Hindawi
Applied and Environmental Soil Science
Volume 2024, Article ID 7459836, 9 pages
https://doi.org/10.1155/2024/7459836

Research Article

Effect of NPS and Zinc Fertilizer Rates on Growth and Yield of Onion (*Allium cepa* L.) at Shewa Robit, North Shewa, Ethiopia

Kelem Muluneh,[1,2] Tiru Tesfa,[2] and Bizuayehu Desta[1]

[1]*Department of Horticulture, College of Agriculture and Natural Resource Sciences, Debre Berhan University, P.O. Box 445, Debre Berhan, Ethiopia*
[2]*Department of Horticulture, College of Agriculture and Environmental Sciences, University of Gondar, P.O. Box 196, Gondar, Ethiopia*

Correspondence should be addressed to Bizuayehu Desta; bdesta4@gmail.com

Received 9 August 2022; Revised 14 December 2023; Accepted 12 April 2024; Published 22 April 2024

Academic Editor: Claudio Cocozza

Onions, a crucial bulb crop cultivated globally, including in Ethiopia, face significant production challenges. These constraints encompass poor soil fertility, inappropriate fertilizer usage, limited availability of improved varieties, disease and insect pests, and the high costs associated with commercial fertilizers. Among these limitations, improper fertilizer application amounts and types play a pivotal role in restricting onion production. To address this, a field experiment was conducted during the 2020-2021 cropping season in the Shewa Robit district of the North Shewa zone. The study assessed the impact of NPS and Zn fertilizer rates on onion growth and yield. The treatments included four NPS fertilizer rates (0, 121, 242, and 363 kg/ha) and four levels of $ZnSO_4$ (0, 0.25, 0.5, and 0.75% w/v). The experiment was laid out as a randomized complete block design in a factorial arrangement and replicated three times. The results demonstrated that the interaction effect of NPS and Zn fertilizers significantly influenced various onion parameters, including days to maturity, plant height, leaf length, marketable bulb yield, unmarketable bulb yield, and total bulb yield. The application of NPS at a rate of 242 kg/ha and 0.75% $ZnSO_4$ led to the highest plant height (65.20 cm), leaf length (51.93 cm), marketable bulb yield (34.87 t/ha), and total bulb yield (35.04 t/ha). In addition, this treatment combination yielded the highest net benefit (908,628.89 ETB/ha) with an acceptable MRR (313.64%) compared to other treatments. Hence, it can be recommended for economical production of onion in the study area and areas with similar agroecologies.

1. Introduction

The onion (*Allium cepa* L.) belongs to the Allium genus within the Alliaceae family. It is believed to have originated in southwestern Asia, a region known for its rich diversity. Since its initial worldwide distribution, it has been cultivated in over 4,700 countries for bulb production [1]. The onion is primarily grown as a vegetable crop due to its bulb [2].

Onions are prized for their distinctive flavor and their capacity to elevate the taste of various dishes [3]. In addition, they are suggested for managing or preventing conditions such as the flu, atherosclerosis, and heart disease. Notably, onions play a role in inhibiting cholesterol synthesis and lowering fibrinogen levels [4]. Moreover, onion bulbs exhibit elevated levels of dry solids and soluble carbohydrates, whereas the green leaves are abundant in nitrogen compounds, minerals, and vitamins [5].

China, India, and Pakistan are the leading producers of onions, including common onions, shallots, and green onions. Together, these countries contribute over 20 million tons of onions, accounting for 84% of the total global onion production. In addition, Japan, South Korea, Bangladesh, Indonesia, and New Zealand are among the other onion-producing nations [6]. Furthermore, onions thrive in nearly all tropical countries in Africa, including Ethiopia.

Onions have a vital economic role in Ethiopia. The nation has substantial potential to cultivate this crop throughout the year, catering to both domestic consumption and export markets. Onion production further plays a key role in commercializing the rural economy and creating numerous off-farm job opportunities [7].

The cultivation of onions continues to expand over time, primarily driven by its lucrative returns per unit of land, ease of cultivation, and the growth of small-scale irrigation zones. Onions are grown during the "meher" season under rainfed conditions and in the offseason using irrigation. In several regions of the country, the offseason crop accounts for a significant portion of the total onion production area [8].

During the 2020-21 growing period in Ethiopia, onion cultivation covered 38,952 hectares, yielding a total production of 346,048 tons with an average yield of 8.8 tons per hectare [9]. However, this production level falls significantly below that of other onion-producing countries. Several factors contribute to this lower output, including soil fertility, inappropriate fertilizer usage, lack of improved onion varieties, disease and insect pests, limited extension services, high costs, and restricted availability of commercial fertilizers for small-scale farmers, especially during the peak growing season [10, 11]. Among these challenges, the suboptimal application rate of mineral fertilizers emerges as a critical constraint in enhancing onion yield in the Shewa Robit district [12, 13].

