GROWTH AND BULB YIELD RESPONSE OF ONION (*Allium cepa* L.) VARIETIES TO VARYING LEVELS OF NITROGEN AND VERMICOMPOST IN BIISHAAN GURACHAA, OROMIA, ETHIOPIA

M.Sc. THESIS

BY

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HAWASSA UNIVERSITY

COLLEGE OF AGRICULTURE

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Hawassa, Ethiopia

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M.Sc. Thesis

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A Thesis Research Submitted to the School of Plant and Horticultural Sciences, School of Graduate Studies College of Agriculture, Hawassa University.

In partial fulfillment for the requirement for the degree of Master of Science in Horticulture.

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SCHOOL OF GRADUATE STUDIES

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APPROVAL SHEET-I
(Submission Sheet – 1)

This is to certify that the thesis entitled **"Growth and bulb yield response of onion (*Allium cepa L.)* varieties to varying levels of nitrogen and vermicompost,"** submitted in partial fulfillment of the requirements for the degree of master with specialization in **horticulture** to the graduate program of the school of plant and horticultural sciences, college of agriculture, is a record of original research that has been carried out by **Badege Ayele Mengesha** under our supervision, and no part of the thesis has been submitted for any other degree or diploma. The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, we recommend it be accepted as fulfilling the thesis requirements.

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DEDICATION

I dedicate this thesis manuscript to my mother, Amarech Yirgu, for her scarification throughout my education, advice, care, and for her partnership in the success of my life.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is a result of my work, and all other sources of material and information used for writing it have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the MSc degree at Hawassa University and is deposited at the university's library to be made available to borrowers under the rules and regulations of the library. I solemnly declare that this thesis has not been submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Signature ________________

Place: Hawassa University

Date of Submission: _______________

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
LSD	Least Significant Difference
CV	Coefficient of Variation
SPSS	Statistical Package for Social Sciences
CRD	Completely Randomized Design
RCBD	Randomized Complete Block Design
DMRT	Duncan‟s Multiple Range Test
HSD	Honestly Significant Difference
FAO	Food and Agriculture Organization
NPK	Nitrogen, Phosphorus, and Potassium
TSS	Total Soluble Solids
EC	Electrical Conductivity
DAT	Days after transplanting

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Growth and bulb yield response of onion (*Allium cepa* L.) Varieties to varying levels of nitrogen and vermicompost in Biishaan Gurachaa, Oromia, Ethiopia

Badege Ayele (BSc), Ashenafi Haile (Ass. Prof.) and Alemayehu Kiflu (Asso.prof)

ABSTRACT

*Onion is a vital horticultural crop in Ethiopia, supporting both rural livelihoods and urban food systems. However, its productivity remains low due to poor nutrient management, declining soil fertility, and continued reliance on unimproved varieties. Excessive nitrogen use often results in delayed maturity and reduced bulb quality, while organic inputs like vermicompost remain underutilized. This study was conducted to evaluate the combined effects of nitrogen and vermicompost on the growth, yield, quality, and economic performance of improved onion varieties under highland conditions. A field experiment was carried out during the off-season at Shallo Farm, using a randomized complete block design (RCBD) with three replications. Treatments were arranged in a 3 × 4 × 3 factorial combinations comprising three onion varieties (Rio Bravo f1, Nafis, and SV Runagrana f1), four nitrogen rates (0, 75, 150, and 225 kg N ha^{-1}), and three vermicompost levels (0, 5, and 7 t ha^{-1}), giving 36 treatment combinations. Data were collected on phenology, growth, yield, and bulb quality parameters, and subjected to both agronomic and economic analyses. The three-way interaction among variety, nitrogen, and vermicompost significantly ($P < 0.01$) influenced most growth, yield, and quality traits. SV Runagrana f1 exhibited the best performance, producing the highest total bulb yield (57.48 t ha^{-1}) and marketable yield (51.13 t ha^{-1}) at 225 kg N ha^{-1} combined with 7 t ha^{-1} vermicompost. Excessive fertilization (>225 kg N + 7 t VC ha^{-1}) increased unmarketable yield, delayed maturity, and lowered bulb quality. Economic analysis further revealed that SV Runagrana f1 at 225 kg N + 7 t VC ha^{-1} provided the highest net field benefit (*4,471,000 *Birr ha^{-1}), benefit–cost ratio (*35.1%*), and marginal rate of return (15,000 %), indicating strong profitability despite higher input costs. In contrast, moderate fertilization (75 kg N + 5 t VC ha^{-1}) offered a favorable trade-off between yield stability, quality, and input efficiency, making it a more sustainable option for smallholder farmers. Therefore, the study demonstrated that onion yield, quality, and economic returns are highly dependent on the interaction between genotype and nutrient management.Further studies should investigate long-term soil fertility effects and validate the economic sustainability of these practices across diverse agro- ecological zones.*

Keywords: *Onion, Yield, Quality, Vermicompost, Nitrogen, Variety*

1. INTRODUCTION

Onion (*Allium cepa* L.) belongs to the family Alliaceae (Amaryllidaceae) and is one of the most important monocotyledonous crops cultivated worldwide. It is classified under the genus Allium and may be biennial or perennial depending on the cultivar (Pareek et al. 2017). Morphologically, the plant is characterized by shallow, adventitious fibrous roots, a bulb, and hollow tubular leaves. The shallow and sparse root system makes onions highly susceptible to nitrate leaching below the root zone with percolating water (Geisseler et al. 2022).

It is one of the most widely cultivated bulbs crops globally. In 2021, world production reached 74.25 million tons from 4.36 million hectares of land, with China as the leading producer followed by India (FAO. 2023).

In Ethiopia, onion ranks second among vegetable crops after tomato. Its cultivation is mainly concentrated in the Central Rift Valley, particularly in the upper Awash and Lake Ziway areas (Okpanachiu, 2022).it is among the leading irrigated horticultural crops, supporting smallholder livelihoods, household income generation, and urban food supply (Nigussie et al. 2015). Despite this importance, national productivity remains below the global average due to multiple challenges, including limited access to improved varieties, nutrient management inefficiencies, soil fertility decline, and overreliance on unimproved varieties, such as ‘Bombay Red’(Addis et al. 2024).

One of the major constraints in onion production is poor nutrient management. Low soil fertility, inappropriate fertilizer use, lack of improved agronomic practices, and reliance on traditional varieties all contribute to low yields (Lemma and Shimelis., 2003). Optimized agronomic practices (including proper spacing, plant population, planting date, and harvesting time) have been shown to substantially increase productivity (Gebretsadkan et al. 2018). Among nutrients, nitrogen (N) is particularly critical for onion growth and yield. Because onions are shallowrooted with limited nutrient uptake capacity, they are highly responsive to external nitrogen application (Boyhan et al. 2001). Adequate nitrogen promotes vegetative growth, leaf expansion, Chlorophyll accumulation, and assimilates production, which is vital for bulb formation (Li et al. 2025). However, excessive nitrogen leads to problems such as excessive vegetative growth, delayed maturity, "thick-neck" formation, and poor storability (Boyhan et al., 2001). Thus, precise and site-specific nitrogen management is essential to maximize yield and maintain bulb quality (Elouattassi et al., 2024).

Varietal adaptability further influences nutrient use efficiency and yield potential. Hybrid onion cultivars often outperform traditional open-pollinated varieties under moderate nitrogen regimes, highlighting the importance of integrating variety selection with nutrient management. Blanket fertilizer recommendations are therefore inefficient, leading to poor resource use and economic losses. At the same time, heavy reliance on mineral fertilizers alone presents challenges such as high input costs, nutrient leaching, soil acidification, and environmental concerns. In Ethiopia, fertilizer price volatility and limited access to balanced fertilizers exacerbate these issues (Yeshiwas et al., 2024).

Organic amendments such as vermicompost are increasingly recognized as sustainable alternatives to supplement mineral fertilizers. Vermicompost, produced through the decomposition of organic matter by earthworms and microorganisms, is a nutrient-rich amendment that improves soil structure, water-holding capacity, and microbial activity. It also contains humic substances and hormone-like compounds that stimulate plant growth and stress resilience (Addis et al. 2024). Studies have shown that vermicompost enhances onion growth, bulb size, yield, and soil health by increasing organic matter, microbial biomass, and nutrient availability (Gebremichael et al., 2017; Setyowati et al., 2021).

Integrating vermicompost with nitrogen fertilization has proven particularly effective. Research in Ethiopia indicates that combined application improves bulb yield and marketable quality more than either input used alone (Addis et al. 2024). This synergy arises because vermicompost enhances soil physical and biological conditions, thereby improving nitrogen use efficiency. (NUE) and reducing nutrient losses. Integrated nutrient management (INM) strategies therefore provide a pathway toward sustainable onion production, ensuring yield gains while maintaining long-term soil fertility (Andishmand and Noori, 2021).

Despite growing evidence, the optimum combinations of nitrogen and vermicompost under Ethiopian conditions remain poorly defined, and the interaction between nutrient management and varietal performance is not well understood. Considering that both variety and nutrient inputs strongly determine growth and yield, research is needed to evaluate onion varieties under different levels of nitrogen and vermicompost. Therefore, this study was designed to investigate the growth and bulb yield performance of onion varieties in response to integrated nitrogen and vermicompost management.

2. LITERATURE REVIEW

2.1. Description of Onion Crop

Onion (*Allium cepa* L.) belongs to the family Alliaceae (Amaryllidaceae) and is one of the most important monocotyledonous crops cultivated worldwide. It is classified under the genus Allium and may be biennial or perennial depending on the cultivar (Pareek et al. 2017). Morphologically, the plant is characterized by shallow, adventitious fibrous roots, a bulb, and hollow tubular leaves. The shallow and sparse root system makes onions highly susceptible to nitrate leaching below the root zone with percolating water (Geisseler et al. 2022).

Onions can be grown across a wide range of climates, though they perform best in moderate environments with limited extremes of heat or cold. Being a cool-season crop, onion tolerates mild frost but grows optimally within a temperature range of 13–24°C. Seedling establishment is favored at 23–27°C, while growth slows considerably above 30°C. High temperatures coupled with low relative humidity are preferred during the bulb maturation, harvest, and curing phases (Purseglove. 1985, Rubatzky and Yamaguchi, 1997; Jilani et al., 2010; Guesh, 2015).

The crop is adaptable to various soil types including sandy loam, clay loam, and silt loam but performs best on deep, friable loam and alluvial soils with good drainage, high moisture-holding capacity, and adequate organic matter (Khade et al.2017). Onion is highly sensitive to soil acidity, alkalinity, salinity, and waterlogging. It does not grow well in soils with pH below 6.0, where micronutrient deficiencies or Al/Mn toxicities commonly occur (Hurst 2018). Optimal bulb growth is supported by consistent seasonal moisture availability of 400–800 mm per crop, while in mineral soils the ideal pH range is 6.5–8.0 (Guesh, 2015).

2.2. Production Status of Onion

Onion is one of the most widely cultivated bulbs crops globally. In 2021, world production reached 74.25 million tons from 4.36 million hectares of land, with China as the leading producer followed by India (FAO. 2023). Productivity is highest in the Republic of Korea (66.16 t ha^{-1}), followed by the USA (56.26 t ha^{-1}), Spain (53.31 t ha^{-1}), and the Netherlands (51.64 t ha^{-1}). The global average productivity stands at 19.79 t ha^{-1} and international trade accounts for about 6.77 million tons of onions annually (Pareek et al., 2017).

In Ethiopia, onion ranks second among vegetable crops after tomato. Its cultivation is mainly concentrated in the Central Rift Valley, particularly in the upper Awash and Lake Ziway areas (Okpanachiu, 2022). The country has considerable potential for onion expansion due to favorable climatic conditions and increasing market demand for bulbs, seeds, and flowers Lemma and Shimeles (2003). However, productivity remains low. During the 2012/2013 season, onions were cultivated on about 21,865 ha, producing 219,919 t with an average yield of 10.06 t ha^{-1}, which is markedly lower than the global average of 19.31 t ha^{-1} (Gebretsadkan et al., 2018).

2.3. Response of Onion Varieties to Nitrogen Application

Nitrogen is a vital macronutrient that strongly influences onion growth, bulb development, yield, and quality. As a fundamental component of amino acids, proteins, enzymes, and chlorophyll, it plays a central role in photosynthesis, vegetative growth, and assimilates partitioning Lawal et al. (2021). Adequate nitrogen fertilization promotes vigorous leaf growth, which directly enhances photosynthetic capacity and supports bulb initiation and enlargement. Since onion yield is closely related to the number and size of functional leaves, nitrogen management is a critical factor in maximizing productivity (Hossain et al., 2020).

Onion varieties differ significantly in their response to nitrogen due to genetic differences in nutrient uptake efficiency, canopy architecture, growth cycle, and environmental adaptability Molla et al. (2019). In Ethiopia, Gebremeskel et al. (2020) reported differential responses among cultivars to nitrogen rates ranging from 0–150 kg N ha^{-1}, with the improved variety „Bombey Red‟ achieving the highest marketable bulb yield at 100 kg N ha^{-1}. Similarly, Molla et al. (2019)

observed that improved cultivars such as Nafis and Adama Red responded more favorably than traditional landraces, producing significantly higher bulb yields under nitrogen fertilization.

International studies support these findings. Singh et al. (2021) noted that Indian varieties such as Pusa Red and Agrifound Dark Red attained maximum bulb yield at 100–125 kg N ha^{-1}, while higher nitrogen levels reduced bulb quality by lowering dry matter content and total soluble solids. In Nigeria, Lawal et al. (2021) found that onion cultivars in the Sudan savanna exhibited variable yield responses, with optimum nitrogen requirements ranging from 75–150 kg N ha^{-1} depending on genotype. Excess nitrogen application has been consistently associated with delayed maturity, excessive vegetative growth, and poor storage quality (Hossain et al., 2020).

