low soil fertility. Vermicompost, as an organic amendment, improves soil structure, water retention, and nutrient availability, while NPS fertilizers provide readily available nutrients needed for plant growth. Combining these two approaches can lead to increased crop yields, reduced reliance on synthetic fertilizers, and improved soil health. Vermicompost can replace a portion of the NPS fertilizer required, reducing the overall input cost for farmers, the cost of producing vermicompost can be significantly lower than purchasing synthetic fertilizers, especially when utilizing locally available organic waste materials. The improved soil health and nutrient availability due to vermicompost and NPS fertilizers can lead to higher crop yields, increasing the overall economic return for farmers.

The analysis of variances indicated that the application rates of NPS and VC, as well as their interaction, had a significant impact on all bulb yields and yield components of Bombay red onion. However, the interaction between NPS and VC regarding days to maturity and bulb length (cm), along with the effect of NPS fertilizer on bulb length, was found to be non-significant. Both fertilizers and their interaction significantly affected all selected physical and chemical properties of the soil after the harvest of Bombay red onion, with the exception of soil pH. This suggests that the combined use of organic and inorganic fertilizers is more beneficial for the sustainable productivity of Bombay red onion and the enhancement of soil properties than the sole application of fertilizers.

The highest marginal rate of return (MRR %) of 10,855% was recorded for plots treated with 400 kg ha^{-1} of NPS fertilizer combined with 5 ton ha^{-1} of vermicompost. Conversely, the highest adjusted marketable bulb yield of 29.45 ton ha^{-1}, along with the greatest net benefit and benefit-to-cost ratio of 1,204,612 Birr ha^{-1} and 108.55, respectively, was observed in plots that received 400 kg ha^{-1} of NPS fertilizer alone, yielding an MRR (%) of 78.24%. Furthermore, the application of 400 kg ha-1 of NPS fertilizer in conjunction with 5 tons ha^{-1} of vermicompost resulted in robust plant growth and enhanced the shelf life of the bulbs, as well as improved most soil physical and chemical properties.

5.2 RECOMMENDATION

To improve the physical and chemical properties of the soil and increase the yield of Bombay red onions in Meskan Woreda, it has been suggested to apply 400 kg of NPS fertilizer ha^{-1} alongside 5 ton of vermicompost ha^{-1}. The effectiveness of Bombay red onion production is significantly influenced by the type of fertilizers used to provide essential nutrients. The integration of both organic and inorganic fertilizers is crucial for ensuring long-term productivity sustainability. Consequently, the study's findings advocate for the combined application of 5 ton of vermicompost and 400 kg of NPS inorganic fertilizer ha^{-1} to preserve soil fertility and support onion crop yields.

However, assessing the enhancement of soil properties based solely on a single season and location of organic and inorganic fertilizer application is insufficient. Additionally, evaluating bulb yield and the economic advantages of fertilizer use cannot be accurately determined from a one-season trial at a single site. It is essential to adopt integrated nutrient management and land management practices that enhance nutrient availability while minimizing the toxicity of other nutrients. This approach should include the simultaneous application of inorganic NPS fertilizers and vermicompost, along with ongoing monitoring from land preparation through to post-harvest. Therefore, it is advisable to recommend that the experiment be repeated for at least one additional season at the same location, and if possible, across different locations within the study area to formulate applicable recommendations.

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APPENDIX

Appendix 1 Mean squares from analysis of variance for physical and chemical Properties of soil after harvesting of Bombay red as influenced by vermicompost and NPS fertilizer

Source of variation	REP(2)	NPS (3)	VC (2)	NPS*VC(8)	Error(28)	CV (%)
PH	0.043745	0.022685ns	0.038232*	0.039502*	0.05613614	4.048021
BD	0.00001556	0.000336**	0.009765**	0.000201**	0.00010033	0.702855
AvP	2.9998985	30.7208**	10.19168*	0.361923**	0.0001712	0.160773
AvS	782.905669	609.798**	36.61137*	895.122**	0.62198	2.092543
TN	0.00935053	0.007479*	0.013345**	0.009137**	0.00000944	2.093135
OC	0.71920889	1.141446*	6.639896**	1.979059**	0.00115594	2.026707
CEC	88.21742	873.9927**	113.5872**	1341.263**	0.01617	0.299436
AvK	4993.5162	18689.4**	17521.74**	31682.58**	2493.9019	11.99943
EX.Base	60.781202	1027.527**	205.7785*	1181.543**	0.01205	0.284617

and =,significantly different at 5% and 1% respectively PH=soil reaction, BD=bulk density, AvP=available phosphurous, AvS=Available sulfur, TN=Total Nitrogen, OC =Organic Carbon,*

CEC=Cation Exchange Capacity, AvK= Available Potassium,EX.Base=Exchangeable Base, REP=Replication, VC=Nermicompost