In Ethiopian agriculture, the primary fertilizers used are urea and DAP, which supply nitrogen (N) and phosphorus (P). The national recommendation for onion production stands at 105 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} [14]. However, relying solely on N and P fertilizers may not adequately meet the nutritional requirements of onions and other crops. To address this challenge, the Ministry of Agriculture and Natural Resources has recently introduced a new compound fertilizer called NPS. NPS not only contains nitrogen and phosphorus but also includes sulfur (S), with a composition of 19% N, 38% P_2O_5, and 7% S. Currently, NPS has replaced DAP as the primary phosphorus source in Ethiopian crop production [15].

Conversely, micronutrient deficiencies arise due to intensified cropping practices, the adoption of high-yielding varieties, and extensive nitrogen and phosphorus fertilizer usage. A study by ATA [16] revealed that most soils in the research area lack essential macronutrients (N, P, K, Ca, S, and Mg) as well as micronutrients (Cu, Mn, Zn, B, and Fe).

Moreover, in the study area, most onion producers apply NPS fertilizers in incorrect amounts either surpassing or falling short of the recommended levels while overlooking micronutrient supplementation. This mismanagement substantially impacts yield reduction. Consequently, evaluating different combinations of NPS and zinc (Zn) fertilizers becomes essential to improve onion production in the study area.

2. Materials and Methods

2.1. Experimental Site. The experiment was conducted at Shewa Robit Integrated Development Project site of Debre Berhan University (DBU) during the 2020-21 cropping season. The research site is located at a latitude of 10°00′N and a longitude of 39°54′E, with an elevation of 1280 meters above the sea level. The area received an average annual rainfall of 1007 mm, and the annual mean minimum and maximum temperatures were 16.5°C and 31°C, respectively [17].

The Shewa Robit district, located in the Robit valley, predominantly consists of basalt and related pyroclastic rock formations from the Tertiary age. Alluvial and colluvial deposits within the valley originate from these rocks. The alluvial plain of the Robit river features primarily Calcaric Fluvisols, Gleyic Cambisols, and Orthic Luvisols. In the alluvial fan area of the district, Eutric and Pellic Vertisols dominate, while the lower piedmont regions are primarily covered by Calcaric Gelysols and Calcic Cambisols [16]. In addition, the site includes vertisols resulting from the soil formation processes mentioned above. In the previous cropping season, maize (*Zea mays* L.) was cultivated in the experimental field.

2.2. Experimental Materials. The study utilized the "Bombay red" onion variety as the planting material. This variety, which was released by the Melkassa Agricultural Research Center in 1980, exhibits a light red bulb skin color, dark green leaf color, and a flat globe bulb shape. In addition, its bulb flesh color is reddish white [18]. Notably, this early-maturing variety reaches maturity in less than 120 days [18]. In the Shewa Robit district, "Bombay red" is widely recognized as one of the most commonly used and improved onion varieties. The study employed a combination of blended NPS (19 : 38 : 7% N : P : S), urea (46% N), and zinc sulfate (21 : 5% Zn : S) as fertilizer sources.

2.3. Treatments and Experimental Design. The experimental treatments comprised various combinations of NPS rates (0, 121, 242, and 363 kg/ha) and $ZnSO_4$ rates (0, 0.25, 0.5, and 0.75%). These treatments were arranged in a randomized complete block design (RCBD) with three replications. The blanket recommendation of urea and DAP for onion production was 100 kg/ha and 200 kg/ha, respectively [19]. To determine the appropriate $N : P_2O_5 : S$ fertilizer rates, 50% of the nutrients from the blanket recommendation were either added or subtracted using $N : P_2O_5$ fertilizer.

2.4. Management of Experimental Plants. The land was ploughed to a depth of 25–30 cm, harrowed, and leveled. Manual preparation of ridges and furrows was carried out using hand tools. On January 20, 2021, healthy and uniform seedlings at the 3 or 4 true leaf stages were taken from the nursery and transplanted into the experimental field. Each experimental plot covered an area of 2.4 m × 1.6 m, totaling 3.84 m^2. Within each plot, there were four double rows, with 16 plants in each row and a total of 128 plants per plot. Planting occurred on the ridges, following the recommended spacing of 40 cm between furrows, 20 cm between rows on the ridge, and 10 cm between individual plants. The outer double rows on both sides of the plot, as well as one plant at each end of the rows, served as border plants to minimize edge effects. The middle two double rows, with a net plot size of 1.2 m × 1.4 m (1.68 m^2), were designated for data collection. A distance of 0.5 m between plots and 1 m between blocks facilitated cultural practices. The experiment utilized furrow irrigation, with a four-day irrigation interval during the first four weeks. Subsequently, the interval was extended to five to seven days until 15 days before harvest, when irrigation ceased completely. Other cultural practices, such as earthing up, weeding, and chemical spraying, followed recommended guidelines for the crop [19].

