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Response of Garlic (*Allium sativum* L.) Bulb Yield to Integrated Organic and Inorganic Fertilizer

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Abstract: An experiment conducted at the Holeta Agriculture Research Center in the Welmera District from 2020 to 2022 was aimed to investigate the effects of vermicompost and inorganic nutrients on garlic yield and associated traits. The study sought to explore the influence of inorganic and vermicompost fertilizers on garlic growth and production parameters (*Allium sativum* L.) and determine the optimal fertilizer dosage at the field level. The experiment involved a randomized complete block design (RCBD) with three replications and seven experimental treatments, including negative Control, 100% Recommended NP (standard check), 100% NPS, 100% vermicompost, 75% recommended NPS + 25% vermicompost, 50% recommended NPS + 50% vermicompost and 25% NPS + 75% vermicompost. The results indicated that the interaction effects of NPS and vermicompost significantly ($P<0.05$) influenced plant height, mean fresh bulb weight, marketable bulb yield and total bulb yield. The combination of 50% recommended NPS with 50% vermicompost fertilizers produced a significantly higher yield than the control plot, with the highest average bulb yield recorded at 7.93 tons/ha. Conversely, the lowest total bulb yield of 3.60 tons/ha was obtained from the untreated plot. Similarly, the application of 50% recommended NPS with 50% vermicompost fertilizers led to a steady improvement in marketable yield and growth parameters. In conclusion, the application of 50% recommended NPS with 50% vermicompost fertilizers per hectare may be necessary for marketable bulb and total bulb yield garlic production in this study area.

Key words: Garlic Bulb Yield · Marketable Yield · Vermicompost · Soil Fertilityimprovement

INTRODUCTION

Garlic (*Allium sativum* L.) holds significant importance worldwide, with a total harvested area of 1, 437.690 hectares and an annual production of 24, 255.303 tonnes of dry bulbs [1]. In Ethiopia, garlic serves as a crucial bulb crop for domestic consumption, used as a spice or condiment in various dishes such as soup, pickles and other preservatives. Additionally, it serves as a source of income for numerous rural farmers across the country [2-4].

Despite its significance and vast potential for production, garlic's current production and productivity levels remain limited and seasonal. Low soil fertility stands out as a major factor constraining the productivity of various crops in Ethiopia, primarily due to erosion, nutrient depletion, inadequate residue management and the absence of crop rotation systems. These issues contribute to lower crop yields [5- 7]. Furthermore, factors such as the lack of improved and adaptable varieties, poor agronomic practices and inadequate post-harvest technologies have been identified as key contributors to the declining yield potential of garlic [8].

Ethiopia faces a wider range of soil fertility challenges beyond the particular focus on chemical fertilizer use, which has traditionally been the primary concern of extension workers and researchers. If left unaddressed, these diverse challenges could significantly limit future agricultural productivity, thereby reducing the effectiveness of chemical fertilizers. These concerns encompass chemical, physical and biological issues that contribute to organic matter loss, depletion of macronutrients and micronutrients, topsoil erosion, soil acidity and other deteriorations in soil physical qualities. Additionally, Ethiopia's soil types exhibit basic characteristics that may pose challenges for agricultural cultivation, necessitating specialized treatment [9].

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Ethiopian farmers have a history of using techniques such crop rotation, intercropping, applying farmyard manure and fallowing to preserve or improve soil fertility in order to address these issues [3]. By enhancing soil characteristics and nutrient status, the application of organic nutrients raises soil fertility and garlic productivity. Similarly, because inorganic fertilizers give nutrients to plants quickly and readily, their proper application can increase the yields of vegetable crops, including garlic [10]. As a result, applying organic and inorganic fertilizers in combination becomes increasingly important from an ecological and economic viewpoint in order to improve soil fertility management and produce the intended results.

The objective of this study is to evaluate the effect of integrating vermicompost with inorganic fertilizer on the growth, yield and yield components of garlic.

MATERIALS AND METHODS

Description of the Study Area: The experiment was conducted in West Shewa Zone of Oromia Regional State for three consecutive cropping seasons (2020 -2022). The experiment site is located at 090 03' N latitude and 380 30' E longitude, 30, 40 and 60 km west of Addis Ababa, respectively, at an altitude of about 2400 m above sea level. The mean annual rainfall of the study area was 1100 mm, of which about 85% falls from June to September and the rest from march to May and the mean annual temperature was about 14.3°C, with the mean maximum and minimum temperatures of 21.7ºC and 6.9°C, respectively and mean relative humidity of 60.6% (HARC, 2016-2021 Figure 1)). The environment is seasonally humid and the major soil type is Nitisols [11].