Recent evidence also highlights variety-specific differences in nitrogen use efficiency. For instance, Mohammed et al. (2022) demonstrated that the Nafis variety responded optimally at 150 kg N ha^{-1} under irrigated Ethiopian conditions, showing improved bulb size, yield, and dry matter content, whereas higher rates conferred no additional benefits. Hybrid cultivars generally utilize nitrogen more efficiently than open-pollinated types. Thus, the response of onion varieties to nitrogen application is influenced by both genetic and environmental factors. While most cultivars perform best within 75–225 kg N ha^{-1}, the exact requirement is variety- and site-specific (Gebremeskel et al., 2020; Mohammed et al., 2022). This underscores the need for variety-specific nitrogen recommendations tailored to local agroecological conditions to enhance productivity, bulb quality, and storability.

2.4. Response of Onion to Organic Fertilizer

Organic fertilizers play a critical role in improving soil physical, chemical, and biological properties that support sustainable onion production. By enhancing soil structure, water-holding capacity, microbial activity, and nutrient availability, they stimulate root growth and improve crop performance (Xu et al., 2023; Jiang et al., 2023; Abdel-Rahman et al., 2025; Ali et al.,2021; Zhang et al., 2023).Among organic amendments, vermicompost has received particular attention. Produced through the decomposition of organic material by earthworms and microbes, vermicompost acts as a reservoir of nutrients, enhances soil health, and mitigates some negative effects of chemical fertilizers. It is also a valuable source of potassium, which is released gradually to meet onion nutrient demands throughout growth. Moreover, vermicompost promotes carbohydrate accumulation and alters fructan metabolism, contributing to bulb dry weight and storability (Juan et al., 2006).

Several studies highlight the benefits of vermicompost on onion performance. Alemu (2016) reported that different rates of vermicompost significantly improved vegetative traits including plant height, number of leaves, and biomass accumulation. These effects are attributed to increased soil microbial activity and micronutrient supply beyond NPK. Similarly, Reddy and Reddy (2005) and Surindra (2009) observed taller plants and improved growth under vermicompost, while Thanunathan et al. (1997) noted yield increases from 2.72 g/plant to 38.05 g/plant. Vermicompost has also been shown to improve bulb quality and storability (Rizk et al., 2002). In Ethiopia, Bangali et al. (2012) reported that vermicompost applied at 6 t ha^{-1} significantly enhanced plant height, number of leaves per plant, and leaf area index compared to lower levels. Overall, vermicompost improves both vegetative growth and bulb yield of onion while also sustaining soil fertility, making it a valuable component of organic nutrient management.

2.5. Interaction Effect of Nitrogen and Vermicompost on Onion Production

Due to the shallow and UN branched root system of onion, the crop is inherently inefficient in extracting nutrients, particularly immobile elements. As a result, it responds strongly to external nutrient supply, and optimal productivity requires integrating nutrient management with suitable varieties and agronomic practices (Limeneh et al., 2020).

Integrated nutrient management (INM) emphasizes the complementary use of organic and inorganic inputs to improve crop yield and sustain soil health (Asgele et al., 2018). In Ethiopia, limited farmer knowledge of optimum nitrogen rates and the benefits of combining vermicompost with mineral fertilizers has constrained productivity. Environmentally friendly, low-cost INM approaches can enhance nutrient use efficiency and reduce dependence on costly synthetic fertilizers (Rai et al., 2014).

Studies have demonstrated significant benefits of such integration. Andishmand and Noori (2021) recommended a combination of 20 t ha^{-1} farmyard manure with 150 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5, and 100 kg ha^{-1} K_2O for optimal onion yield. Kitila et al. (2022) found that the interaction of onion varieties (Adama Red, Monarch, and Nafis) with NPS fertilizer significantly influenced maturity, marketable yield, and bulb characteristics. The Monarch variety recorded the highest number of leaves per plant (16.08) and maximum marketable bulb yield (26.41 t ha^{-1}) at 150 kg NPS ha^{-1}, while total bulb yield reached 29.35 t ha^{-1} at 200 kg NPS ha^{-1}. Similarly, Gebremichael et al. (2017) reported that integrating 5 t ha^{-1} vermicompost with 50% recommended inorganic nitrogen achieved the best results in plant growth, bulb characteristics, and yield components, including plant height (71.67 cm), bulb diameter (5.90 cm), mean bulb weight (92.64 g), marketable yield (35.13 t ha^{-1}), and total yield (35.25 t ha^{-1}). This integrated approach also improved bulb dry weight, harvest index, and overall soil fertility, while minimizing postharvest weight loss.

3. MATERIALS AND METHODS

3.1. Description of the Experimental Site

The experiment was conducted April 30 to October 15 at Shallo Farm, located in Shashemene District**,** West Arsi Zone of the Oromia National Regional State**,** Ethiopia. Geographically, the site lies at approximately 7°12′ N latitude and 38°36′ E longitude, with an elevation ranging from 1,900 to 2,100 meters above sea level**.** The area is characterized by a mid-altitude (woina dega) agro-ecological zone. The climate is bimodal**,** consisting of a short rainy season (Belg) from February to May and a main rainy season (Meher) extending from June to September**.** The mean annual rainfall ranges between 900 and 1,200 mm**,** and the mean annual temperature **v**aries from 15 to 25°C**.** The dominant soil types of the farm are Vertisols and Nitisols**,** which are generally clay loam to clay in texture with slightly acidic to neutral pH (6.0–7.0). These soils have moderate fertility but are prone to drainage problems under excessive moisture conditions.

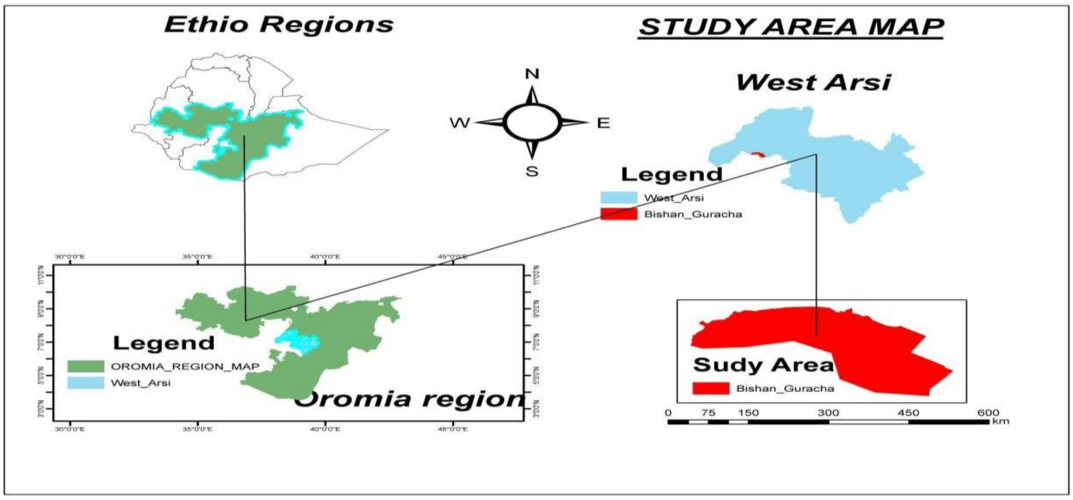

Figure 1. Study area map

3.2. Experimental Materials, Treatment and Design

Three onion varieties namely Bravo f1, Nafis, and SV Runagrana f1 were used in this experiment. The main distinguishing characteristics of the three onion varieties used in this study are summarized as follows:

Table 1: Description of onion varieties used in the study

Trait	Rio Bravo f1	Nafis	SV Runagrana f1
Leaf Color	Not well documented in scientific sources.	Deep green	No reliable published document.
Leaf Arrangement	Not clearly described in the literature.	Erect.	Not documented in accessible sources.
Bulb Size	No consistent published mm or size-class data.	100–130 mm (size-class) according to cultivar characterization.	No published size-class or diameter data was found.
Bulb Shape	Data not available from trustworthy sources.	Globe shaped	Not clearly described in the sources reviewed.
Bulb Skin Color	Not reliably documented in peer-reviewed literature.	Medium red skin.	No reliable published description.
Bulb Flesh Color	Undocumented in available literature.	Reddish-white flesh.	Not documented in reviewed sources.
Days to Maturity	Very limited information; not clearly described in scientific reports.	~90–100 days (reported by cultivar characterization)	No dependable published data found.
Total Soluble Solids (TSS)	No reliable published TSS data.	10–18% (from cultivar characterization)	Not documented in accessible scientific sources.
Dry Bulb Yield (t ha⁻¹)	Not clearly documented in scientific cultivar descriptions.	~40 t/ha (according to characterization table)	No published data was found in the sources consulted.

For Nafis, the cultivar characteristic table by Zeleke & Derso (2015) provides most of the above trait data.

Urea containing 46% nitrogen was used as the source of inorganic nitrogen fertilizer. Vermicompost was prepared between April 10 and May 25 by Elfora Agro-Industries PLC at Shallo Farm. The composting substrates consisted of *Amaranthus* weed, common bean straw, animal dung, mixture of cabbage and Kosta leaves, mixed at a ratio of 3:1:4:6. The dry matter content of the respective substrates was 20.47%, 61.08%, 16.97%, and 10.65%.

The treatments comprised of 3 ×4×3 factorial combinations of three levels of vermicompost, namely (0, 5, and 7 t ha^{-1}), four levels of nitrogen fertilizers, namely (0, 75, 150, and 225 kg ha^{-1}), and three improved onion varieties, namely Nafis, Rio Bravo f1, and SV Runagrana f1 thus the total combination of treatments were 36. The treatments were replicated three times and laid out in a randomized complete block design. Onion bulbs were planted in double rows; the spacing between water ridge furrows was kept at 40 cm, between the double rows 20 cm and between plants 5 cm (EARO, 2004).

3.3. Experimental Procedures and Crop Management

Onion seedlings were raised from April 30 to June 25 on a 5 m × 1 m seedbed. Seeds were sown in

15 cm rows, covered with plastic mulch until emergence, and thinned three weeks after germination. Seedbeds were irrigated twice daily, and seedlings were watered before uprooting to minimize root damage.

Vermicompost was incorporated one month before transplanting by placing it in furrows (10–15 cm depth) along planting rows. Healthy and uniform seedlings (56 days) were transplanted on June 25. Each plot measured 3.6 m^2 (1.2 m × 3 m) with a spacing of 0.5 m between plots and 1 m between blocks, giving a total experimental area of 667.7 m^2. Each plot contained three double rows with 60 plants per row (360 plants/plot).

Nitrogen fertilizer (urea, 46% N) was applied in two splits: 50% during transplanting and the remaining 50% one month later, before bulb initiation. Pesticides and fungicides were applied as needed to control onion thrips and fungal diseases, following recommended rates. All other agronomic practices were uniformly applied across treatments . Bulbs from the central three double rows were harvested at 60% top fall for analysis.

3.4. Vermicompost Sample Analysis

Vermicompost samples were analyzed before field application. Samples were randomly collected from the center of storage bags, air-dried, and sieved through a 2 mm sieve. pH was determined in a 1:2.5 vermicompost-to-water suspension using a glass electrode digital pH meter (Page et al., 1982). Electrical conductivity (EC), total nitrogen, phosphorus, potassium, and organic carbon were also analyzed. Total nitrogen was determined by the Kjeldahl method (Jackson, 1958), phosphorus by the Olsen method with spectrophotometry (Burt, 2014), exchangeable potassium using a flame photometer (Schulte and Corey, 1963), and organic carbon by the Walkley and Black wet digestion method (Walkley and Black, 1934).

3.5. Soil Sampling and Analysis

Soil samples were collected from the experimental site prior to planting. Composite samples (0–30 cm depth) were taken randomly in a zigzag pattern using an auger, air-dried, and sieved through a 2 mm sieve for laboratory analysis at Hawassa University. Soil properties analyzed included pH, total nitrogen, available phosphorus, potassium, organic matter, cation exchange capacity (CEC), and texture. Soil pH was measured in a 1:2.5 soil-to-water ratio with a pH meter, organic carbon by the Walkley and Black method (1934), available phosphorus by (Olsen et al. 1954), and total nitrogen by the Kjeldahl method (Jackson, 1958). The results were used to determine baseline soil fertility and guide nitrogen fertilizeapplication for onion production as shown in the table below.

Table 2: Physical and chemical Properties of the Experimental Soil and vermicompost

Physical property of soil before planting	Value
Sand (%)	59
Silt (%)	21.8
Clay (%)	19.2
Soil texture	Sandy loam
Bulk density (g/cm^3)	1.09
Soil color	10 YR 3/2
Chemical property of soil before planting	**Value**
pH.H20 (1:2.5)	6.7
E.C(ds/m)	0.175
Ava.P (ppm)	20.85
Organic carbon (%)	0.51
Organic matter (%)	0.89
Total Nitrogen (%)	0.04
C:N ratio	13

3.6. Data collected

3.6.1. Phenology and Growth Parameters of the onion Plant

Data on onion growth and phenology were collected following standard procedures. Days to maturity were recorded as the number of days from transplanting until 70% of the plants in each plot exhibited neck fall, which was also considered as the time when bulbs were physiologically mature and ready for harvest (Seifu, 2015). Plant height (cm) was measured on ten randomly selected plants per plot from the ground level to the tip of the longest mature leaf at 25-day intervals, up to 75 days after transplanting (Shura et al., 2022). The number of leaves per plant was counted on the same ten plants at 75 days after transplanting to determine vegetative vigor (Shura et al., 2022). Leaf diameter (mm) was measured at the mid-point of the widest leaf from ten representative plants in the net plot (Wassie et al., 2022), while leaf length (cm) was determined by measuring the longest leaf from its point of emergence to the tip at 75 days after transplanting (Shura et al., 2022).

3.6.2. Quality Parameter of Onion Bulb

Quality parameters were determined from randomly selected onion bulbs. Total soluble solids (TSS, °Brix) were measured by squeezing bulbs to extract juice and placing a drop on a Handheld refractometer, with readings expressed in °Brix (Shura et al., 2022). Titratable acidity (TA) was analyzed by titrating a known volume of onion extract with standardized sodium hydroxide solution using phenolphthalein as an indicator, and the results were expressed as percent citric acid equivalents. Salt content (%) was determined by titrating the extract against standardized silver nitrate solution using potassium chromate as an indicator, with results expressed as percent sodium chloride. The acid-to-salt ratio was then calculated as the ratio of titratable acidity (%) to sodium chloride content (%), providing an integrated measure of flavor balance.