NPS=Nitrogen, Phosphorous and Sulfur, CV=Coefficient of Variation

Appendix 2. Mean squares from analysis of variance for bulb yields of Bombay red onion as influenced by vermicompost and NPS fertilizer

Parameter	Replication (2)	NPS(3)	VC(2)	VC*NPS (8)	Error(28)	CV (%)
BD(cm)	2.616667	8.225899*	13.53857**	2.124077**	0.053332	3.93644
BL(cm)	3.316667	8.402596*	13.87959**	2.361337**	0.057371	4.106113
MBW(g)	282.6	2929.661**	3521.705**	377.2465**	22.35619	6.098323
MBY(t ha -1)	10803.94	54746.39**	41444.64*	1544.822**	768.6657	14.75885
TBY(t ha -1)	2487.379	33593.56**	55733.14**	1523.636**	93.9807	4.707679

and =,significantly different at 5% and 1% respectively BL=Bulb length, BD= Bulb diameter, MBW= Mean bulb weight,*
MBY= Marketable bulb yield, TBY= Total bulb yield.

Appendix 3 Annual (Rainfall in mm) Annual average temperature (max and min) oC

Station name: - Butajira, Year: - 2011_2021GC

Year	ANRf	Anav Tmax	Anav Tmin
2011	797.3	27.7	12.8
2012	781.6	27	12.6
2013	1322.2	27.9	11.9
2014	1761.1	26.9	13.1
2015	454.8	28.4	11.8
2016	322.83	28.8	11.5
2017	203.6	27.8	11.1
2018	627.5	25.9	10.5
2019	960.2	32.4	11.4
2020	1445	29.4	13
2021	328.9	28.9	12.4

Key: *ANRf = Annual Rainfall, Anav Tmax =Annual average maximum temprature*
And Anav Tmax = Annual average minimum temprature

Appendix 4 Correlation analysis for the given parameters

	REP	VC	NPS	BL	Bdiameter	BW	MBY	UMBY	TBY	PH	BD	AvaiP	avaiS	TN	OC	OM	CEC	AvaiK	ExNa	Exk	Exca	Exmg	Exbase
REP	1.00	0.06667	0.01925	0.2717	0.24945	0.1301	0.22646	-0.36725	0.12397	-0.20207	0.01147	0.02085	-0.37103	-0.17506	0.09916	0.08322	-0.05248	0.04432	0.19548	0.13361	-0.00655	-0.00597	-0.0104
VC		1.000	0	0.55311	0.55877	0.54208	0.56613	0.06676	0.64353	0.10914	-0.84899	0.26292	-0.01301	0.26673	0.56293	0.58533	-0.10474	0.08356	0.27235	0.34542	-0.11109	-0.416	-0.14615
NPS			1.000	0.62747	0.63369	0.72052	0.72702	-0.52032	0.71922	-0.00864	-0.09273	0.9301	0.23335	0.22543	0.1874	0.20785	0.24463	0.39583	0.49456	0.43298	0.27328	0.40857	0.28765
BL				1.000	0.99342	0.92368	0.86819	-0.3725	0.87195	0.01471	-0.49207	0.76663	-0.0328	0.09175	0.46889	0.41757	0.13624	0.50578	0.5632	0.506	0.16416	0.07284	0.17233
Bdiameter					1.000	0.93119	0.84457	-0.34839	0.88588	0.06818	-0.48378	0.777	-0.02632	0.09042	0.45963	0.40295	0.1353	0.52135	0.55796	0.51113	0.16074	0.06735	0.16677
BW						1.000	0.85655	-0.33205	0.90964	0.08385	-0.49184	0.83263	0.04863	0.28198	0.5371	0.41249	0.00732	0.3905	0.58003	0.57175	0.04549	-0.01181	0.04798
MBY							1.000	-0.49223	0.92687	-0.1747	-0.56058	0.80595	0.08117	0.2179	0.45375	0.52498	0.17313	0.39367	0.63175	0.57165	0.22252	0.1314	0.20453
UMBY								1.000	-0.29862	0.32116	0.13302	-0.41254	0.01245	0.08316	0.11887	0.03798	-0.20077	-0.17939	-0.07702	0.02279	-0.28062	-0.31948	-0.25105
TBY									1.000	0.08542	-0.56933	0.8366	0.11925	0.24263	0.48565	0.5152	0.14885	0.44259	0.64342	0.62627	0.18333	0.06917	0.16244
PH										1.000	-0.10063	0.06486	-0.138	0.10415	0.13602	-0.13833	-0.25921	0.18848	-0.09914	0.04258	-0.27537	-0.2729	-0.27973
BD											1.000	-0.2813	-0.07379	-0.22041	-0.42687	-0.44219	0.04427	0.00098	-0.17113	-0.18461	0.0498	0.27141	0.07961
AvaiP												1.000	0.26212	0.35349	0.37041	0.35463	0.1751	0.46293	0.55947	0.52357	0.16657	0.25408	0.19631
avaiS													1.000	0.23412	-0.03135	0.38953	0.61199	-0.29673	0.30323	0.06945	0.53945	0.56684	0.59744
TN														1.000	0.78725	0.52409	-0.47917	-0.13593	0.3173	0.5171	-0.49567	-0.42477	-0.46293
OC															1.000	0.66767	-0.46978	0.01361	0.53848	0.71509	-0.46154	-0.50275	-0.43551
OM																1.000	0.21819	-0.14173	0.64078	0.55302	0.2119	0.05672	0.23455
CEC																	1.000	0.03443	0.21415	-0.14113	0.97736	0.90173	0.98902
AvaiK																		1.000	0.19603	0.29513	0.06386	0.03646	0.03238
ExNa																			1.000	0.88749	0.21604	0.24774	0.25855