All NPS was applied during planting, while urea at a rate of 100 kg/ha was split into two applications; half at planting and the other half side-dressed 45 days after transplanting [20]. Uniform application of urea was maintained across all treatments, including the control. In addition, three foliar applications of zinc sulfate (at concentrations of 0, 0.25, 0.5, and 0.75%) were administered at monthly intervals, starting 30 days after transplanting [21].

2.5. Soil Sampling and Analysis. Before planting, soil samples were collected from ten representative sampling points using an auger, at a depth of 0–20 cm. These samples were taken from the entire experimental field and combined to create one composite sample weighing one kilogram. Selected soil physicochemical properties were determined based on this composite sample. The collected soil samples were air-dried, ground using a mortar and pestle, and then sieved through a 2 mm mesh. Proper labeling and bagging were done, and the samples were transported to the Ethiopian Construction Design and Supervision Works Corporation in Addis Ababa for analysis. The analysis included assessing soil texture, soil pH, soil organic matter (OM), total nitrogen (TN), cation exchange capacity (CEC), exchangeable potassium (K), available phosphorus (P), available sulfur (S), and extractable zinc (Zn).

Soil pH was measured in a supernatant suspension of a 1 : 2.5 soil-to-distilled water mixture using a pH meter. Soil organic matter (OM), total nitrogen (TN), and cation exchange capacity (CEC) were determined using mid-infrared (MIR) spectral analysis. Available phosphorus (P), available sulfur (S), and extractable zinc (Zn) were determined using the Mehlich III multinutrient extraction procedure [22]. The soil physicochemical properties are summarized in Table 1.

Table 1: Physicochemical characteristics of soil in the experimental site before planting.

Soil properties	Value	Rating	Source
pH (1 : 2.5)	7.6	Slightly alkaline	[23]
Electrical conductivity ($d{\cdot}S{\cdot}m^{-1}$)	0.44	Nonsaline	[24]
Organic matter (%)	0.15	Very low	[25]
Total nitrogen (%)	0.03	Low	[24]
Exchangeable K (c mol(+)/kg)	1.5	Sufficient	[26]
Available P (ppm)	15	Marginal	[27]
Available S (ppm)	23	Medium	[28]
Zn (ppm)	0.48	Low	[29]
Particle size distribution			
Sand (%)	40.2		
Silt (%)	33.07		
Clay (%)	26.67		
Textural class	Sandy loam		[24]

2.6. Sampling and Data Collection

2.6.1. Phenology and Growth Parameters

Days to maturity: the days to maturity were determined by measuring the actual number of days from transplanting until 80% of the plant's foliage had fallen.

Plant height (cm): plant heights of ten randomly selected plants in the net plot area were measured from the soil surface to the tip of the longest leaf using a ruler, and the mean values were computed for further analysis.

Leaf length (cm): the longest leaves of ten randomly selected plants in the net plot area were measured using a ruler, expressed as a mean value in centimeters, and used for further analysis.

Leaf number per plant: the total number of leaves of ten randomly selected plants per net plot area was counted, and the mean values were computed.

2.6.2. Yield and Yield Components

Bulb length (cm): the bulb length was determined by randomly selecting ten plants from the net plot area. It was measured longitudinally by using a caliper after curing.

Bulb diameter (cm): the bulb diameter was determined by randomly selecting ten plants from the net plot area. It was measured at the middle cross section of the bulb by using a caliper after curing.

Marketable bulb yield (t ha^{-1}): bulbs that were free of mechanical injury, disease and insect pest damage, uniform in color, and medium to large in size (20–160 g) were considered the marketable bulb yield [30]. The weight of such bulbs was calculated from the net plot area of each plot and expressed as t ha^{-1} using a scaled balance.

Unmarketable bulb yield (t ha^{-1}): harvested bulbs that were undersized as well as oversized (<20 g and >160 g), misshaped, decayed, discolored, diseased, and physiologically disordered were considered the unmarketable bulb yield [30]. The weight of such bulbs was calculated from the net plot area of each plot and expressed as t ha^{-1} using a scaled balance.

Total bulb yield (t ha^{-1}): the total bulb yield was measured from the total harvest of net plot area as a sum weight of marketable and unmarketable bulb yields that was measured in kilograms per plot and finally converted into t ha^{-1}.

2.7. Statistical Analysis. Data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) of the SAS statistical package [31]. All significant pairs of treatment means were compared using Duncan's multiple range test (DMRT) at a 5% level of significance [32].

2.8. Economic Analysis. Economic analysis in the form of partial budget analysis and marginal rate of return (MRR) was done following the procedures described by CIMMYT [33]. It was done to identify economically feasible treatment combination of NPS and zinc fertilizers where variable costs (cost of fertilizers and labor), gross benefits, and net benefits were calculated based on CIMMYT [33]. The marketable bulb yield was downscaled by 10% and gross income was calculated by multiplying it with the average local price (30 ETB·kg^{-1}) at the time of the study. The purchasing prices of NPS and $ZnSO_4$ were 20 ETB and 1200 ETB·kg^{-1}, respectively. The cost for daily labor during the season was 100 ETB per day.