3.6.3. Bulb Yield Parameters

Bulb and yield traits were measured at harvest following standard procedures. Bulb diameter (cm) was recorded at the widest portion of ten randomly selected mature bulbs using calipers (Wassie et al., 2022). Average bulb weight (g) was determined from five randomly selected bulbs per plot using a digital balance, while bulb fresh weight (g) was obtained by weighing harvested bulbs after removing leaves and roots (Shura et al., 2022). Bulb dry weight (g) was measured by oven-drying ten bulbs to constant weight. Marketable bulb yield (t ha^{-1}) was obtained from the central rows of each plot and included healthy bulbs weighing 20–160 g, free from physiological disorders or pest damage, whereas unmarketable yield (t ha^{-1}) included undersized (<20 g), diseased, or physiologically defective bulbs (Wassie et al., 2022; Lemma and Shimeles, 2003). Total bulb yield (t ha^{-1}) was calculated as the sum of marketable and unmarketable yields, converted from kilograms per plot. Finally, total dry biomass (g) was determined by oven-drying the shoots and bulbs of ten randomly selected plants to constant weight (Shura et al., 2022).

Partial Budget Analysis

The partial budget analysis described by CIMMYT (1988) was conducted to determine the economic feasibility of onion production using prevailing market prices for inputs at planting and for outputs at harvest. The analysis considered additional input and labor costs and the gross benefits from onion production. The economic analysis was computed using the procedure described by CIMMYT (1988) to identify economically attractive combinations of nitrogen fertilizer, vermicompost, and onion varieties. The partial budget analysis was used to analyze the economic feasibility of fertilizer application using combined seed yield data. The crop‟s potential response to the added fertilizer and the price of fertilizer at planting determined the economic feasibility.

- ✓ **Gross average yield (AvY)** was calculated as the average yield of each treatment.
- ✓ **Adjusted yield (AjY)** was calculated by reducing AvY by 10% to account for differences between experimental and farmer field conditions:
  - ✓ AjY = AvY − (AvY × 0.1)
- ✓ **Gross field benefit (GFB)** was computed by multiplying the adjusted yield by the farm gate price received by farmers at harvest.
- ✓ **Total cost** included the cost of urea, vermicompost, and onion seeds based on 2024 prices. Costs of other inputs and labor (land preparation, planting, weeding, crop protection, and harvesting) were assumed to be similar across treatments.
- ✓ **Net benefit (NB)** was calculated by subtracting total cost from gross field benefit:
  - ✓ NB = Gross field benefit − Total cost

3.7. Data Analysis

All measured parameters were subjected to analysis of variance (ANOVA) appropriate for a factorial experiment in a Randomized Complete Block Design (RCBD), using SAS software version 9.4 (SAS, 2002). The analysis and interpretation followed procedures described by Gomez. (1984). Treatment means were separated using the Least Significant Difference (LSD) test at a 5% probability level.

4. RESULTS AND DISCUSSON

4.1 .Physical Properties of the Experimental Soil

The soil at the experimental site consisted of 50.9% sand, 21.8% silt, and 19.2% clay, classifying it as a sandy loam according to the USDA soil texture classification. This texture provides good drainage, aeration, and moderate water retention, making it suitable for onion cultivation. The high sand content allows rapid infiltration and reduces the risk of waterlogging, while the moderate silt fraction aids in moisture retention. The measured bulk density was 1.09 g cm^{-3}, which is low, indicating favorable porosity and soil structure that support root growth, aeration, and microbial activity. The soil color, recorded as 10 YR 3/2 (very dark grayish brown) on the Munsell chart, reflects a substantial organic matter content and fertile topsoil. Therefore, the soil can be characterized as well-tilled and moderately fertile sandy loam with favorable physical properties for onion production (Brady and Weil, 2017; Hazelton and Murphy, 2016; FAO, 2019), as shown in (Table 2).

The chemical properties of the soil before planting are also presented in Table 2. The soil had a pH (H_2O, 1:2.5) of 6.7, which falls within the neutral range (Tekalign, 1991), indicating suitable soil reaction for onion production, as onions grow best in slightly acidic to neutral soils (pH 6.0–7.0). The neutral pH also favors the availability of most essential nutrients. Soil electrical conductivity (EC) was 0.175 dS m^{-1}, well below the threshold of 2 dS m^{-1} for saline soils (Hazelton and Murphy, 2007), indicating a non-saline condition with no expected adverse effects on seedling establishment, nutrient uptake, or bulb development.

Available phosphorus (20.85 ppm) was rated medium to high (Cottenie, 1980), sufficient to support root growth and bulb formation. Organic carbon content was 0.51%, corresponding to an organic matter content of 0.89%, both classified as low (Landon, 1991). This suggests limited nutrient supply and suboptimal soil structure, likely due to low crop residue return and rapid decomposition under warm conditions. Total nitrogen was 0.04%, also considered low (<0.1%)

(Landon, 1991), indicating a nitrogen deficiency that could restrict vegetative growth and chlorophyll formation. Consequently, nitrogen fertilization was necessary to ensure vigorous growth and higher yields. The carbon-to-nitrogen (C:N) ratio was 13, within the optimal range (10–15) for mineralization (Brady and Weil, 2002), suggesting balanced organic matter decomposition and steady nitrogen release during the growing period. It is evident from the analysis result, the pre-planting soil was neutral, non-saline, and moderately fertile but low in nitrogen and organic matter, highlighting the importance of applying nitrogen fertilizer combined with organic amendments such as vermicompost to improve soil nutrient availability and onion productivity.

4.2 Moisture Content of Vermicompost

The moisture content of the vermicomposting sample was assessed to be 30% in relation to its wet weight. This measurement was achieved by oven drying 100 g of fresh vermicompost at a temperature of 105°C for duration of 48 hours, resulting in a weight reduction to 70 g. The 30 g difference signifies the volume of water evaporated during the drying process, indicating that roughly one-third of the vermicompost's mass consisted of moisture. A moisture content of 30% falls within the acceptable range for well-matured vermicompost. As stated by Edwards et al. (2011) and Yadav and Garg (2016), the ideal moisture content for vermicompost generally falls between 25% and 40%. This specific range enhances microbial activity, maintains nutrient stability, and also averts anaerobic conditions and spoilage. Moisture levels that fall below this range can impede microbial activity and nutrient mineralization, while excessively high moisture levels may lead to compaction, reduced aeration, and the development of anaerobic zones, all of which adversely affect the quality of compost.the measured 30% moisture content therefore indicates that the vermicompost used in this experiment was properly stabilized and adequately cured**,** with a suitable physical condition for field application. Such a moisture level facilitates easy handling and uniform incorporation into soil while supporting the activity of beneficial microorganisms that enhance nutrient availability and soil structure upon application.

4.3 Effect of different vermicompost rates on selected chemical properties of the soil After harvest

Application of vermicompost had a considerable influence on several soil chemical properties after harvest. Soil pH increased with the addition of vermicompost, with the highest value (6.93) recorded at 7 t ha^{-1}, followed by 5 t ha^{-1} (6.87), both significantly higher than the control (6.56). This improvement is attributed to the release of basic cations during the mineralization of organic matter, which helped neutralize soil acidity and maintain pH within the optimum range for onion production. Similarly, electrical conductivity (EC) increased significantly with higher vermicompost rates, rising from 0.2637 dS m^{-1} in the control to 1.769 dS m^{-1} at 7 t ha^{-1}, reflecting the release of soluble nutrients; however, all values remained below the 2 dS m^{-1} threshold, indicating no salinity risk. Available phosphorus improved markedly, reaching 18.84 and 20.50 ppm under 5 and 7 t ha^{-1} vermicompost, respectively, compared with only 3.51 ppm in the control. These values approached or exceeded the recommended P level for onion production, suggesting that vermicompost effectively enhanced P solubility through the release of organic acids and humic substances. Organic carbon and organic matter contents showed numerical differences among treatments but did not exhibit significant positive trends, likely due to the rapid decomposition of vermicompost and high variability among samples. Total nitrogen increased slightly at 5 t ha^{-1} (0.0433%) but declined at 7 t ha^{-1} (0.0267%), possibly due to nitrogen immobilization at higher decomposition rates, although both treatments remained comparable to the control. The C: N ratio decreased from 10.33 in the control to 9.00 in the amended treatments, indicating enhanced microbial activity and more rapid nutrient mineralization. Overall, application of vermicompost, especially at 7 t ha^{-1}, substantially improved key soil fertility parameters most notably available phosphorus, pH, and EC thereby creating more favorable soil conditions for onion growth and nutrient uptake.

Table 3: Effect of different vermicompost rates on selected chemical properties of the soil after harvest

Vermicompost (ton ha^{-1})	pH (1:2.5 ratio)	E.C (dS/M)	Ava.P (ppm)	Organic carbon	Organic matter	Total nitrogen	C:N Ratio
0	6.5667^{ab}	0.2637^{b}	3.507^{c}	0.4433^{a}	0.7633^{a}	0.04ab	10.333^{a}
5	6.8667^{a}	1.4853^{a}	18.840^{b}	0.4567^{a}	0.79^{a}	0.0433^{ab}	9^{a}
7	6.9333^{a}	1.769^{a}	20.500^{a}	0.2233^{a}	0.3867^{a}	0.0267^{b}	9^{a}
Recommended N (kg ha^{-1})	6.3^{b}	0.7013^{b}	20.007^{c}	0.71^{a}	1.22^{a}	0.0567^{a}	12.667^{a}
LSD (5%)	0.25	0.37	10.2	0.26	0.48	0.016	6.85
CV	3.75	34.2	16.69	63.15	63.25	33.94	43.27

4.4 Phenology and Growth Parameters

4.4.1 Days to maturity

The data presented in Appendix Table 4 indicated that the three-way interaction effect of onion variety, nitrogen and vermicompost significantly ($P < 0.01$) influenced days to maturity. As shown in Table 4, the longest days to maturity (119.33 days) were observed in the SV Runagrana f_1 onion variety grown with 225 kg ha^{-1} of nitrogen and 7 t ha^{-1} of vermicompost, which was statistically similar to the same variety grown at 225 kg ha^{-1} nitrogen and 5 t ha^{-1} vermicompost. The shortest Days to maturity (65.33 days) were recorded in the Rio Bravo F_1 onion variety grown under the Control treatment. All other treatment combinations resulted in intermediate values. The observed delay in days to maturity with increasing nitrogen and vermicompost levels is consistent with previous findings in Ethiopia, where higher nitrogen applications prolonged the growth period of onion varieties (Gebru et al., 2024). Similarly, the combined use of organic and inorganic fertilizers has been shown to influence both onion growth duration and bulb yield (Welde, 2020), indicating that nutrient interactions play a critical role in regulating phenological development. This supports the current result, where SV Runagrana f_1 responded strongly to higher nutrient inputs with delayed maturity, whereas Rio Bravo F_1 exhibited minimal response and consistently reached maturity earlier under lower nitrogen and vermicompost rates (0–5 t ha^{-1}). These differences suggest varietal-specific sensitivity to nutrient availability, highlighting the importance of matching fertilizer management to the growth characteristics of each onion variety to optimize both yield and growth duration.

Table 4. Interaction effect of variety, nitrogen and vermicompost on days to maturity

Var	N (kg ha^{-1})	Vc (t ha^{-1})	Days to maturity
Rio Bravo f1	0	0	65.33 ^{p}
	75	0	69.00 ^{o}
	150	0	72.67 ^{n}
	225	0	74.33 ^{m}
	0	5	65.33 ^{p}
	75	5	68.67 ^{o}
	150	5	71.67 ^{n}
	225	5	74.67 ^{m}
	0	7	71.67 ^{n}
	75	7	69.00 ^{o}
	150	7	72.33 ^{n}
	225	7	74.67 ^{m}
Nafis	0	0	91.33 ^{kl}
	75	0	94.00 ^{ij}
	150	0	97.00 ^{h}
	225	0	99.00 ^{g}
	0	5	90.33 ^{l}
	75	5	94.33 ^{i}
	150	5	97.33 ^{h}
	225	5	99.67 ^{g}
	0	7	91.00 ^{l}
	75	7	92.67 ^{jk}
	150	7	97.33 ^{h}
	225	7	99.33 ^{g}
SV Runagrana f1	0	0	90.33 ^{l}
	75	0	98.33 ^{gh}
	150	0	112.33 ^{c}
	225	0	116.67 ^{b}
	0	5	91.00 ^{l}
	75	5	104.00 ^{e}
	150	5	112.00 ^{c}
	225	5	118.00 ^{ab}
	0	7	94.00 ^{ij}
	75	7	101.33 ^{f}
	150	7	107.67 ^{d}
	225	7	119.33 ^{a}
LSD (5%)			1.48
CV (%)			1

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, Least Significant difference and Coefficient of Variation, respectively.

4.4.2 Plant height

The plant height of onion varieties was significantly influenced ($p < 0.01$) by the three-way interaction of variety, nitrogen, and vermicompost across all growth stages (25–75 days after transplanting) (Appendix Table 1).