Exk	1.000	-0.1321	-0.1287	-0.11516
Exca		1.000	0.89422	0.98724
Exmg			1.000	0.92558
Exbase				1.0000

Appendix 5 Ratings of cation exchange capacity and exchangeable

Rating or	A Landon	FAO	FAO	FAO	FAO
class	CEC	Exch ca	Exch.Mg	Exch.K	Exch.Na
Very low	<5	>2	<3	>0.2	<0.10
Low	5-15	2-5	0.3-1.0	0.2-0.3	0.1-0.3
Medium	15-25	5-10	1.0-3.0	0.3-0.6	0.3-0.7
High	25-40	10-20	3-8	0.6-1.2	0.7-2
Very high	>40	>20	>8.0	>1.2	>2

Sources: Landon (1991); FAO (2006b)

Appendix 6 Ratings of Bulk Density and Particle size for given soil

Rating (g.cm^3)	Bulk density	Percent of sand, silt and clay
Very Low	<1	<10
Low	1.0-1.3	10-25
Medium	1.3-1.6	25-40
High	1.6-1.9	40-50
Very high	>1.9	>50

Source: HaZelton,P and B.Murphy (2007)

Appendix 7 Ratings of soil reaction based on PH (H2O)

Soil reaction class	P^H (1:2.5 H_2O)
Very strongly acidic	<4.5
Strongly acidic	4.5-5.2
Moderately acidic	5.3-5.9
Slightly acidic	6-6.6
Neutral	6.7-7.3
Moderately alkaline	7.4-8
Strongly acidic	>8

Sources: Tekalign (1991)

Appendix 8 Rating of soil organic matter, organic carbon and total nitrogen

Rating	Murphy (1968)	Tekalign (1991)	Murphy (2007)
	OM	**OC**	**TN**
Very low	<1.0	<0.50	Not Given
Low	1-2	0.5-1.5	<0.10
Medium	2.3	1.5-3.0	0.10-0.15
High	3-5	>3	0.15-0.25
Very high	>5	Not Given	>0.25

Sources: Murphy (1968), and Tekalign (1991)

Appendix 9 Analysis of variance (ANOVA) table for Ph

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	0.57070817	0.03566926	0.64	0.8281
Error	28	1.57181183	0.05613614		
Corrected Total	44	2.14252000			

Appendix 10 Analysis of variance (ANOVA) table for BD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	0.02251522	0.00140720	14.03	<.0001
Error	28	0.00280923	0.00010033		
Corrected Total	44	0.02532444			

Appendix 11 Analysis of variance (ANOVA) table for av.P

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	152.1617442	9.5101090	55556.7	<.0001
Error	28	0.0047930	0.0001712		
Corrected Total	44	152.1665372			

Appendix 12 Analysis of variance (ANOVA) table for av.S

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	11239.20204	702.45013	1129.38	<.0001
Error	28	17.41541	0.62198		
Corrected Total	44	11256.61744			

Appendix 13 Analysis of variance (ANOVA) table for TN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	0.14840523	0.00927533	982.48	<.0001
Error	28	0.00026434	0.00000944		
Corrected Total	44	0.14866957			

Appendix 14 Analysis of variance (ANOVA) table for OC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	35.11706474	2.19481655	1898.73	<.0001
Error	28	0.03236637	0.00115594		
Corrected Total	44	35.14943111			

Appendix 15 Analysis of variance (ANOVA) table for CEC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	14629.68557	914.35535	56554.8	<.0001
Error	28	0.45269	0.01617		
Corrected Total	44	14630.13826			

Appendix 16 Analysis of variance (ANOVA) table for Exbase

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	14095.57107	880.97319	73117.6	<.0001
Error	28	0.33736	0.01205		
Corrected Total	44	14095.90843			