3. Results and Discussion

3.1. Phenology and Growth Parameters

3.1.1. Days to Maturity. Days to maturity was significantly affected by the main and interaction effects of NPS and Zn fertilizers. Applying NPS fertilizer at a rate of 242 kg/ha and 0.75% $ZnSO_4$ resulted in the longest maturity period (107 days), which was statistically similar to the application of NPS fertilizer at the same rate but with 0.5% $ZnSO_4$, as well as the combination of 363 kg/ha NPS with 0.5% and 0.75% $ZnSO_4$. However, the earliest maturity (100 days) was observed in the treatment without NPS and $ZnSO_4$ application (Table 2). Specifically, the application of NPS fertilizer at a rate of 242 kg/ha and 0.75% $ZnSO_4$ resulted in a 7-day delay in maturity compared to the combined application of 0 kg/ha NPS and 0% $ZnSO_4$.

The delay in days to maturity can be attributed to the availability of essential nutrients and increased chlorophyll synthesis, which enhances photosynthetic activities and assimilate production, leading to robust vegetative growth. In line with this, Assefa [34] reported that the longest days to maturity for onion bulbs (118.87 days) were observed when applying NPS fertilizer at a rate of 361.5 kg/ha, while earlier maturity (114.83 days) occurred in the treatment without NPS fertilizer. Kitila et al. [35] also noted that higher NPS levels (ranging from 0 to 200 kg/ha) caused delays in maturity.

Furthermore, Arora and Singh [36] observed that increased zinc levels led to greater vegetative growth in onion crops, resulting in maturity delays. Similarly, Tisdale et al. [37] described how elevated zinc amounts caused stem or stalk elongation, contributing to delayed maturity.

3.1.2. Plant Height. The height of plants was significantly affected by the main and interaction effects of NPS and Zn fertilizers. Applying NPS and Zn at a rate of 242 kg/ha NPS and 0.75% $ZnSO_4$ resulted in the tallest plant height (65.20 cm). Conversely, the shortest plant height (50.00 cm) was observed in the treatment without NPS and $ZnSO_4$ application (Table 2). The use of 242 kg/ha NPS and 0.75% $ZnSO_4$ led to a 30.4% growth boost in plant height compared to applying 0 kg/ha NPS and 0% $ZnSO_4$ together.

Table 2: The interaction effect of NPS and Zn fertilizer levels on days to maturity, plant height, and leaf length.

NPS (kg/ha)	$ZnSO_4$ (%)	DTM	PH (cm)	LL (cm)
0	0	100.00^{d}	50.00^{d}	39.86^{e}
	0.25	103.33^{c}	52.53^{c}	43.40^{c-e}
	0.5	103.33^{c}	52.93^{c}	44.80^{b-d}
	0.75	104.00^{c}	53.60^{c}	46.33^{bc}
121	0	105.00^{bc}	53.53^{c}	44.06^{b-e}
	0.25	104.00^{c}	53.53^{c}	44.60^{b-d}
	0.5	104.00^{c}	53.86^{c}	44.06^{b-e}
	0.75	105.00^{bc}	54.06^{c}	44.13^{b-d}
242	0	105.00^{bc}	54.13^{c}	42.40^{c-e}
	0.25	104.00^{c}	54.60^{bc}	42.00^{de}
	0.5	107.00^{a}	57.20^{b}	44.00^{b-e}
	0.75	107.00^{a}	65.20^{a}	51.93^{a}
363	0	103.33^{c}	53.93^{c}	42.80^{c-e}
	0.25	104.00^{c}	54.53^{bc}	42.53^{c-e}
	0.5	106.00^{ab}	54.80^{bc}	44.06^{b-e}
	0.75	106.00^{ab}	54.93^{bc}	47.93^{b}
Significance level		**	***	*
CV%		1.94	2.65	4.89

*, **, ***Significant at probability level of $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively; CV = coefficient of variation; DTM = days to maturity; PH = plant height; LL = leaf length; means followed by the same letter(s) are not significantly different.

The tallest plant height was achieved through the application of higher NPS and Zn. This increase in height can be attributed to the abundant availability of nutrients and enhanced chlorophyll synthesis, leading to greater assimilates production. Consequently, vigorous vegetative growth ensued. These findings align with Assefa et al. [38]'s research, where they observed that applying N, P, and S at a rate of 130 : 20 : 21 and Zn at 15 kg/ha resulted in a plant height of 64.27 cm, while the treatment without N, P, S, and Zn had the shortest height of 37.00 cm. Similarly, Nigatu et al. [39] reported that applying NPS fertilizers at a rate of 73.5 : 92 : 16.95 kg/ha led to the longest plant height (60.07 cm), whereas the treatment without NPS fertilizer had the shortest height of 50.30 cm. In addition, Kitila et al. [35] noted that increasing the NPS fertilizer rate positively impacted the plant height of three onion varieties.