The tallest plants (65.7 cm) were recorded at 75 days in Nafis supplied with 225 kg N ha^{-1} combined with 7 t VC ha^{-1}**,** followed closely by SV Runagrana f1 (63.2 cm) under the same treatment combination, indicating their strong and sustained response to integrated nutrient application. At 50 days, the same varieties maintained superior height performance, with **Nafis** reaching 56.8 cm and SV Runagrana f1 54.5 cm, showing that the positive effects of nutrient supplementation became more pronounced as growth progressed. In contrast, Rio Bravo f1 consistently produced the shortest plants throughout the growing period, ranging from 14.6 cm at 25 days to 28.4 cm at 75 days under 0 kg N ha^{-1} and 0 t VC ha^{-1}**,** demonstrating its lower adaptability and nutrient use efficiency under limited input conditions. The steady height increment observed across all varieties with increasing nitrogen and vermicompost levels underscores the synergistic role of organic and inorganic fertilizers in enhancing vegetative vigor, improving nutrient uptake, and promoting overall plant growth from early establishment to advanced developmental stages. The data presented in Table 5 indicate that onion growth was significantly influenced by the interaction between genetic potential and nutrient management strategies. The observed increase in plant height with rising nitrogen and vermicompost levels aligns with findings from previous studies (Ali et al., 2020; Alemu et al., 2020; Andishmand and Noori, 2021), which reported that the integrated use of organic and inorganic fertilizers significantly enhances onion growth. Nitrogen supports vegetative development by promoting chlorophyll synthesis, cell division, and elongation (Arancon et al., 2006; Atiyeh et al., 2002). Vermicompost, on the other hand, improves soil aeration, enhances microbial activity, and facilitates nutrient mineralization, thereby improving nutrient uptake (Barati et al., 2022). Moreover, the combined application of nitrogen and vermicompost ensures a more synchronized nutrient release and uptake throughout the crop cycle, fostering sustained plant growth (Abdel-Rahman et al., 2025).

Table 5. Interaction effect of variety, nitrogen and vermicompost on 25, 50 and 75-day plant height

			Plant height		
Var	N (kg ha^{-1})	Vc (t ha^{-1})	25 days	50 days	75 days
Rio Bravo f1	0	0	7.000 ^{h}	12.000 ^{g}	17.000 ^{j}
	75	0	22.000 ^{d}	30.000 ^{cd}	36.000 ^{fg}
	150	0	15.000 ^{ef}	20.000 ^{ef}	27.000 ^{hi}
	225	0	16.000 ^{e}	21.000 ^{ef}	28.000 ^{hi}
	0	5	9.000 ^{gh}	15.000 ^{fg}	21.000 ^{ij}
	75	5	14.500 $^{e-g}$	20.000 ^{ef}	26.000 ^{hi}
	150	5	14.500 $^{e-g}$	19.500 ^{ef}	26.000 ^{hi}
	225	5	19.830 ^{de}	24.830 ^{de}	29.000 ^{gh}
	0	7	10.000 $^{f-h}$	16.000 ^{fg}	22.000 $^{h-j}$
	75	7	16.000 ^{e}	21.000 ^{ef}	27.000 ^{hi}
	150	7	15.000 ^{ef}	20.000 ^{ef}	28.000 ^{hi}
	225	7	35.000 ^{a}	40.000 ^{ab}	46.000 $^{a-e}$
Nafis	0	0	25.190 ^{cd}	36.387 $^{a-c}$	39.000 ^{ef}
	75	0	35.227 ^{a}	39.513 ^{ab}	49.450 $^{a-c}$
	150	0	35.463 ^{a}	40.650 ^{ab}	50.780 $^{a-c}$
	225	0	34.263 ^{a}	38.003 ^{ab}	44.630 $^{a-e}$
	0	5	33.187 ^{ab}	38.087 ^{ab}	50.000 $^{a-c}$
	75	5	29.870 $^{a-c}$	40.793 ^{ab}	51.380 ^{ab}
	150	5	34.593 ^{a}	36.757 ^{ab}	44.607 $^{a-e}$
	225	5	34.963 ^{a}	39.183 ^{ab}	45.763 $^{a-e}$
	0	7	31.007 ^{ab}	35.043 ^{bc}	41.720 $^{d-f}$
	75	7	31.213 ^{ab}	41.727 ^{a}	49.267 $^{a-c}$
	150	7	33.870 ^{ab}	37.360 ^{ab}	46.530 $^{a-d}$
	225	7	33.553 ^{ab}	41.130 ^{ab}	48.390 $^{a-d}$
SV Runagrana f1	0	0	31.307 ^{ab}	38.177 ^{ab}	43.953 $^{c-e}$
	75	0	33.870 ^{ab}	37.407 ^{ab}	46.423 $^{a-d}$
	150	0	35.090 ^{a}	41.703 ^{a}	51.650 ^{a}
	225	0	34.610 ^{a}	39.693 ^{ab}	49.147 $^{a-c}$
	0	5	28.353 ^{bc}	39.160 ^{ab}	44.557 $^{a-e}$
	75	5	31.590 ^{ab}	36.300 $^{a-c}$	44.367 $^{b-e}$
	150	5	30.773 $^{a-c}$	40.423 ^{ab}	48.717 $^{a-d}$
	225	5	33.703 ^{ab}	38.233 ^{ab}	47.573 $^{a-d}$
	0	7	30.057 $^{a-c}$	35.917 $^{a-c}$	46.217 $^{a-e}$
	75	7	32.407 ^{ab}	40.037 ^{ab}	49.353 $^{a-c}$
	150	7	32.670 ^{ab}	42.027 ^{a}	49.663 $^{a-c}$
	225	7	34.850 ^{a}	40.223 ^{ab}	48.010 $^{a-d}$
LSD (5%)			5.76	6.5	7.28
CV (%)			13.06	12.05	10.9

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, Least Significant difference and Coefficient of Variation, respectively.

4.4.3 Leaf number

Leaf number of onion varieties was significantly influenced ($p < 0.01$) by the three-way interaction of variety, nitrogen, and vermicompost across all growth stages (25–75 days after transplanting) (Appendix Table 1). The interaction of variety, nitrogen, and vermicompost significantly influenced onion leaf number across the 25–75-day growth stages (Table 5). The maximum leaf number (16.0) was recorded at 75 days in Rio Bravo f_1 when supplied with 225 kg N ha^{-1} combined with 7 t VC ha^{-1}, followed by 12.0 leaves at 50 days and 9.0 leaves at 25 days under the same treatment. In contrast, the minimum leaf number (2.0) was observed at 50 days in Rio Bravo f_1 at 150 kg N ha^{-1} with 7 t VC ha^{-1}, with similarly low values at 25 and 75 days (2.5 leaves each). Across varieties, Nafis showed relatively stable leaf numbers, ranging from 3.88 to 6.35 leaves, with the highest values obtained under moderate nitrogen (150 kg N ha^{-1}) and vermicompost levels. SV Runagrana f_1 displayed intermediate responses, with leaf numbers varying between 3.39 and 6.12 leaves, the maximum being observed at 225 kg N ha^{-1} + 7 t VC ha^{-1} at 75 days. Thus, Rio Bravo f_1 was the most responsive to combined fertilizer application, producing both the highest and lowest leaf numbers depending on N and VC levels, while Nafis and SV Runagrana f_1 maintained relatively consistent leaf production across treatments (Table 6).

These findings highlight the critical role of the interaction between genetic traits and nutrient inputs in influencing leaf development in onions. The results suggest that the genetic potential of different varieties, along with their efficiency in nutrient utilization, significantly impacts leaf initiation and expansion. This observation aligns with previous studies by Ali et al. (2020), Alemu et al. (2020), and Andishmand and Noori (2021), who reported that the combined application of organic and inorganic fertilizers improved vegetative growth parameters, including leaf count, in onions. Nitrogen is a fundamental component of chlorophyll and amino acids and is essential for vigorous vegetative growth, leaf expansion, and enhanced photosynthetic activity (Atiyeh et al., 2002; Arancon et al., 2006). In contrast, vermicompost contributes to improved soil structure, moisture retention, and microbial activity, all of which promote better root development and nutrient uptake (Barati et al., 2022).

Table 6. Interaction effect of variety, nitrogen and vermicompost on 25, 50 and 75-day leaf number

			Leaf number		
Var	N (kg ha^{-1})	Vc (t ha^{-1})	25 days	50 days	75 days
Rio Bravo f1	0	0	4.26 $^{f-l}$	6.70 ^{c}	7.00 ^{d}
	75	0	4.28 $^{e-k}$	4.78 $^{g-j}$	5.26 $^{h-k}$
	150	0	3.00 ^{q}	5.00 $^{e-j}$	7.00 ^{d}
	225	0	3.00 ^{q}	4.00 ^{k}	4.50 ^{l}
	0	5	4.63 $^{c-f}$	5.13 $^{d-j}$	5.61 $^{e-k}$
	75	5	4.31 $^{e-k}$	4.81 $^{g-j}$	5.29 $^{h-k}$
	150	5	6.00 ^{b}	9.50 ^{b}	11.00 ^{b}
	225	5	5.00 ^{c}	7.00 ^{c}	9.00 ^{c}
	0	7	4.89 ^{cd}	5.39 $^{d-h}$	5.87 $^{e-i}$
	75	7	4.36 $^{e-j}$	4.86 $^{f-j}$	5.34 $^{g-k}$
	150	7	2.50 ^{r}	2.00 ^{l}	2.50 ^{m}
	225	7	**9.00 ^{a}**	**12.00 ^{a}**	**16.00 ^{a}**
Nafis	0	0	4.07 $^{i-n}$	4.99 $^{e-j}$	5.47 $^{f-k}$
	75	0	3.92 $^{k-o}$	5.33 $^{d-i}$	5.81 $^{e-j}$
	150	0	4.65 $^{c-e}$	5.87 ^{d}	6.35 ^{de}
	225	0	4.03 $^{i-n}$	4.60 $^{i-k}$	5.08 $^{j-l}$
	0	5	4.12 $^{h-n}$	4.85 $^{g-j}$	5.33 $^{h-k}$
	75	5	4.19 $^{g-m}$	5.29 $^{d-i}$	5.77 $^{e-j}$
	150	5	4.19 $^{g-m}$	5.08 $^{e-j}$	5.56 $^{f-k}$
	225	5	3.88 $^{l-o}$	4.80 $^{g-j}$	5.28 $^{h-k}$
	0	7	4.49 $^{e-h}$	5.06 $^{e-j}$	5.54 $^{f-k}$
	75	7	4.20 $^{g-m}$	5.52 $^{d-g}$	6.00 $^{e-h}$
	150	7	4.24 $^{f-m}$	4.92 $^{e-j}$	5.40 $^{f-k}$
	225	7	4.26 $^{f-l}$	5.44 $^{d-h}$	5.92 $^{e-i}$
SV Runagrana f1	0	0	3.76 $^{n-p}$	4.96 $^{e-j}$	5.44 $^{f-k}$
	75	0	4.10 $^{h-n}$	5.24 $^{d-j}$	5.72 $^{e-k}$
	150	0	3.88 $^{l-o}$	4.72 $^{h-k}$	5.20 $^{i-l}$
	225	0	4.09 $^{i-n}$	5.04 $^{e-j}$	5.52 $^{f-k}$
	0	5	3.96 $^{k-n}$	5.60 $^{d-f}$	6.08 $^{e-g}$
	75	5	3.76 $^{n-p}$	4.53 ^{jk}	5.01 ^{kl}
	150	5	4.42 $^{e-i}$	4.98 $^{e-j}$	5.46 $^{f-k}$
	225	5	3.97 $^{j-n}$	4.94 $^{e-j}$	5.42 $^{f-k}$
	0	7	3.86 $^{m-o}$	5.14 $^{d-j}$	5.62 $^{e-k}$
	75	7	3.39 ^{pq}	4.61 $^{i-k}$	5.09 $^{j-l}$
	150	7	3.54 ^{op}	4.90 $^{e-j}$	5.38 $^{f-k}$
	225	7	4.52 $^{d-g}$	5.64 ^{de}	6.12 ^{ef}
LSD (5%)			0.39	0.75	0.75
CV (%)			5.65	8.56	7.59

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, Least Significant difference and Coefficient of Variation, respectively.

4.4.4 Leaf length

Leaf length of onion varieties was significantly influenced ($p < 0.01$) by the three-way interaction of variety, nitrogen, and vermicompost across all growth stages (25–75 days after transplanting) (Appendix Table 1). The result presented in Table 6 revealed that the interaction of variety, nitrogen, and vermicompost significantly influenced onion leaf length across all growth stages (25–75 days). The maximum leaf length (55.0 cm) was obtained at 75 days in Rio Bravo f_1 supplied with 225 kg N ha^{-1} and 7 t ha^{-1} of vermicompost, followed by 45.0 cm at 50 days and 30.0 cm at 25 days under the same treatment. In contrast, the minimum leaf length (10.0 cm) was recorded at 25 days in Rio Bravo f_1 under 150 kg N ha^{-1} combined with 7 t ha^{-1} of vermicompost, which also resulted in reduced values at later stages (15 cm at 50 days and 22 cm at 75 days). Among the onion variety varieties tested in this study, Nafis exhibited relatively high and stable leaf length across treatments, with values ranging from 21.7 to 43.1 cm, the highest being at 150 kg N ha^{-1} without vermicompost at 75 days. SV Runagrana f_1 also maintained consistently higher leaf lengths, ranging from 25.6 to 44.2 cm, with the maximum observed at 225 kg N ha^{-1} + 7 t ha^{-1} of vermicompost at 75 days. The result revealed that, Rio Bravo f_1 showed the highest variability, producing both the longest and shortest leaves depending on nitrogen and vermicompost combinations, while Nafis and SV Runagrana f_1 maintained more stable leaf length responses (Table 7).

The observed increase in leaf length with elevated levels of nitrogen and vermicompost can be attributed to the synergistic interaction between organic and inorganic nutrient sources. Nitrogen enhances chlorophyll synthesis, boosts photosynthetic efficiency, and stimulates vegetative growth, thereby promoting leaf elongation and broader canopy development (Ali et al., 2020; Alemu et al., 2020). Vermicompost, on the other hand, improves soil physical properties, increases microbial activity, and facilitates the gradual release of essential nutrients (particularly nitrogen, phosphorus, and potassium) that support sustained leaf growth (Atiyeh et al., 2002; Arancon et al., 2006; Barati et al., 2022). The combined application of nitrogen and vermicompost likely enhanced soil fertility and moisture retention, ensuring a continuous nutrient supply throughout the vegetative phase, which contributed to robust leaf development.