Experimental Design and Treatments: The experiment was laid out in randomized complete block design (RCBD) with three replications was employed and each plot measured 2m * 2.5m. Planting was done with a row spacing of 30cm and plant spacing of 10cm. The study utilized garlic cloves, NP, NPS, urea fertilizers and vermicompost as planting materials. Urea (46-0-0) and TSP was used as source of N and P. TSP and NPS fertilizer was applied as basal application at planting and N in urea was applied in split form. The rate of NPS fertilizers was determined based on the blanket recommendation of 200 kg/ha of di-ammonium phosphate (DAP) and 150 kg/ha of urea. Both organic sources materials were applied three weeks before planting. The rate of both organic sources was calculated based on recommended inorganic N fertilizer equivalence. Uniform seed cloves sourced from the outer ring cloves of the improved variety of Tseday-92 garlic bulbs, devoid of bruises and diseases, were selected as planting material.

Data Collection

Soil Sample Collection and Analysis: Before and after fertilizer application, soil samples were gathered from various points within the experimental field, spanning depths of 0 to 20 cm. A composite sample was formed by preparing and mixing these samples and its physical and chemical properties were analyzed.

Growth, Yield and Yield Components Data: Data pertaining to growth, yield and yield components were collected from five plants within each of the 21 experimental garlic plots. Random sampling was conducted from the three central rows of each plot to determine plant height. Following harvest, data on bulb

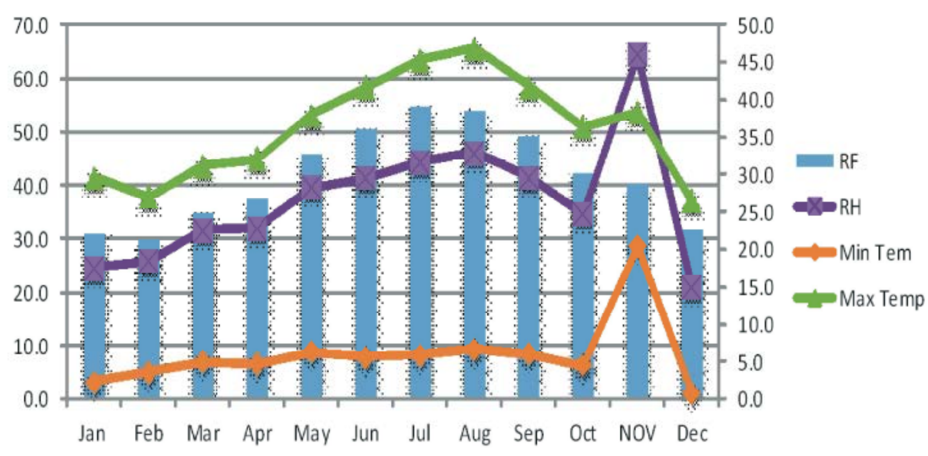

Fig. 1: Mean RF, temperature and RH of the study area

Table 1: Treatment setup and description

Treatment	Description
1	Control
2	Recommended (standard check)
3	100% NPS
4	Full vermicompost based on N equivalency
5	75% NPS + 25% vermicompost based on N equivalency based on N equivalency
6	50% NPS + 50% vermicompost based on N equivalency
7	25% NPS + 75% vermicompost based on N equivalency

yield and yield attributes, including bulb weight per plot, marketable bulb count, bulb diameter, bulb fresh weight and neck thickness of bulbs (in millimeter's), were recorded.

Data Analysis: The collected data were subjected to analysis of variance (ANOVA) using the general linear model of SAS [12]. Significant differences between treatment means were determined using the Least Significant Difference (LSD) test at a significance level of 5%. Simple linear correlation analysis was employed to assess associations between yield and yield-related traits.

RESULTS AND DISCUSSION

Soil Characteristics of the Experimental Site

Soil Physico-Chemical Properties Before Planting: The soil pH of the experimental site is 5.120, indicating slightly acidic conditions, which are generally suitable for many crops, including garlic. The soil texture is classified as clay, with sand, silt and clay contents of 18.75%, 13.75% and 67.5%, respectively. Clay soil tends to hold water and nutrients well but may have poor drainage and can be challenging to work with. Texture: The soil was classified as clay, with varying percentages of sand, silt and clay content.

Clay soils are common in Ethiopia, particularly in regions with high rainfall and volcanic activity [13]. While clay soils have high water and nutrient retention capacity, they can also be prone to compaction and poor drainage. Proper soil management practices, such as organic matter addition and tillage techniques, can help improve soil structure, microbial activities and fertility [14].