Bhat et al. [40] reported that increased Zn application leads to greater plant height, likely due to Zn's involvement in cell division and other physiological processes such as photosynthesis and nitrogen metabolism. In addition, Zn plays a crucial role in tryptophan production, which serves as a precursor for auxin, an essential growth hormone in plants. Similarly, Mishra et al. [41] and Manna [21] found that plant height significantly increased with higher levels of zinc fertilizers.

3.1.3. Leaf Length. The leaf length was significantly influenced by both the main effect of Zn and the interaction effect of NPS and Zn fertilizers. On the other hand, the main effect of NPS did not have a significant impact on this parameter.

Notably, applying NPS fertilizer at a rate of 242 kg/ha and 0.75% $ZnSO_4$ resulted in the longest leaf length (51.93 cm), while the treatment without NPS and $ZnSO_4$ application recorded the shortest leaf length (39.86 cm) (Table 2). In comparison to the treatment with 0 kg/ha NPS and 0% $ZnSO_4$, the combined application of 242 kg/ha of NPS and 0.75% $ZnSO_4$ fertilizers resulted in a 30.28% increase in leaf length.

The greater leaf length resulting from the combined application of higher NPS and Zn fertilizers can be attributed to increased nutrient availability and elevated chlorophyll content. This, in turn, led to enhance assimilate production and vigorous vegetative growth, ultimately contributing to the observed longer leaf length. A study by Nigatu et al. [42] found that the longest leaf length (51.07 cm) was achieved with the application of $N:P_2O_5:S$ fertilizer at a ratio of 136.5 : 119.6 : 22 kg/ha, while the shortest leaf length (44.33 cm) occurred in treatments without NPS fertilizer. Furthermore, according to Kitila et al. [35], the increase in NPS fertilizer rate had a positive impact on leaf length across three onion varieties.

Arshad et al. [43] found that applying Zn at a rate of 10 kg/ha resulted in the maximum leaf length of onion (42.31 cm), while the treatment without Zn fertilizer application yielded the minimum leaf length (38.16 cm). Similarly, Tisdale et al. [37] found that zinc (Zn) is involved in auxin metabolism and other enzymatic reactions, leading to an enhancement in leaf length.

3.1.4. Leaf Number. The leaf number was significantly influenced by the main effect of NPS fertilizer. However, neither the main effect of Zn nor the interaction effect of NPS and Zn had a significant impact on this parameter. The highest leaf number (11.68) was observed when NPS fertilizer was applied at a rate of 242 kg/ha, which was statistically similar to the application of NPS at a rate of 363 kg/ha. Conversely, the lowest leaf number (9.47) was recorded in the treatment without NPS application (Table 3). Applying NPS fertilizer at a rate of 242 kg/ha resulted in a 23.33% increase in leaf number compared to the application of 0 kg/ha NPS.

The increase in leaf count due to increased NPS fertilizer application can be attributed to the ample availability of nutrients, which promoted robust vegetative growth. Consequently, onion plants exhibited an increased number of leaves. In agreement with this, Gashaw [44] found that applying NPS fertilizer at a rate of 57 : 114 : 21 kg/ha $N:P_2O_5:S$ resulted in the highest garlic leaf count (13.63), while the lowest count (7.63) occurred in the treatment without NPS fertilizer. Similarly, Assefa [34] reported that the highest onion leaf count (12.46) was observed with NPS application at a rate of 271.12 kg/ha, whereas the lowest count (11.33) occurred without NPS fertilizer. Additionally, Kitila et al. [35] noted that increased NPS fertilizer levels led to more number of leaves in three onion varieties. In contrast, Nigatu et al. [39] found no significant impact of NPS fertilizer on the onion leaf number.

Table 3: Main effect of NPS and Zn fertilizers on leaf number, bulb length, and bulb diameter.

NPS (kg/ha)	LN	BL (cm)	BD (cm)
0	9.47^c	4.70^b	4.59^c
121	10.46^b	5.77^a	5.59^b
242	11.68^a	6.03^a	6.12^a
363	11.03^{ab}	5.87^a	6.01^a
Significance level	***	***	**
$ZnSO_4$%			
0	10.26	5.38	5.08^b
0.25	10.41	5.60	5.36^b
0.5	10.99	5.64	5.83^a
0.75	10.98	5.76	6.02^a
Significance level	ns	ns	**
CV	7.86	6.20	6.61

**, ***Significant at probability level of $p < 0.01$ and $p < 0.001$, respectively; ns = nonsignificant difference; CV = coefficient of variation; LN = leaf number; BL = bulb length; BD = bulb diameter; means followed by the same letter(s) are not significantly different.