These findings are consistent with those of Andishmand and Noori (2021) and Abdel-Rahman et al. (2025), who reported that the integrated use of organic and inorganic fertilizers significantly improved onion growth parameters, including leaf length and overall plant vigor. Notably, the consistent performance of the Nafis and SV Runagrana f_1 varieties under both moderate and high nutrient levels reflects their adaptability and efficient nutrient uptake, traits that are particularly valuable for sustainable onion production across a range of soil fertility conditions.

Table 7. Interaction effect of variety, nitrogen and vermicompost on 25, 50 and 75-day leaf length

			Leaf length		
Var	N (kg ha^{-1})	Vc (t ha^{-1})	25 days	50 days	75 days
Rio Bravo f1	0	0	15.00 ^{gh}	25.000 ^{no}	30.000 ^{gh}
	75	0	28.33 $^{a-e}$	34.830 $^{c-k}$	31.250 $^{f-h}$
	150	0	16.00 $^{f-h}$	31.000 $^{j-m}$	30.000 ^{gh}
	225	0	15.00 ^{gh}	21.000 ^{o}	33.000 $^{e-h}$
	0	5	17.00 ^{fg}	28.000 $^{l-n}$	35.000 $^{c-h}$
	75	5	27.83 $^{b-e}$	34.160 $^{c-k}$	38.320 $^{b-h}$
	150	5	22.00 $^{d-f}$	35.000 $^{c-k}$	42.000 $^{b-h}$
	225	5	22.00 $^{d-f}$	35.000 $^{c-k}$	40.000 $^{b-h}$
	0	7	26.33 $^{c-e}$	33.450 $^{e-l}$	35.000 $^{c-h}$
	75	7	34.50 ^{ab}	32.100 $^{h-m}$	30.674 ^{gh}
	150	7	10.00 ^{h}	15.000 ^{p}	22.000 ^{i}
	225	7	30.00 $^{a-c}$	45.000 ^{a}	55.000 ^{a}
Nafis	0	0	29.92 $^{a-c}$	34.973 $^{c-k}$	37.983 $^{b-h}$
	75	0	28.72 $^{a-d}$	32.720 $^{f-l}$	35.723 $^{c-h}$
	150	0	33.27 ^{ab}	41.723 ^{ab}	43.057 $^{b-h}$
	225	0	30.11 $^{a-c}$	32.390 $^{h-m}$	34.943 $^{d-h}$
	0	5	30.72 $^{a-c}$	33.220 $^{e-l}$	35.553 $^{c-h}$
	75	5	30.36 $^{a-c}$	34.537 $^{c-k}$	36.860 $^{b-h}$
	150	5	30.61 $^{a-c}$	34.830 $^{c-k}$	36.497 $^{c-h}$
	225	5	21.72 $^{e-g}$	26.943 ^{mn}	30.277 ^{gh}
	0	7	28.08 $^{a-e}$	34.223 $^{c-k}$	35.443 $^{c-h}$
	75	7	34.05 ^{ab}	38.500 $^{b-e}$	41.167 $^{b-h}$
	150	7	28.78 $^{a-d}$	31.520 $^{i-m}$	33.943 $^{e-h}$
	225	7	29.72 $^{a-c}$	33.723 $^{d-k}$	35.250 $^{c-h}$
SV Runagrana f1	0	0	30.95 $^{a-c}$	36.723 $^{b-i}$	40.723 $^{b-h}$
	75	0	25.61 $^{c-e}$	32.543 $^{g-l}$	35.273 $^{c-h}$
	150	0	31.83 $^{a-c}$	36.663 $^{b-i}$	39.667 $^{b-h}$
	225	0	30.50 $^{a-c}$	38.180 $^{b-f}$	42.747 $^{b-h}$
	0	5	29.83 $^{a-c}$	39.280 $^{b-d}$	41.623 $^{b-h}$
	75	5	28.45 $^{a-e}$	37.337 $^{b-h}$	40.337 $^{b-h}$
	150	5	34.44 ^{ab}	36.780 $^{b-i}$	40.397 $^{b-h}$
	225	5	25.94 $^{c-e}$	30.110 $^{k-n}$	35.133 $^{c-h}$
	0	7	31.08 $^{a-c}$	36.557 $^{b-j}$	39.553 $^{b-h}$
	75	7	33.28 ^{ab}	39.333 ^{bc}	40.333 $^{b-h}$
	150	7	34.67 ^{a}	41.890 ^{ab}	42.630 $^{b-h}$
	225	7	32.31 $^{a-c}$	38.090 $^{b-g}$	44.223 $^{b-h}$
LSD (5%)			6.79	5.56	0.75
CV (%)			15.19	10.05	9.36

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, least Significant difference and coefficient of variation, respectively.

4.5 Yield parameters

4.5.1 Total Bulb Yield (TBY)

The analysis of variance indicated that total bulb yield (TBY) was significantly affected ($p < 0.01$) by the three-way interaction of variety, nitrogen, and vermicompost (Appendix Table 5). Among the tested varieties, SV Runagrana f1 (Var 3) consistently produced the highest TBY across all nutrient management treatments. The maximum TBY of 57.48 t ha^{-1} was achieved under 225 kg N ha^{-1} combined with 7 t ha^{-1} vermicompost, followed by 150 kg N ha^{-1} + 7 t ha^{-1} Vc, which produced 38.97 t ha^{-1}. Rio Bravo f1 (Var 1) showed a substantial increase in TBY from 20.14 t ha^{-1} at 0 N and 0 Vc to 42.25 t ha^{-1} at 225 N + 7 Vc. Similarly, Nafis (Var 2) exhibited improvement from 23.17 to 32.83 t ha^{-1} as nitrogen and vermicompost levels increased (Table 8). These results indicate that both the genetic potential of the variety and the nutrient management strategy jointly influenced total bulb production.

The superior TBY of SV Runagrana f1 can be attributed to its high nutrient-use efficiency and the synergistic effect of combined inorganic nitrogen and vermicompost application. Nitrogen is known to stimulate vegetative growth and enhance bulbing by supporting chlorophyll synthesis and plant metabolism, while vermicompost improves soil fertility, water-holding capacity, cation exchange capacity, and microbial activity, thereby creating optimal soil conditions for bulb formation (Brady & Weil, 2002). The steady increase in TBY for Rio Bravo f1 and Nafis confirms that integrated nutrient management consistently enhances yield, although varietal differences highlight the importance of selecting nutrient-responsive cultivars. These findings are in agreement with studies conducted in Ethiopia, where combined applications of vermicompost and mineral fertilizers significantly increased TBY (Kiros et al., 2023). Similarly, research in India reported that integrating vermicompost with inorganic nitrogen enhanced onion yields more effectively than chemical fertilizer alone (Reddy et al., 2017; Rai et al., 2020). In the Amhara region, Alemu et al. (2017) observed that the combined application of organic and inorganic nutrients produced significantly higher TBY compared to the use of either source alone.

4.5.2 Marketable Bulb Yield (MBY)

Marketable bulb yield (MBY) was also significantly influenced ($p < 0.01$) by the interaction of variety, nitrogen, and vermicompost. SV Runagrana f1 recorded the highest MBY of 51.13 t ha^{-1} under 225 kg N ha^{-1} + 7 t ha^{-1} Vc, followed by 150 kg N ha^{-1} + 7 t ha^{-1} Vc with 37.17 t ha^{-1}. Rio Bravo f1 showed an increase from 18.40 t ha^{-1} at 0 N + 0 Vc to 39.50 t ha^{-1} at 225 N + 7 Vc, while Nafis improved from 21.45 to 27.83 t ha^{-1} as nutrient levels increased (Table 8). The strong correlation between TBY and MBY indicates that increases in total yield were accompanied by improved bulb quality and marketability.

The higher MBY observed in SV Runagrana f1 and other varieties can be justified by the synergistic effects of nitrogen and vermicompost on plant growth and soil health. Nitrogen enhances vegetative vigor, leading to larger and uniform bulbs, while vermicompost improves soil structure, nutrient availability, and microbial activity, all of which contribute to better bulb size, quality, and marketable yield (Brady and Weil, 2002). These results are consistent with findings from Ethiopia, where combined application of organic and inorganic fertilizers enhanced both total and marketable yields of onions (Kiros et al., 2023). In India, Reddy et al. (2017) and Rai et al. (2020) reported that integrated nutrient management significantly improved MBY compared to sole chemical fertilization. The varietal differences in MBY further emphasize the need for selecting nutrient-responsive cultivars to achieve optimal productivity and superior marketable quality.

Table 8. Interaction effect of variety, nitrogen and vermicompost on marketable bulb yield, total bulb yield and unmarketable bulb yield

Variety	N (kgha⁻¹)	Vc (t ha⁻¹)	Total bulb Yield (t ha⁻¹)	Marketable bulb Yield (t ha⁻¹)
Rio Bravo f1	0	0	20.14^{o}	18.40^{p}
	75	0	21.11^{m-o}	18.73^{op}
	150	0	21.98^{l-o}	19.23^{no}
	225	0	22.65^{l-o}	20.00^{mn}
	0	5	20.65^{no}	18.92^{op}
	75	5	22.49^{l-o}	20.23^{mn}
	150	5	22.87^{l-o}	20.17^{mn}
	225	5	29.80^{h}	20.33^{j-l}
	0	7	22.33^{l-o}	19.17^{n-p}
	75	7	23.32^{l-n}	19.33^{mn}
	150	7	27.03^{h-j}	20.50^{i-k}
	225	7	$42.25^{\ c}$	20.50^{c}
Nafis	0	0	23.17^{l-n}	21.45^{mn}
	75	0	24.23^{J-L}	22.52^{lm}
	150	0	26.42^{i-k}	24.92^{h-j}
	225	0	26.49^{hi}	25.25^{h-j}
	0	5	23.13^{l-n}	21.33^{mn}
	75	5	24.74^{k-m}	21.92^{mn}
	150	5	$27.22^{\ j-l}$	25.42^{m}
	225	5	28.10^{hi}	26.50^{h}
	0	7	24.43^{j-l}	22.68^{k-m}
	75	7	26.41^{i-k}	24.67^{h-j}
	150	7	26.90^{IJ}	24.67^{h-j}
	225	7	32.83^{b}	27.83^{b}
SV Runagrana f1	0	0	26.65^{ij}	25.00^{h-j}
	75	0	30.98^{hi}	28.63^{hi}
	150	0	34.03^{g}	31.26^{g}
	225	0	35.83^{fg}	32.83^{fg}
	0	5	33.28^{g}	31.17^{g}
	75	5	35.72^{fg}	33.42^{ef}
	150	5	37.17^{ef}	34.92^{e}
	225	5	44.00^{cd}	39.50^{d}
	0	7	33.92^{g}	31.67^{fg}
	75	7	34.88^{fg}	32.38^{fg}
	150	7	38.97^{de}	37.17^{d}
	225	7	$\mathbf{57.48^{a}}$	$\mathbf{51.13^{a}}$
LSD (5%)			2.82	1.88
CV			5.86	4.25

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, Least Significant difference and Coefficient of Variation, respectively.

4.5.3 Bulb dry weight

The analysis of variance revealed that bulb dry weight was significantly influenced by the main effects of onion variety, nitrogen fertilizer, and vermicompost, as well as their two-way and three-way interactions (P < 0.01; Appendix Table 5). The highest bulb dry weight (57.81 g) was Recorded under the treatment combination of SV Runagrana with 225 kg nitrogen per hectare and 5 tons of vermicompost per hectare. The second-highest value (47.23 g) occurred in SV Runagrana under unfertilized conditions, indicating that this variety maintains relatively high dry matter accumulation even without nutrient inputs. In contrast, the lowest bulb dry weight (18.90 g) was observed in Rio Bravo f1 with 150 kg nitrogen per hectare and 5 tons of vermicompost per hectare, closely followed by Rio Bravo f1 under unfertilized conditions (20.80 g) (Table 9).

These results suggest that SV Runagrana responds strongly to integrated nutrient management, efficiently directing assimilates toward bulb dry matter accumulation. The relatively high dry weight under unfertilized conditions also indicates that this variety has a strong genetic potential for dry matter accumulation. Conversely, the low dry weight of Rio Bravo f1 highlights its poor performance and limited adaptability under the tested agroecological and management conditions. Similar findings were reported by Gurmessa et al. (2023), who observed higher bulb dry weight in SV Runagrana f1 under integrated nutrient management, and by Tadesse et al. (2022), who reported maximum dry matter accumulation with 225 kg nitrogen per hectare combined with organic amendments. Studies from Egypt further support this trend; Abd-Elrahman et al. (2025) demonstrated significant increases in onion dry matter when combining organic fertilizers, such as vermicompost and rabbit manure, with bio fertilizers. Conversely, Gebremedhin et al. (2021) and Nigussie et al. (2023) found that Rio Bravo consistently produced lower bulb dry weight than SV Runagrana and Nafis under Ethiopian conditions, likely due to limited adaptation to local soils and climate.

4.5.4 Bulb fresh weight

The analysis of variance indicated that bulb fresh weight was significantly affected by the three-way interaction of onion variety, nitrogen fertilizer, and vermicompost (P < 0.01; Appendix Table 5). The highest fresh weights were recorded in SV Runagrana with 150 kg nitrogen per

Hectare and 7 tons of vermicompost per hectare (181.67 g) and in Nafis under the same nutrient Combination (174 g), which were statistically similar. In contrast, the lowest fresh weight (42.73 g) was observed in Rio Bravo f1 without any nitrogen or vermicompost application (Table 9).

These results suggest that moderate nitrogen application combined with higher vermicompost improved nutrient uptake, water retention, and assimilate allocation toward bulb enlargement, particularly in SV Runagrana. Nafis also responded positively, though slightly less efficiently than SV Runagrana. Conversely, the absence of external nutrient inputs markedly reduced fresh bulb weight, with Rio Bravo f1 being the most severely affected, reflecting its limited adaptability to the local growing conditions. These findings are consistent with previous studies. Tadesse et al. (2022) reported that integrated nitrogen and organic treatments enhance onion fresh weight by improving nutrient absorption and soil fertility. Similarly, Gurmessa et al. (2023) and Abd-Elrahman et al. (2025) observed that combining mineral and organic fertilizers significantly increased onion bulb weight. Conversely, Nigussie et al. (2023) and Gebremedhin et al. (2021) documented consistently lower fresh weights for Rio Bravo f1 compared with SV Runagrana f1 and Nafis, highlighting genotype-dependent responses and limited adaptability under Ethiopian agroecological conditions.