The soil's organic carbon content is measured at 1.15%, providing essential nutrients and contributing to soil fertility and structure. The total nitrogen content in the soil is 0.12%, which, while sufficient for plant growth, may require supplementation depending on crop demands.

The available phosphorus in the soil is 7.82 mg/kg, indicating a moderate level that may benefit from phosphorus fertilization to support optimal plant growth and yield. The available phosphorus level is relatively low, suggesting that phosphorus fertilization may be required to optimize plant growth and yield, particularly for phosphorus-demanding crops like garlic.

Soil Chemical Properties after Harvesting Under Different Treatments:
The analysis of soil chemical properties after harvesting revealed variations among treatments (Table 3). Notably, the application of different fertilizer combinations influenced soil pH, organic carbon content, total nitrogen and available phosphorus levels.

Table 2 presents the experimental site's soil parameters and potential for crop growth, while Table 3 clarifies the effects of various input treatments on the chemical properties of the soil following the application of vermicompost. Comparing treated and untreated plots, treatments using organic inputs-especially vermicompost show improvements in soil fertility indicators like pH, organic carbon, nitrogen and phosphorus levels. The soil's pH varied between 4.86 and 5.22 depending on the treatment, indicating circumstances that were either mildly acidic or neutral. According to Bewket and Teferi [15], Ethiopian soils are renowned for their variable pH levels, which can range from moderately acidic to alkaline depending on the location. The pH range that has been observed is appropriate for the majority of crops, including garlic. But improvements might be required.

The organic carbon content ranged from 1.76% to 2.62% across different treatments. Organic carbon is essential for soil health as it serves as a source of energy for soil microbes and helps improve soil structure and water retention [16, 17]. The observed organic carbon levels indicate moderate to high soil fertility, which is beneficial for crop production.

The total nitrogen content ranged from 0.166% to 0.28%, while available phosphorus ranged from 7.69 ppm to 9.42 ppm. Nitrogen and phosphorus are crucial nutrients for plant growth and development. The levels observed in the soil indicate moderate to adequate fertility, which is conducive to garlic production.

Table 2: Some selected soil phsico- chemical properties of the experimental site

S/N	Parameter	Result	Remark
1	pH	5.120	-
2	Texture	Clay	With sand, silt and clay contents of 18.75, 13.75 and 67.5% respectively
3	Organic carbon content (%)	1.15	-
4	Total nitrogen (%)	0.12	-
5	Available phosphorus (mg/kg)	7.82	-

Table 3: Soil chemical properties after harvesting

Treatments	pH	OC (%)	TN (%)	Av. P(ppm)
Control(no input)	4.86	1.76	0.166	7.69
100% Recommended NP	5.14	1.89	0.19	8.67
100% recommended NPS	5.12	1.79	0.18	8.46
50% RNP + 50% vermicompost	5.18	2.26	0.25	9.38
100% Full vermicompost	5.22	2.62	0.28	9.42
75% RNP +25% vermicompost	5.10	2.13	0.216	8.97
25% NPS + 75% vermicompost	5.22	2.22	0.228	7.92

Table 4: Mean of growth parameters of garlic as affected by integrated organic and inorganic fertilizer

Treatments	Plant height (cm)	Bulb Fresh Weight (gm)	Bulb Diameter (cm)	Neck thickness of bulb (mm)
Control(no input)	64.23 b	839.0c	42.367	4.67 c
100% Recommended NP	73.53a	1334.7a	38.267	6.51a
100% recommended NPS	72.60a	1397.2a	36.133	6.04abc
50% RNP + 50% vermicompost	71.07a	1077.3b	38.400	6.39ab
100% Full vermicompost	75.27a	1443.9a	37.967	6.28ab
75% RNP +25% vermicompost	69.73ab	1522.9a	45.067	5.28abc
25% NPS + 75% vermicompost	73.67a	1463.3a	39.500	5.01bc
LSD	5.78	193.30	NS	1.39
CV(%)	4.55	8.38	13.59	19.40

Means within a column sharing common letter(s) are not significantly different at $P \leq 0.05$ probability level; LSD, least significant difference; CV, coefficient of variance

However, careful management of these nutrients is essential to prevent nutrient imbalances and environmental pollution. While the soil shows moderate fertility, optimizing nutrient management is essential for maximizing garlic yield and quality. This may involve balanced fertilization strategies, including the integrated use of inorganic fertilizers and organic amendments like vermicompost [18].