3.2. Yield and Yield Components

3.2.1. Bulb Length. The length of onion bulbs was significantly affected by the main effect of NPS fertilizer. However, the main effect of Zn and their interaction did not have a significant influence on this parameter. The longest bulb length (6.03 cm) was observed when NPS was applied at a rate of 242 kg/ha, which was statistically similar to the application of 121 kg/ha and 363 kg/ha of NPS. Conversely, the shortest bulb length (4.70 cm) was recorded in the treatment without NPS fertilizer application (Table 3). Applying 242 kg/ha of NPS resulted in a 28.29% increase in bulb length compared to the application of 0 kg/ha of NPS.

The elongation of onion bulbs resulting from NPS application can be attributed to the improved nutrient availability, which fosters robust vegetative growth and enhances assimilate production. Consequently, assimilates are more efficiently transported into the bulbs, leading to an overall increase in bulb length. In agreement with this, Assefa [34] observed that the highest bulb length (5.08 cm) was achieved with NPS applied at a rate of 271.12 kg/ha, while the lowest length (4.59 cm) occurred in the treatment without NPS application. In contrast, Nigatu et al. [39] reported that NPS fertilizer did not significantly impact the onion bulb length.

3.2.2. Bulb Diameter. The diameter of onion bulbs was significantly influenced by the main effects of NPS and Zn fertilizers. However, their interaction did not have a significant impact on this parameter. The widest bulb diameter (6.12 cm) was recorded when NPS was applied at a rate of 242 kg/ha, which was statistically similar to the application of NPS at a rate of 363 kg/ha. In contrast, the narrowest bulb diameter (4.59 cm) was observed in the treatment without NPS application (Table 3). The application of 242 kg/ha of NPS led to a 33.33% increase in bulb diameter, in contrast to using 0 kg/ha of NPS.

The widest bulb diameter (6.02 cm) was observed when $ZnSO_4$ was applied at a rate of 0.75%, which was statistically similar to the application of $ZnSO_4$ at a rate of 0.5%. In contrast, the narrowest bulb diameter (5.08 cm) was recorded in the treatment without $ZnSO_4$ application (Table 3). The application of 0.75% $ZnSO_4$ resulted in 18.50% increase in bulb diameter compared to the treatment with 0% $ZnSO_4$.

The increase in bulb diameter may be attributed to the application of NPS, which likely played a synergistic role by providing a balanced supply of nutrients to the crop. Applying a well-balanced amount of nitrogen (N), phosphorus (P), and sulfur (S) had a significant impact on vegetative growth and assimilate production. Consequently, this led to increased translocation of assimilates into the bulbs, resulting in larger bulb diameters. Similarly, Assefa [34] found that the widest onion bulb diameter (5.34 cm) was achieved with NPS application at a rate of 271.12 kg/ha, while the narrowest diameter (4.68 cm) occurred in the treatment without NPS application. Shiferaw [45] also observed an increase in garlic bulb diameter with higher NPS fertilizer application. However, Nigatu et al. [39] reported that NPS fertilizer did not significantly influence onion bulb diameter.

The increase in onion bulb diameter due to zinc application may be attributed to its role in enhancing the accumulation of higher photosynthates within the bulbs. This, in turn, ensures a larger bulb diameter. In line with this, Babaleshwar et al. [46] found that applying Zn fertilizer at a rate of 0.5% resulted in the widest onion bulb diameter (6.0 cm), while the narrowest diameter (5.4 cm) was observed in the treatment without Zn fertilizer application. Similarly, Bhat et al. [40] reported that the widest bulb diameter (6.32 cm) occurred with Zn application at a rate of 7.5 kg/ha, whereas the narrowest diameter (5.13 cm) was recorded in the treatment without Zn fertilizer application.

3.2.3. Marketable and Unmarketable Bulb Yield. The marketable and unmarketable bulb yields of onions were significantly influenced by the main and interaction effects of NPS and Zn fertilizers. The highest marketable bulb yield (34.87 t/ha) was observed when NPS was applied at a rate of 242 kg/ha along with 0.75% $ZnSO_4$, which was statistically similar to the yield obtained from the application of NPS at a rate of 363 kg/ha combined with 0.75% $ZnSO_4$. Conversely, the lowest marketable bulb yield (23.26 t/ha) occurred in the treatment without NPS and $ZnSO_4$ application (Table 4). The application of NPS at 242 kg/ha along with 0.75% $ZnSO_4$ led to a remarkable 49.91% boost in marketable bulb yield, in contrast to the combined application of 0 kg/ha NPS and 0% $ZnSO_4$.

The enhanced marketable bulb yield resulting from the combined application of NPS and Zn can be attributed to improved nutrient availability and increased chlorophyll synthesis. These factors contribute to higher photo assimilate production and efficient translocation to the bulbs, ultimately leading to an increase in marketable yield. In line with this, Kitila et al. [35] also reported that an elevated NPS level correlates with an increase in marketable bulb yield.

Manna [21] found that the highest marketable bulb yield of onion (31.52 t/ha) resulted from applying 0.5% $ZnSO_4$, while the lowest marketable bulb yield (19.62 t/ha) occurred in the treatment without $ZnSO_4$ application. Similarly, Babaleshwar et al. [46] obtained that the highest marketable bulb yield (34.13 t/ha) occurred when 0.5% $ZnSO_4$ was applied, while the lowest yield (25.76 t/ha) was observed in the treatment without $ZnSO_4$.