4.5.5 Bulb diameter

Bulb diameter was significantly affected by the three-way interaction of onion variety, nitrogen, and vermicompost ($p < 0.01$; Appendix Table 5). The largest bulbs (65.85 mm) were produced by SV Runagrana under unfertilized conditions, indicating that this variety efficiently develops large bulbs even under minimal input. In contrast, the smallest diameter (26.09 mm) was observed in Rio Bravo f1 with no nitrogen and 5 tons of vermicompost per hectare, likely reflecting a limited genetic response under low-input conditions (Table 9).

These findings are consistent with previous studies. Mishra et al. (2020) reported significant interactive effects of nitrogen and vermicompost on bulb diameter in nutrient-responsive cultivars. Rahman et al. (2018) observed that hybrid onion varieties respond positively to combine organic and inorganic fertilizers, aligning with the significant three-way interactions found in this study. Similarly, Ali et al. (2020) and Mekonnen et al. (2022) documented improvements in bulb diameter under optimal nitrogen and organic matter combinations, while Hossain et al. (2021) emphasized genotype-dependent responses, supporting the current results.

Table 9: Interaction effect of variety, nitrogen and vermicompost on dry weight ,bulb fresh weight, and bulb diameter per bulb.

Var	N (kg ha^{-1})	Vc (t ha^{-1})	dry weight per bulb (g)	fresh weight per bulb(g)	diameter per bulb(mm)
Rio Bravo f1	0	0	20.8^{s}	42.73^{m}	31.10 ^{qr}
	75	0	27.86^{ij}	88 $^{f\text{-}k}$	39.53 $^{m\text{-}p}$
	150	0	22.75^{qr}	106.77 $^{c\text{-}g}$	48.80 $^{g\text{-}l}$
	225	0	21.75^{rs}	68.8 $^{j\text{-}m}$	61.16 $^{a\text{-}c}$
	0	5	24.64 $^{n\text{-}p}$	69.1 $^{i\text{-}m}$	26.09 ^{r}
	75	5	22.34^{r}	76.50 $^{h\text{-}l}$	39.83 $^{m\text{-}p}$
	150	5	18.9^{t}	120.40 $^{c\text{-}e}$	39.58 $^{m\text{-}p}$
	225	5	27.89^{ij}	97.67 $^{c\text{-}j}$	52.37 $^{d\text{-}h}$
	0	7	25.45$^{l\text{-}o}$	67.17 $^{k\text{-}m}$	32.79 $^{p\text{-}r}$
	75	7	20.90^{s}	95.33 $^{c\text{-}k}$	43.39 $^{j\text{-}o}$
	150	7	24.29 $^{n\text{-}p}$	119.77 $^{c\text{-}e}$	36.38 $^{o\text{-}q}$
	225	7	38.487e	129.33 ^{bc}	27.96 ^{r}
Nafis	0	0	26.95^{jk}	52.82 ^{lm}	39.12 $^{m\text{-}p}$
	75	0	26.11 $^{k\text{-}m}$	86.67 $^{g\text{-}k}$	51.45 $^{e\text{-}i}$
	150	0	22.377^{r}	120.00 $^{c\text{-}e}$	43.35 $^{k\text{-}o}$
	225	0	26.56^{kl}	105.33 $^{c\text{-}h}$	56.76 $^{c\text{-}f}$
	0	5	24.24^{op}	73.47 $^{i\text{-}l}$	37.76 $^{n\text{-}q}$
	75	5	28.47^{hi}	119.60 $^{c\text{-}e}$	45.39 $^{h\text{-}m}$
	150	5	26.86^{jk}	153.87^{ab}	50.193 $^{f\text{-}l}$
	225	5	24.54 $^{n\text{-}p}$	117.17 $^{c\text{-}f}$	50.75 $^{f\text{-}j}$
	0	7	25.13 $^{m\text{-}o}$	72.83 $^{i\text{-}l}$	26.243 ^{r}
	75	7	27.83^{ij}	111.20 $^{c\text{-}g}$	43.29 $^{k\text{-}o}$
	150	7	23.70^{pq}	174.00^{a}	50.19 $^{f\text{-}l}$
	225	7	43.8^{c}	130.33^{bc}	51.41 $^{e\text{-}i}$
SV Runagrana f1	0	0	47.23^{b}	53.67^{lm}	65.85 ^{a}
	75	0	27.81^{ij}	103.33 $^{c\text{-}h}$	42.93 $^{l\text{-}o}$
	150	0	41.68^{d}	98.33 $^{c\text{-}i}$	64.42 ^{ab}
	225	0	25.51 $^{l\text{-}n}$	103.33 $^{c\text{-}h}$	50.63 $^{f\text{-}k}$
	0	5	24.88 $^{n\text{-}p}$	68.43 $^{j\text{-}m}$	43.94 $^{j\text{-}n}$
	75	5	29.54^{h}	125.90 $^{b\text{-}d}$	59.20 $^{a\text{-}d}$
	150	5	33.36^{g}	106.33 $^{c\text{-}g}$	44.90 $^{i\text{-}n}$
	225	5	57.81^{a}	118.90 $^{c\text{-}e}$	56.01 $^{c\text{-}g}$
	0	7	44.03^{c}	69.33 $^{i\text{-}m}$	43.51 $^{j\text{-}o}$
	75	7	36.88^{f}	125.23 $^{b\text{-}d}$	58.19 $^{b\text{-}e}$
	150	7	29.12^{h}	181.67^{a}	56.65 $^{c\text{-}f}$
	225	7	42.83^{cd}	129.33 ^{bc}	55.61 $^{c\text{-}g}$
LSD (5%)			1.22	29.40	7.38
CV (%)			2.54	17.64	9.82

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, *Least Significant difference and Coefficient of Variation, respectively.*

4.5.6 Average bulb fresh weight

Analysis of variance showed that onion variety, nitrogen (N), vermicompost (Vc), and their three-way interaction significantly influenced average bulb weight (ABW) ($P < 0.01$; Appendix Table 5). The interaction effect revealed that SV Runagrana f_1 (V3) consistently produced the highest ABW across most N and Vc combinations. The maximum ABW (119.81 g) was recorded in V3 × N3 (150 kg ha^{-1}) × Vc1 (control), which was significantly higher than all other treatments. In contrast, Rio Bravo f1 (V1) and Nafis (V2) produced much lower ABW under suboptimal nutrient combinations. Moderate ABW values were observed in these varieties at intermediate N and Vc levels, showing slight increases under moderate fertilization but substantial decreases under both low and high nutrient levels (Table 10).

These results indicate that ABW is strongly influenced by genotype × fertility interactions, with each variety responding differently to nitrogen and vermicompost levels. SV Runagrana F_1 exhibited superior ABW, suggesting high yield potential and better nutrient use efficiency, whereas Rio Bravo F_1 consistently produced lower ABW, indicating limited responsiveness. The optimal N–Vc combination differed among varieties, emphasizing that over- or under-application of either nutrient can reduce bulb weight. These findings are consistent with previous studies demonstrating genotype-specific nutrient responses. Abdissa et al. (2011) reported significant variety × nitrogen interactions for onion bulb yield, highlighting genotype-dependent nitrogen responsiveness. El-Sayed et al. (2022) observed significant three-way interactions among onion genotype, compost, and nitrogen, showing that compost modulates nitrogen use efficiency differently across cultivars. Similarly, Gashaw et al. (2016) found that vermicompost enhances nitrogen uptake differently among onion varieties, resulting in variable bulb weight outcomes. Overall, the results suggest that integrated nutrient management tailored to specific varieties is essential to maximize bulb size and overall productivity.

Table 10: Interaction effect of variety, nitrogen and vermicompost on Average bulb weight

Var	N (kg ha^{-1})	Vc (t ha^{-1})	Average bulb fresh weight (g)
Rio Bravo f1	0	0	57.06 l
	75	0	80.95 h
	150	0	48.30 p
	225	0	50.72 op
	0	5	90.52 f
	75	5	50.27 op
	150	5	42.14 q
	225	5	75.17 i
	0	7	66.22 jk
	75	7	57.63 l
	150	7	86.33 g
	225	7	63.93 k
Nafis	0	0	56.27 l-n
	75	0	53.36 m-o
	150	0	43.22 q
	225	0	53.20 no
	0	5	56.86 lm
	75	5	68.88 j
	150	5	55.33 l-n
	225	5	51.46 op
	0	7	49.39 p
	75	7	73.39 i
	150	7	57.19 l
	225	7	113.73 c
SV Runagrana f1	0	0	118.29 ab
	75	0	80.95 h
	150	0	**119.81 a**
	225	0	73.76 i
	0	5	66.83 jk
	75	5	94.23 e
	150	5	112.12 c
	225	5	118.13 ab
	0	7	112.78 c
	75	7	114.80 bc
	150	7	104.19 d
	225	7	93.49 ef
LSD (5%)			3.62
CV (%)			2.95

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, *vermicompost, Least Significant difference and Coefficient of Variation, respectively*.

4.5.7 Bulb length

The analysis of variance revealed that bulb length was significantly influenced by the main effects of onion variety, nitrogen level, and vermicompost rate ($P < 0.01$; Appendix Table 5). The results Table 11, showed that the longest bulbs (45.77 cm) were recorded at 225 kg nitrogen per hectare, which was significantly greater than all other treatments. Nitrogen levels of 75 and 150 kg per hectare produced intermediate bulb lengths that were statistically similar, while the shortest bulbs (33.80 cm) were observed in the absence of nitrogen, confirming the essential role of nitrogen in promoting vegetative growth and bulb elongation. Regarding vermicompost, the application of 7 tons per hectare resulted in significantly longer bulbs, whereas 5 tons per hectare and the control were not significantly different from each other. The positive effect of vermicompost is likely associated with improved nutrient availability, enhanced soil water-holding capacity, and increased microbial activity, all of which contribute to bulb elongation. Among the varieties, SV Runagrana f1 produced the longest bulbs, significantly outperforming both Rio Bravo f1 and Nafis. This indicates that genetic potential plays a strong role in determining bulb morphology, in addition to the effects of nutrient management (Table 11).

Similarly, Abdissa et al. (2011) reported that increasing nitrogen up to 200 kg per hectare significantly improved onion bulb size by enhancing vegetative growth and cell expansion. El-Sayed et al. (2022) noted that nitrogen generally promotes bulb elongation up to 225 kg per hectare, although excessive nitrogen may plateau in effect or reduce quality. Conversely, Brewster (2008) cautioned that excessive nitrogen can result in overly vegetative growth, delayed maturity, and potential reductions in bulb firmness and storability. Several studies have also highlighted the benefits of vermicompost: Gopinath et al. (2008) and El-Sayed et al. (2022) reported that vermicompost enhances bulb length and diameter through gradual nutrient release and improved soil health, while Kumar et al. (2014) observed that higher vermicompost rates significantly improved onion bulb parameters compared with controls. Varietal differences further influence bulb length and shape due to inherent genetic variation in growth vigor (El-Sayed et al., 2022; Getahun et al., 2021), and improved cultivars can exploit available nutrients more efficiently, producing larger and longer bulbs (Abdissa et al., 2011).

Table 11. Effects of variety, nitrogen and vermicompost on bulb length of onion

Nitrogen in (kg ha^{-1})	Bulb length (mm)
0	33.795^{c}
75	38.068^{b}
150	39.301^{b}
225	**45.768^{a}**
LSD (5%)	3.5
Vermicompost (t ha^{-1})	
0	36.282^{b}
5	38.861^{b}
7	**42.556^{a}**
LSD (5%)	3
Variety	
Rio bravo f1	37.721^{b}
Nafis	36.707^{b}
SV Runagrana	**43.271^{a}**
LSD (5%)	5
CV%	14.64

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, Least Significant difference and Coefficient of Variation, respectively.

4.6 Quality parameters

4.6.1 Total Soluble Solid

The analysis of variance (ANOVA) revealed that TSS was significantly affected only by the main effect of variety ($p < 0.01$), whereas nitrogen, vermicompost, and their interaction effects were not significant (Appendix Table 6). Results presented in Table 12 indicate that the highest TSS value (7.86 °Brix) was recorded in SV Runagrana f_1 (V3), while the lowest (6.05 °Brix) was observed in Rio Bravo f_1 (V1). The variety Nafis (V2) showed an intermediate value (6.97°Brix), which was statistically distinct from both extremes. Although TSS values tended to increase slightly with higher nitrogen application, the differences were statistically non-significant. The highest average (7.11 °Brix) was obtained at 225 kg N ha^{-1}, suggesting that nitrogen application had only a marginal effect under the conditions of this study. Similar findings were reported by Kumar et al. (2017), who noted that nitrogen influences carbohydrate metabolism, thereby affecting sugar accumulation in onion bulbs. However, excessive nitrogen can dilute soluble sugar concentrations, which may explain the absence of a clear trend in TSS with increasing nitrogen levels.

Likewise, vermicompost application did not significantly influence TSS. Previous studies suggest that vermicompost can enhance soil structure, nutrient supply, and physiological processes such as sugar and organic acid biosynthesis (Arancon et al., 2004; Enhanci, 2008). Nonetheless, Singh and Chaure (2020) argued that high organic nutrient availability may dilute sugar concentration in bulbs, reducing measurable TSS differences. Therefore, in the present study, the lack of significant effect of vermicompost on TSS could be attributed to limited influence on sugar accumulation in mature onion bulbs.

Table 12. Effects of variety on Total Soluble Solid of onion

Variety	Total Soluble Solid
SV Runagrana f1	7.86[a]
Nafis	6.97[b]
Rio Bravo f1	6.05[c]
LSD (%)	0.89
CV (5%)	17.49

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, Least Significant difference and Coefficient of Variation, respectively.