Soil testing and nutrient budgeting can help adapt fertilizer applications to meet the specific needs of garlic crops and maintain soil health over the long term by Applying soil management measures [19, 20]. This includes promoting agro ecological approaches that integrate traditional knowledge with modern agricultural technologies to enhance soil fertility, resilience and productivity [21].

Overall, by implementing these strategies and incorporating scientific findings into agricultural practices, Ethiopian farmers can improve soil health, increase garlic productivity and ensure long-term food security and livelihoods.

Growth and Bulb Yield Parameters

Plant Height: Treatments 100% NPS, Rec NP, 75% NPS + 25% VC and 25% NPS + 75% VC resulted in significantly taller plants compared to the control. Treatment 50% NPS + 50% VC also showed an increase in plant height, although not statistically significant. Combined application of NPS and vermicompost showed not a significant variation in plant height at different combinations (Table 4). Plant height increased gradually with increasing the combinations of nutrient types NPS and vermicompost within the recommended doses. The tallest plants (75.27cm) were recorded in plots fertilized with combined 75% NPS + 25% VC fertilizers. Conversely, the shortest plants (64.23 cm) were measured from control plots (Table 4).

A significant variation in fresh weight of bulb at harvest was observed due to application of different combinations of nutrients (Table 4).

Bulb Fresh Weight: Integrated Application of NPS fertilizer rate with vermicompost rate had no a significant effect on bulb diameter of garlic (Table 4). Treatments 100% NPS, Rec NP, 75% NPS + 25% VC, 50% NPS + 50% VC and 25% NPS + 75% VC resulted in significantly higher bulb fresh weights compared to the control. Treatment 100 VC also showed an increase in bulb fresh weight, though not statistically significant. The maximum weight of fresh bulb (1522.g in average) was obtained in plots fertilized with 50% NPS + 50% VC nutrients while the minimum weight of bulb 839.0 g in was recorded in the control treatment.

Bulb Diameter: Treatments 50% NPS + 50% VC and 25% NPS + 75% VC resulted in significantly larger bulb diameters compared to the control. Other treatments did not show significant differences in bulb diameter.

Neck Thickness of Bulb: Treatment 100% NPS resulted in significantly thicker necks compared to other treatments. However, other treatments did not show significant differences in neck thickness. Neck thickness bulb (mm) was also influenced significantly by Integrated Application of NPS fertilizer rate with vermicompost rate. Whereas, the higher (6.39 mm) neck thickness was noted with full dose of vermicompost (100% vermicompost ha^{-1}). However, the lowest thickness was recorded from untreated plot (Table 4).

Bulb Yield: Significant differences in bulb yield were observed across different fertilizer treatments during the cropping seasons of 2020/2021 and 2021/2022 (Table 5). The interaction effect of vermicompost and recommended NP fertilizers significantly influenced bulb yield and yield components. The combination of Recommended NP and vermicompost nutrients significantly increased garlic yield, with the maximum yields obtained from plots treated with 50% Recommended NP + 50% VC and 75% Recommended NP + 25% VC. The given results show the mean marketable bulb yield (MBY) and total bulb yield (TBY) of garlic across various treatments over two consecutive years. In both years, treatments with organic and inorganic fertilizers produced higher MBY and TBY than the control. Treatments such as Rec NP, 75% NP + 25% VC and 50% NP + 50% VC consistently increased yields, exceeding the control and other treatments.

This table presents the mean marketable bulb yield (MBY) and total bulb yield (TBY) of garlic for the year 2022/2023 under different treatments. Similar to previous years, treatments with integrated organic and inorganic fertilizers generally outperformed the control in terms of MBY and TBY. Treatments such as 50% NP + 50% VC consistently showed the highest yields, indicating the effectiveness of this fertilizer combination. Year 2022/2023 showed variations in yield compared to the previous years, with some treatments exhibiting increased yield while others remained stable or decreased. The results from Tables 4, 5, 6 and 7 align with existing literature on the influence of fertilizer treatments on garlic growth and yield. Similar studies have reported that integrated application of organic and inorganic fertilizers can improve garlic yield and quality compared to sole application of inorganic fertilizers or untreated controls [22, 23]. These findings focus on the importance of optimizing fertilizer management practices to enhance garlic productivity while ensuring sustainable soil health and environmental stewardship [24]. Overall, integrated organic and inorganic fertilizer treatments showed significant improvements in various growth parameters of garlic compared to the control, status their effectiveness in enhancing garlic growth and yield [25-27].