The lowest unmarketable bulb yield (0.33 t/ha) resulted from applying 242 kg/ha of NPS and 0.75% $ZnSO_4$, whereas the highest unmarketable bulb yield (1.63 t/ha) was observed in the treatment without NPS and $ZnSO_4$ application (Table 4). The increase in unmarketable bulb yield due to the absence of NPS and $ZnSO_4$ fertilizers may be attributed to essential nutrient deficiencies in the soil, resulting in undersized and decayed bulbs with reduced yield. Similarly, studies by Kibebew et al. [47] and Kitila et al. [35] found that the highest unmarketable bulb yield was obtained when no NPS fertilizer was applied (0 kg/ha).

3.2.4. Total Bulb Yield. The combined effects of NPS and Zn fertilizers significantly impacted the total bulb yields of onions. The highest total bulb yield (35.04 t/ha) was achieved when applying 242 kg/ha NPS along with 0.75% $ZnSO_4$, which was statistically comparable to the yield obtained from 363 kg/ha NPS combined with $ZnSO_4$ at rates of 0.5% and 0.75%, as well as 242 kg/ha NPS with 0.5% $ZnSO_4$. Conversely, the lowest total bulb yield (24.90 t/ha) occurred in treatments without NPS and $ZnSO_4$ application (Table 4). Notably, the application of NPS at a rate of 242 kg/ha along with 0.75% $ZnSO_4$ led to a substantial 40.72% boost in the total bulb yield when compared to the combined use of 0 kg/ha NPS and 0% $ZnSO_4$.

The increase in the total bulb yield resulting from the combined application of NPS and Zn fertilizers can be attributed to improved nutrient availability and heightened chlorophyll content. Consequently, this led to an elevated photosynthetic rate, facilitating greater production and translocation of photo assimilates to the onion bulbs. Yadav et al. [48] observed a similar phenomenon, where a balanced nutrient application promoted vegetative growth and chlorophyll synthesis, ultimately enhancing assimilate production and bulb yield in onions. Similarly, Assefa et al. [38] found that applying NPS fertilizer at a rate of 130 : 20 : 21 and Zn at 15 kg/ha resulted in the highest bulb yield (25.38 t/ha), while the lowest yield (9.81 t/ha) occurred with 0 : 0:0 kg/ha NPS and 0 kg/ha Zn. Kitila et al. [35] also found that the highest total bulb yield (29.35 t/ha) resulted from applying 200 kg/ha NPS, while the lowest yield (12.42 t/ha) occurred with no NPS application.

Babaleshwar et al. [46] observed that higher levels of Zn application led to an increase in the total bulb yield of onions. This enhancement was likely due to improved synthesis and translocation of photosynthates to the bulbs. Specifically, the highest total bulb yield (38.28 t/ha) occurred when Zn was applied at a rate of 0.5%, while the lowest yield (29.89 t/ha) was recorded in the treatment without $ZnSO_4$ application. Similarly, Manna [21] reported that applying

Table 4: The interaction effect of NPS and Zn fertilizers on marketable, unmarketable, and total bulb yield of onion.

NPS (kg/ha)	$ZnSO_4$ (%)	MBY (t/ha)	UMBY (t/ha)	TBY (t/ha)
0	0	23.26^{f}	1.63^{a}	24.90^{e}
	0.25	25.91^{d-f}	1.41^{a-c}	27.32^{c-e}
	0.5	25.56^{d-f}	1.30^{a-c}	26.86^{c-e}
	0.75	24.41^{ef}	1.13^{c}	25.50^{de}
121	0	24.55^{d-f}	1.30^{a-c}	25.85^{c-e}
	0.25	26.30^{d-f}	1.41^{a-c}	27.72^{c-e}
	0.5	25.23^{d-f}	1.41^{a-c}	26.65^{c-e}
	0.75	27.39^{de}	1.26^{a-c}	28.65^{b-d}
242	0	28.11^{cd}	1.15^{bc}	29.10^{b-d}
	0.25	27.95^{c-e}	1.38^{a-c}	29.34^{bc}
	0.5	31.04^{bc}	0.61^{de}	31.65^{ab}
	0.75	34.87^{a}	0.33^{e}	35.04^{a}
363	0	26.40^{d-f}	1.60^{ab}	27.62^{c-e}
	0.25	27.69^{de}	1.60^{ab}	29.29^{bc}
	0.5	31.62^{b}	1.41^{a-c}	33.04^{a}
	0.75	33.99^{ab}	0.98^{cd}	34.97^{a}
Significance level		*	*	*
CV%		6.68	12.15	6.59

*Significant at probability level of $p < 0.05$; CV = coefficient of variation; MBY = marketable bulb yield; UMBY = unmarketable bulb yield; TBY = total bulb yield; means followed by the same letter(s) are not significantly different.