4.6.2 Titrable acidity

Titratable acidity of onion bulb juice was significantly ($P < 0.05$) influenced by both variety and vermicompost application rate (Table 6). The TA values ranged from 0.0164 to 0.0184 across the varieties and from 0.0170 to 0.0181 among the vermicompost levels. The highest titratable acidity (0.0184) was recorded from the variety SV Runagrana f1, which was significantly higher than those of Nafis (0.0173) and Rio Bravo f1 (0.0164). The latter two varieties were statistically similar. The higher acidity in SV Runagrana f1 may be attributed to its greater accumulation of organic acids and sulfur-containing compounds that are characteristic of pungent onion cultivars. This result agrees with findings of Assefa et al. (2021) and Sharma et al. (2019**)**, who reported significant varietal differences in bulb acidity among onion hybrids, mainly due to inherent genetic variation and sulfur metabolism pathways.

Vermicompost also exerted a significant effect on bulb acidity. The application of 5 t ha^{-1} vermicompost produced the highest titratable acidity (0.0181**),** which was significantly higher than the control **(**0 t ha^{-1}**)** and 7 t ha^{-1} treatments, both of which recorded statistically similar values **(**0.0170**).** The increase in acidity with moderate vermicompost rate could be related to improved nutrient availability, particularly nitrogen and sulfur, enhancing amino acid and organic acid synthesis in bulbs. Similar trends were observed by Kumar et al. (2020) and Tesfaye et al. (2023)**,** who reported that moderate organic amendments improved bulb quality attributes by promoting balanced nutrient uptake and metabolic activity. However, the decline at 7 t ha^{-1} might be due to excessive organic matter leading to higher pH buffering or dilution effects in bulb tissue.

Table 13. Effect of variety and vermicompost on titirable acidity

Variety	TA
Rio bravo f1	0.0164[b]
Nafis	0.0173[b]
SV Runagrana f1	**0.0184[a]**
LSD (%)	0.000902
Vermicompost (t ha^{-1})	
Control	0.017[b]
5	**0.0181[a]**
7	0.017[b]
LSD (0.05)	0.000902
CV (%)	11.05

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, Least Significant difference and Coefficient of Variation, respectively.

4.6.3 Sugar to acid ratio (SAR)

The ANOVA results revealed that the main effect of both vermicompost and variety as well as the two-way interaction effect of nitrogen and vermicompost significantly influence (solute to Acid ratio $p<0.05$, Appendix Table 6). The results of the LSD analysis for sugar to acid ratio showed significant differences among the varieties ($LSD_{0.05} = 21.339$). SV Runagrana f1 variety recorded the highest sugar to acid ratio value (429.37), followed by Nafis (401.50), and while the lowest value (368.16) was observed in Rio Bravo f1 (Table 14). This shows that the varieties differed significantly in their inherent sweetness potential. Given that titratable acidity (TA) values among varieties showed only small numerical variation, the higher TSS of SV Runagrana f1 variety translates directly into a higher sugar–to–acid ratio. This suggests that SV Runagrana f1 variety possesses superior bulb sweetness, better flavor quality, and potentially improved storage characteristics. Such varietal differences are commonly attributed to genetic variation controlling carbohydrate synthesis; assimilate partitioning, and organic acid metabolism. The lower TSS and expected lower sugar–acid ratio in Rio Bravo f1 variety indicate a comparatively mild flavor with reduced sugar accumulation during bulb development.

Table 14: Effect of Variety on Sugar–to–Acid Ratio

Varieties	**Mean**
SV Runagrana f1	429.37^{a}
Nafis	401.5^{b}
Rio Bravo f1	368.16^{c}

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, Least Significant difference and Coefficient of Variation, respectively.

Among interaction, the combination between nitrogen and vermicompost significantly influenced TSS values (LSD $_{0.05}$ = 42.679), and this variation directly reflects differences in the sugar–acid ratio across treatments. The highest TSS value (441.78), obtained under the 225 kg/ha with controlled vermicompost treatment (225 kg N ha^{-1} + 0 t ha^{-1} vermicompost), indicates that this treatment likely produced the highest sugar–to–acid ratio. While the lowest (363.08) Sugar to acid ratio recorded in 150 kg/ha nitrogen with controlled vermicompost. The variation in the sugar to acid ratio under different nutrient combinations may be explained by the influence of nitrogen and vermicompost on photosynthesis, carbohydrate formation, and organic acid metabolism. Higher nitrogen rates enhance leaf growth and photosynthetic activity, resulting in greater assimilate production and sugar accumulation in bulbs. Vermicompost improves soil nutrient availability, moisture retention, and microbial activity, which may enhance nutrient uptake and affect both sugar synthesis and acid dilution. The combined effect determines the final balance of sugars and acids in the bulb.

Table 15: Interaction of vermicompost and nitrogen on Sugar to acid ratio

	Sugar to acid ratio		
	Vermicompost (t ha^{-1})		
Nitrogen rate (kg ha^{-1})	0	5	7
0	415.79^{abc}	376.21^{cd}	419.95^{ab}
75	413.99^{abc}	380.04^{bcd}	383.78^{bcd}
150	363.08^{d}	401.12^{abcd}	407.7^{abc}
225	441.78$^{\mathbf{a}}$	378.61^{bcd}	414.07^{abc}
LSD (%)			42.68
CV (5%)			11.36

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance. The abbreviation Var, N, Vc, LSD and CV stand for variety, nitrogen, vermicompost, Least Significant difference and Coefficient of Variation, respectively.

4.7 Partial Budget Analysis

Partial budget analysis was carried out to evaluate the economic feasibility of onion production under different combinations of nitrogen and vermicompost levels for the varieties SV Runagrana F_1 and Nafis. The parameters considered include total variable cost (TVC), gross field benefit (GFB), net field benefit (NFB), benefit-cost ratio (BCR), and marginal rate of return (MRR). Dominance analysis was used to identify dominated treatments (D), which were excluded from the MRR calculation.

The results presented in Table 15 show that among the evaluated treatment combinations, SV Runagrana F_1 supplied with 225 kg N ha^{-1} and 7 t ha^{-1} vermicompost gave the highest adjusted marketable bulb yield (46.02 t ha^{-1}), gross field benefit (4,602,000 Birr ha^{-1}), and net field benefit (4,471,000 Birr ha^{-1}). The treatment also provided the highest benefit-cost ratio (35.1%), indicating high profitability per unit of investment. Its marginal rate of return (MRR) was 15,000%, which is well above the minimum acceptable rate of return (100%), showing that this treatment is economically most attractive.

The same variety under a slightly lower vermicompost level (5 t ha^{-1}) and the same nitrogen rate (225 kg ha^{-1}) recorded a lower adjusted marketable yield (35.55 t ha^{-1}), gross field benefit (3,555,000 Birr ha^{-1}), and net field benefit (3,423,500 Birr ha^{-1}) with a benefit-cost ratio of 27%. Although this treatment was profitable, its economic advantage was relatively lower than the combination with 7 t ha^{-1} vermicompost, suggesting that increasing vermicompost from 5 t to 7 t ha^{-1} under high nitrogen supply substantially improved yield and economic return.

In the case of the Nafis variety, the highest adjusted marketable yield (25.05 t ha^{-1}) and net field benefit (2,376,000 Birr ha^{-1}) were obtained from the treatment receiving 225 kg N ha^{-1} + 7 t ha^{-1} vermicompost. However, its benefit-cost ratio (19.4%) was markedly lower than that of SV

Runagrana F_1 under similar nutrient combinations, indicating a weaker response to the applied inputs. The second-highest economic performance in Nafis was recorded at 225 kg N ha^{-1} + 5 t ha^{-1} vermicompost with a BCR of 22%, followed closely by 150 kg N ha^{-1} + 5 t ha^{-1} vermicompost (BCR = 22.5%). The lowest performance was obtained from 75 kg N ha^{-1} + 7 t ha^{-1} vermicompost, which had the smallest adjusted yield (22.2 t ha^{-1}) and a BCR of 19.1%.

All Nafis treatments were economically non-dominant (N), yet their profitability was substantially lower compared with the SV Runagrana F_1 treatments. The dominance analysis further confirmed that SV Runagrana F_1 at 225 kg N ha^{-1} + 7 t ha^{-1} vermicompost was the most economically viable treatment combination, yielding the highest benefit and acceptable marginal rate of return.

In general, the results demonstrated that integrating high nitrogen with adequate vermicompost levels considerably enhances both productivity and profitability of onion, especially for the hybrid variety SV Runagrana F_1. These findings agree with reports by Reddy et al. (2017)**,** Rai et al. (2020)**,** and Wubet et al. (2020)**,** who also found that combined organic and inorganic fertilization significantly increased bulb yield and net returns in onion production

Table 16: Partial budget analysis for growth and bulb yield response of onion varieties to nitrogen and vermicompost levels

Varieties	N ($kgha^{-1}$)	Vc (tha^{-1})	MBY (tha^{-1})	AVMBY ($kgha^{-1}$)	TVC (Birr)	GFB (Birr)	NFB (Birr)	BCR (%)	MRR (%)	Dominance (N/D)
Nafis	150	5	25.42	22.88	97,200	2,288,000	2,190,800	22.5	–	N
Nafis	225	5	26.5	23.85	103,800	2,385,000	2,281,200	22	–	N
Nafis	75	7	24.67	22.2	115,800	2,220,000	2,104,200	19.1	–	N
Nafis	225	7	27.83	25.05	129,000	2,505,000	2,376,000	19.4	–	N
SV Runagrana f1	225	7	51.13	46.02	131,000	4,602,000	4,471,000	35.1	15,000	N
SV Runagrana f1	225	5	39.5	35.55	131,500	3,555,000	3,423,500	27	14,900	N

N=Nitrogen,VC vermicompost,MBY=marketable bulb yield,AVMBY= average marketable bulb yield,TVC total variable cost,GFB,=Gross field benefit,,NFB=net field benefit,BCE=benefit cost ratio,MRR= marginal rate of return

5. SUMMARY AND DISCUSSION

The study revealed that onion growth, yield, quality, and economic returns are strongly influenced by both variety selection and nutrient management strategies. Among the varieties tested, SV Runagrana f1 exhibited superior adaptability and responsiveness to integrated nutrient inputs, consistently producing the highest yields and quality bulbs under balanced fertilization. The combination of 225 kg N ha^{-1} with 7 t ha^{-1} vermicompost emerged as the most effective treatment, optimizing both agronomic performance and economic returns. In contrast, excessive application of nitrogen and vermicompost did not result in further yield improvements and instead contributed to increased unmarketable produce and delayed bulb maturity. These findings underscore the importance of balanced fertilization and the selection of nutrient-efficient, high-yielding varieties to achieve sustainable onion production.

Based on these results, several practical recommendations are proposed. First, farmers are encouraged to adopt Integrated Nutrient Management (INM) by applying 225 kg N ha^{-1} in combination with 7 t ha^{-1} vermicompost to maximize yield, enhance bulb quality, and improve profitability while maintaining soil health. Second, the use of high-yielding varieties, particularly SV Runagrana f1, is recommended due to its strong performance under integrated nutrient inputs. Third, over-fertilization should be avoided, as nitrogen applications above 225 kg ha^{-1} or vermicompost above 7 t ha^{-1} proved economically inefficient, increasing unmarketable yield and delaying maturity. Fourth, promotion of organic fertilizers through local production and improved access to vermicompost can reduce reliance on synthetic inputs, improve soil fertility, and enhance long-term sustainability. Finally, multi-location and multi-season trials are advised to validate these findings under different agro-ecological conditions and to assess the long-term impacts of integrated nutrient management on onion productivity and soil health.

The present study evaluated the effects of three onion varieties (Rio Bravo f1, Nafis, and SV Runagrana f1) under varying levels of nitrogen (0, 75, 150, and 225 kg ha^{-1}) and vermicompost

(0, 5, and 7 t ha^{-1}) on phenology, growth, and yield parameters. Phenological observations revealed that days to maturity were significantly influenced by the three-way interaction of variety, nitrogen, and vermicompost. SV Runagrana f1 exhibited the longest maturity period, reaching up to 119.33 days under high nutrient levels, whereas Rio Bravo f1 matured earliest (65.33 days) under low-input conditions, indicating the strong responsiveness of SV Runagrana f to integrated nutrient management. Growth parameters, including plant height, leaf number, and leaf length, increased significantly with rising nitrogen and vermicompost levels. Nafis and SV Runagrana f1 consistently produced taller plants, attaining maximum heights of 65.7 cm and 63.2 cm, respectively, at 75 days under 225 kg N ha^{-1} combined with 7 t ha^{-1} vermicompost. Leaf number and length were also significantly affected by the three-way interaction, with Rio Bravo f1 showing greater variability while Nafis and SV Runagrana f1 maintained more stable leaf growth, achieving a maximum leaf number of 16 and leaf length of 55 cm under high nutrient conditions.

Yield parameters were strongly influenced by both variety and nutrient management. SV Runagrana f1 consistently outperformed other varieties, producing the highest total and marketable bulb yields of 57.48 t ha^{-1} and 51.13 t ha^{-1}, respectively, under 225 kg N ha^{-1} + 7 t ha^{-1} vermicompost. Similarly, SV Runagrana f1 recorded the highest bulb weight, diameter, and dry and fresh weight, reflecting superior genetic potential and nutrient use efficiency. Average bulb weight also exhibited a significant variety × nitrogen × vermicompost interaction, with SV Runagrana f1 achieving a maximum weight of 119.81 g, whereas Rio Bravo f1 and Nafis produced lower weights under suboptimal fertilization. The study demonstrated that both nitrogen and vermicompost, individually and synergistically, enhanced vegetative growth and bulb development. Nitrogen primarily promoted vegetative vigor, chlorophyll synthesis, and bulb enlargement, while vermicompost improved soil fertility, microbial activity, moisture retention, and nutrient availability. The integrated application of these nutrients resulted in optimal growth and yield across all measured parameters.