Table 5: Mean of marketable and total bulb yield of garlic as affected by integrated organic and inorganic fertilizer

		Year 2020/21		Year 2021/22	
No.	Treatments	MBY (ton/ha)	TBY (ton/ha)	MBY (ton/ha)	TBY (ton/ha)
1	Control(no input)	3.8b	3.93b	1.95c	3.45 c
2	100% Recommended NP	3.9b	4.18b	2.85abc	5.68ab
3	100% recommended NPS	4.9a	5.27a	3.18ab	5.68ab
4	50% RNP + 50% vermicompost	4.3ab	4.70ab	2.28bc	4.78 b
5	100% Full vermicompost	4.6ab	5.0ab	3.95a	6.45a
6	75% RNP +25% vermicompost	5.08a	5.42a	3.61a	6.45a
7	25% NPS + 75% vermicompost	3. 8b	4.85b	3.95a	6.11a
LSD		0.20	0.07	1.16	1.02
CV		26.26	20.55	21.28	10.51

LSD (Least Significant Difference): Means within a column sharing common letter(s) are not significantly different at $P \leq 0.05$ probability level; LSD, least significant difference; CV, coefficient of variance

Table 6: Mean of marketable and total bulb yield of garlic as affected by integrated organic and inorganic fertilizer, 2022/2023

Treatments	UMBY (ton/ha)	MBY (ton/ha)	TBY (ton/ha)
Control (no input)	0.17 B	3.43 c	3.60 d
100% Recommended NP	0.37a	6.13 b	6.50b
100% recommended NPS	0.43a	6.57ab	7.07ab
50% RNP + 50% vermicompost	0.50a	4.60 c	5.13 c
100% Full vermicompost	0.50a	6.83ab	7.30ab
75% RNP +25% vermicompost	0.47a	7.50a	7.93a
25% NPS + 75% vermicompost	0.50a	6.57ab	7.03ab
LSD	0.186	1.28	1.26
CV	24.97	12.15	11.21

LSD (Least Significant Difference): Means within a column sharing common letter(s) are not significantly different at P≤0.05 probability level; LSD, least significant difference; CV, coefficient of variance

Table 7: Simple Correlation analysis between bulb yield, yield component and growth parameters

	MBY	UMBY	TBY	BFW	Plh	BD	Neck
MBY	1						
UMBY	0.43*	1					
TBY	0.99**	0.50*	1				
BFW	0.93**	0.54*	0.94**	1			
Plh	0.47**	0.56**	0.51*	0.53*	1		
BD	0.083ns	-0.01ns	0.07ns	0.20*	-0.12ns	1	
Neck	0.03ns	0.27*	0.06ns	0.03ns	0.66**	-0.117ns	1

Correlation Analysis Between Bulb Yield and Growth Parameters: This table presents the correlation coefficients between bulb yield (MBY, UMBY, TBY), yield components (BFW - Bulb Fresh Weight), growth parameters (plh - Plant Height, BD - Bulb Diameter) and neck thickness of the bulb (Table 7).

Positive correlations were observed between bulb yield and yield components (BFW), indicating that higher bulb fresh weights contribute to increased bulb yield. Plant height (plh) showed positive correlations with bulb yield and yield components, suggesting that taller plants may lead to higher yields. Bulb diameter (BD) and neck thickness of the bulb exhibited weak or non-significant correlations with bulb yield and other parameters (Table7). These correlations provide understandings into the relationships between yield, yield components and growth parameters, supporting in understanding the factors influencing garlic yield and informing management practices for optimizing yield potential.

CONCLUSION

The findings of this study demonstrate the effectiveness of integrating vermicompost with inorganic fertilizers in improving garlic growth and yield.

Specifically:

- Soil analysis indicated the importance of nutrient management in enhancing soil fertility, which is critical for maximizing garlic productivity.
- The combination of vermicompost and recommended NP fertilizer significantly increased bulb yield compared to individual fertilizer applications and the control.
- Integrated fertilizer application positively influenced growth parameters such as plant height, bulb fresh weight and neck thickness of bulbs.
- The positive correlations between yield components emphasize the significance of optimizing growth conditions to achieve higher bulb yields.

To concluded, the integrated application of vermicompost with inorganic fertilizers is recommended for garlic crop growing to improve soil fertility, enhance growth parameters and increase bulb yield. This approach offers a sustainable and effective strategy for garlic production, contributing to food security and income generation for farmers. Further research may focus on optimizing fertilizer proportions and exploring additional agronomic practices to further enhance garlic productivity.

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