Among the varieties, SV Runagrana f1 was highly responsive to nutrient management, achieving superior growth, yield, and quality, whereas Nafis showed moderate responsiveness and stable performance across treatments. Rio Bravo f1 exhibited lower adaptability, particularly under limited nutrient conditions, although some improvement was observed with high nitrogen and vermicompost application. Overall, the findings indicate that onion growth, phenology, and yield are strongly influenced by the interaction between genetic potential and nutrient management. Optimizing nitrogen and vermicompost levels, specifically 225 kg N ha^{-1} combined with 7 t ha^{-1} vermicompost, is essential to maximize yield and quality, particularly for high-performing varieties such as SV Runagrana f1. These results emphasize the importance of variety-specific nutrient management, suggesting that farmers should consider both varietal characteristics and soil fertility status to achieve sustainable and profitable onion production.

5.1 CONCLUSION

The present study revealed that the growth, phenology, and yield of onion varieties are strongly influenced by the interaction between genetic potential and nutrient management. Days to maturity, plant height, leaf number, leaf length, bulb weight, diameter, and yield components were significantly affected by the combined effects of variety, nitrogen, and vermicompost levels. SV Runagrana f1 consistently exhibited superior performance across all measured growth and yield parameters, demonstrating its high responsiveness to integrated nutrient management, while Nafis showed moderate stability and Rio Bravo f1 performed better under low-input conditions but was less responsive to increased nutrient levels.

Nitrogen and vermicompost, individually and synergistically, enhanced vegetative growth, chlorophyll content, bulb enlargement, and yield. Nitrogen primarily promoted vegetative vigor and bulb development, whereas vermicompost improved soil fertility, microbial activity, nutrient availability, and moisture retention. The integrated application of 225 kg N ha^{-1} with 7 t ha^{-1} vermicompost produced the highest total and marketable bulb yield and average bulb weight, particularly for SV Runagrana f1, highlighting the effectiveness of combined organic and inorganic nutrient management. The study also demonstrated the importance of variety-specific nutrient management, as each variety responded differently to nitrogen and vermicompost. These results suggest that selecting high-performing varieties, such as SV Runagrana F_1, combined with optimal nutrient management, is essential for achieving maximum yield, improved bulb quality, and sustainable onion production in the study area. Farmers and agronomists should consider both varietal characteristics and soil fertility status to develop site-specific nutrient management strategies that enhance productivity and profitability.

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7. APPENDICES

Appendix Table 1. Analysis of variance for plant height at 25, 50 and 75 days of onion varieties as affected by different level of nitrogen and vermicompost

		Mean squares		
Source of variation	DF	25 days	50 days	75 days
Rep	2	3.55^{ns}	90.91^{ns}	119.5**
Var	2	3235.02**	3594.11**	4511.64**
N	3	289.24**	189.55**	254.32**
Vc	2	26.95^{ns}	32.74^{ns}	38.32^{ns}
Var*N	6	66.32*	96.22*	87.67*
Var*Vc	4	34.67*	17.93^{ns}	37.52^{ns}
N*Vc	6	52.76**	52.74**	71.27**
Var*N*Vc	12	34.43**	39.39**	45.03*
Error	70	12.53	15.95	20

, ** and * Significant at 5 %, 1 % and 0.1 % probability levels, respectively and ns-stands for non-significant (p>0.05). The abbreviation DF, Rep, Var, N and Vc indicates degrees of freedom, replication, variety, nitrogen and vermicompost, respectively.*

Appendix Table 2. Analysis of variance for leaf number at 25, 50 and 75 days of onion varieties as affected by different level of nitrogen and vermicompost

		Mean squares		
Source of variation	DF	25 days	50 days	75 days
Rep	2	0.2403^{ns}	3.9124^{ns}	3.9124^{ns}
Var	2	4.07362**	8.7013**	25.8898**
N	3	2.06542**	4.4174**	11.5096**
Vc	2	2.83629**	1.9716**	3.476**
Var*N	6	1.91858**	4.9619**	12.1891**
Var*Vc	4	2.97956**	2.5228**	3.8498**
N*Vc	6	4.80362**	12.2181**	19.7621**
Var*N*Vc	12	2.93874**	8.8162**	14.8118**
Error	70	0.05751	0.2112	0.2112

, ** and * Significant at 5 %, 1 % and 0.1 % probability levels, respectively and ns-stands for non-significant (p>0.05). The abbreviation DF, Rep, Var, N and Vc indicates degrees of freedom, replication, variety, nitrogen and vermicompost, respectively.*

Appendix Table 3. Analysis of variance for leaf length at 25, 50 and 75 days of onion varieties as affected by different level of nitrogen and vermicompost

		Mean squares		
Source of variation	DF	25 days	50 days	75 days
Rep	2	22.2ns	7.321ns	16.61ns
Var	2	818.673**	342.406**	236.669**
N	3	85.609**	17.212ns	33.537*
Vc	2	102.493**	30.215*	30.259*
Var*N	6	155.555**	73.269**	122.165**
Var*Vc	4	42.528*	58.23**	100.2**
N*Vc	6	69.023**	115.592**	122.48**
Var*N*Vc	12	38.383*	103.809**	61.852**
Error	70	17.407	11.655	12.159

, ** and * Significant at 5 %, 1 % and 0.1 % probability levels, respectively and ns-stands for non-significant (p>0.05). The abbreviation DF, Rep, Var, N and Vc indicates degrees of freedom, replication, variety, nitrogen and vermicompost, respectively.*

Appendix Table 4. Analysis of variance for days to maturity of onion varieties as affected by different level of nitrogen and vermicompost

		Mean squares
Source of variation	DF	Days to maturity
Rep	2	4.5**
Var	2	11417.4**
N	3	1007**
Vc	2	6.5*
Var*N	6	190.5**
Var*Vc	4	8**
N*Vc	6	14.4**
Var*N*Vc	12	6.7**
Error	70	0.8

, ** and * Significant at 5 %, 1 % and 0.1 % probability levels, respectively and ns-stands for non-significant (p>0.05). The abbreviation DF, Rep, Var, N and Vc indicates degrees of freedom, replication, variety, nitrogen and vermicompost, respectively.*

Appendix Table 5. Analysis of variance for marketable bulb yield, un marketable bulb yield, bulb dry weight, total bulb yield, bulb fresh weight, bulb diameter, average bulb fresh weight, and bulb length respectively, of onion varieties as affected by different level of nitrogen and vermicompost

Source of variation	DF	MBY	BDW	TBY	BFW	BD	ABFW	BL
Rep	2	9.46**	3.91**	12.25**	679.7^{ns}	14.52^{ns}	0.04185^{ns}	322.474**
Var	2	1222.24**	1452.84**	1715.13**	4066.1**	1698.97**	17613**	449.501**
N	3	371.84**	303.49**	404.85**	21952.2**	915.33**	39.7042**	662.756**
Vc	2	541.47**	149.44**	338.18**	8897.3**	345.06**	1632.35**	357.955**
Var*N	6	20.27**	38.93**	17.47**	653.3^{ns}	149.92**	796.349**	62.812^{ns}
Var*Vc	4	19.45**	5.34**	51.99**	243.1^{ns}	61.74*	209.264**	6.642^{ns}
N*Vc	6	273.59**	242.77**	593.52**	683.6^{ns}	185.21**	523.548**	15.833^{ns}
Var*N*Vc	12	16.17**	197.53**	30.19**	664.9*	182.17**	1578.95**	25.036^{ns}
Error	70	1.34	0.56	1.42	325.5	20.51	4.94297	32.987

, ** and * Significant at 5 %, 1 % and 0.1 % probability levels, respectively and ns-stands for non-significant (p>0.05). The abbreviation DF, MBY, UNMBY, BDW, TBY, BFW, BD, ABW, BL, Rep, Var, N and Vc indicates degrees of freedom, marketable bulb yield, unmarketable bulb yield, bulb dry weight, total bulb yield, bulb fresh weight, bulb diameter, average bulb weight, bulb length, replication, variety, nitrogen and vermicompost, respectively.*

Appendix Table 6. Analysis of variance for bulb chemical quality parameters of onion varieties as affected by different level of nitrogen and vermicompost

Source of variation	DF	Total Soluble Solid	Titrable Acidity	Sugar to acid Ratio
Rep	2	0.3448	5.529	1612.6
Var	2	29.6129**	3.331**	33813.8**
N	3	0.5868^{ns}	3.639^{ns}	2607.6^{ns}
Vc	2	0.0056^{ns}	1.277*	6685.8*
Var*N	6	1.1225^{ns}	4.961^{ns}	1549.1^{ns}
Var*Vc	4	0.1315^{ns}	2.163^{ns}	893^{ns}
N*Vc	6	2.0868^{ns}	1.524^{ns}	5307.9*
Var*N*Vc	12	0.5856^{ns}	3.444^{ns}	1337^{ns}
error	70	1.4815	3.681	2060.6

, ** and * Significant at 5 %, 1 % and 0.1 % probability levels, respectively and ns-stands for non-significant (p>0.05). The abbreviation DF, Rep, Var, N and Vc indicates degrees of freedom, replication, variety, nitrogen and vermicompost, respectively.*

Appendix Table 7. Partial budget analysis of growth and bulb yield response of onion varieties to nitrogen and vermicompost levels

Variety	N (kg ha⁻¹)	Vc (t ha⁻¹)	MBY (t ha⁻¹)	AVMBY (kg ha⁻¹)	TVC (Birr)	GFB (Birr)	NFB (Birr)	BCR (%)	MRR (%)	Dominance N/D
Nafis	0	0	21.45	19.31	6,000	1,931,000	1,925,000	322	–	D
Rio Bravo f1	0	0	18.4	16.56	8,500	1,656,000	1,647,500	196	–	D
SV Runagrana f1	75	0	28.63	27	10,100	1,407	1,395,900	66	–	D
Rio Bravo f1	75	0	18.73	16.86	15,100	1,686,000	1,670,900	110	–	D
SV Runagrana f1	150	0	31.26	28.13	21,200	2,813,000	2,791,800	132	–	D
Rio Bravo f1	150	0	19.23	18.3	21,700	1,830,000	1,808,300	84.4	–	D
Nafis	225	0	25.25	22.73	25,800	2,273,000	2,247,200	87.8	–	D
SV Runagrana f1	225	0	32.83	29.55	27,800	2,955,000	2,927,200	106	–	D
Rio Bravo f1	225	0	20	18.9	28,300	1,890,000	1,861,700	66.8	–	D
Nafis	75	0	22.52	20.27	12,600	2,027,000	2,014,400	161	–	D
Nafis	150	0	24.92	22.43	19,200	2,243,000	2,223,800	117	–	D
SV Runagrana f1	75	5	33.42	30.08	92,600	3,008,000	2,915,400	32.5	–	D
Rio Bravo f1	75	5	20.23	18.77	93,100	1,877,000	1,783,900	20.1	–	D
Nafis	150	5	25.42	22.88	97,200	2,288,000	2,190,800	22.5	–	N
SV Runagrana f1	150	5	34.92	31.43	99,200	3,143,000	3,043,800	31.7	–	D
SV Runagrana f1	225	5	37.05	33.35	105,800	3,335,000	3,229,200	31.5	–	D
Rio Bravo f1	225	5	20.33	21.9	106,300	2,190,000	2,083,700	19.6	–	D
Rio Bravo f1	0	5	18.92	17.03	86,500	1,703,000	1,616,500	19.7	–	D
Nafis	0	5	21.33	19.2	84,000	1,920,000	1,836,000	22.9	–	D
Rio Bravo f1	0	7	19.17	18.15	111,700	1,815,000	1,703,300	16.2	–	D
SV Runagrana f1	0	5	31.17	28.05	86,000	2,805,000	2,719,000	32.6	–	D

Nafis	0	7	22.68	20.41	109,200	2,041,000	1,931,800	17.7	–	D
Rio Bravo f1	75	7	19.33	18.9	118,300	1,890,000	1,771,700	16	–	D
SV Runagrana f1	0	7	31.67	28.5	111,200	2,850,000	2,738,800	25.6	–	D
Nafis	75	7	24.67	22.2	115,800	2,220,000	2,104,200	19.1	–	N
Rio Bravo f1	150	7	20.25	22.05	124,900	2,205,000	2,080,100	17.7	–	D
SV Runagrana f1	150	7	37.17	33.45	124,400	3,345,000	3,220,600	25.9	–	D
Nafis	225	7	27.83	25.05	129,000	2,505,000	2,376,000	19.4	–	N
SV Runagrana f1	225	7	51.13	46.02	131,000	4,602,000	4,471,000	35.1	15,000	N
SV Runagrana f1	225	5	39.5	35.55	131,500	3,555,000	3,423,500	27	14,900	N
Rio Bravo f1	225	7	20.5	22.95	111,411.83	2,295	2,183,902.6 0	20.5	–	D

Price of nitrogen = 8,000 birr per 100 kg, Price of vermicompost ,= 15000 per ton or 1500 birr per 100 kg or 1 quintal, field price of seed ,50g Rio bravo f1=8500 birr, 50 g Nafis seed = 6000 birr, 50 g SV Runagrana f1 seed =8000,price of onion bulb/kg=100 birr, Vermicompost preparation,10000 birr, AVMBY = average marketable bulb yield, GFB= Gross field benefit, BCR = Benefit Cost ratio, TVC = Total variable cost, NFB = Net field benefit ,MRR = Marginal rate of return, labor worker = 120 birr per man, N = Non-dominated, D = dominated whereas.

BIOGRAPHICAL SKETCH

The author, Badege Ayele, was born on 19 September 1989 in Butajira, East Guraghe Zone, central Ethiopia, to Ayele Mengesha and Amarech Yirgu. He completed his elementary education (grades 1–8) at Dobena Elementary School (1996–2003), his lower secondary education (grades 9–10) at Mekicho Millennium Secondary School (2004–2005), and preparatory education (grades 11–12) at Butajira Preparatory School (2007–2008). In 2009, he enrolled at the College of Agriculture, Wolaita Sodo University, and graduated with a Bachelor of Science (BSc) degree in Plant Science in July 2011.

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