Table 5: Summary of partial budget and marginal rate of return analysis for response of onion production to different rates of NPS and Zinc sulfate.

NPS (kg/ha)	Zn (%)	TVC (ETB/ha)	AvY (t/ha)	AjY (t/ha)	GFB (ETB/ha)	NB (ETB/ha)	MRR (%)
0	0	—	23.26	20.93	627,900.00	628,020.00	0
121	0	4,418.98	24.55	22.09	662,700.00	658,431.02	688.19
242	0	7,861.11	31.04	27.94	838,200.00	830,218.89	4990.74
0	0.25	9,027.00	25.91	23.32	699,600.00	690,543.00	D
363	0	11,260.80	26.40	23.76	712,800.00	701,539.20	D
121	0.25	12,645.98	26.30	23.67	710,100.00	697,454.02	D
242	0.25	16,688.11	27.95	25.15	754,500.00	737,961.89	D
0	0.5	17,244.00	25.56	23.00	690,000.00	672,876.00	D
363	0.25	19,687.80	27.69	24.92	747,600.00	727,942.20	D
121	0.5	20,662.98	25.23	22.71	681,300.00	660,547.02	D
242	0.5	25,005.11	31.04	27.94	838,200.00	813,074.89	D
0	0.75	25,500.00	24.41	21.96	658,800.00	633,570.00	D
363	0.5	28,704.80	31.62	28.46	853,800.00	825,035.20	D
121	0.75	29,218.98	27.39	24.65	739,500.00	710,311.02	D
242	0.75	32,861.11	34.87	31.38	941,400.00	908,628.89	313.64
363	0.75	36,760.80	33.99	30.59	917,700.00	880,969.20	D

TVC: total variable cost; AvY: average yield; AjY: adjustable yield; GFB: gross field benefit; NB: net benefit; ETB: Ethiopian Birr; D: dominated treatment; MRR: marginal rate of return; selling price of onion at farm gate = 30 ETB kg^{-1}; purchasing costs of NPS fertilizer = 20.00 ETB kg^{-1}; cost of $ZnSO_4$ = 1200 ETB kg^{-1}; labor cost = 100 ETB per man day.

0.5% $ZnSO_4$ resulted in the highest total bulb yield (33.34 t/ha), whereas the lowest yield (24.43 t/ha) was observed in the treatment without $ZnSO_4$ application. In addition, studies by Mukesh et al. [49] and Acharya et al. [50] also highlighted that increased application of zinc fertilizer positively influenced the onion bulb yield.

3.3. Economic Analysis. The results of the economic analysis revealed that the combined application of 242 kg/ha NPS and 0.75% $ZnSO_4$ provided the highest net benefit of 908,628.89 ETB/ha with acceptable MRR 313.64%, followed by the combined application of 242 kg/ha NPS and 0% $ZnSO_4$ with the net benefit of 830,218.89 ETB/ha and the highest MRR (4990.74%) (Table 5).

4. Conclusion

The growth and yield parameters of onions in the study area were significantly influenced by the application of NPS and zinc fertilizers. The results indicated that the highest leaf count (11.68), longest bulb length (6.03 cm), and widest bulb diameter (6.12 cm) were recorded when NPS was applied at a rate of 242 kg/ha. On the other hand, the combined application of 242 kg/ha NPS and 0.75% $ZnSO_4$ resulted in the longest plant height (65.20 cm), leaf length (51.93 cm), highest marketable bulb yield (34.87 t/ha), total bulb yield (35.04 t/ha), and lowest unmarketable yield (0.33 t/ha). An economic analysis further revealed that the combined application of 242 kg/ha NPS and 0.75% $ZnSO_4$ led to the highest net benefit (908,628.89 ETB/ha) with an acceptable MRR (313.64%). In addition, the combination of 242 kg/ha NPS and 0% $ZnSO_4$ yielded a net benefit of 830,218.89 ETB/ha with the highest MRR (4990.74%). Therefore, this study suggest utilizing the combined application of 242 kg/ha NPS and 0.75% $ZnSO_4$ to enhance the economic efficiency of onion production in the study area and similar agro-ecological regions.

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

The authors confirm that the content of the manuscript has not been published or submitted for publication elsewhere.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

KM is the first author of the research article, whereas the coauthors have contributed equally to the literature collection, data collection and analysis, manuscript documentation, and its revision. All the authors have read and approved the final manuscript.

Acknowledgments

The authors would like to acknowledge University of Gonder and Debre Berhan University for their supports.

References

[1] J. L. Brewster, *Onions and Other Vegetable Alliums*, vol. 15, CABI, Wallingford, UK, 2008.

[2] G. E. Welbaum, *Vegetable Production and Practices*, Virginia Tech University, Blacksburg, VA, USA.

[3] A. N. Bagali, H. B. Patil, V. P. Chimmad, P. L. Patil, and R. V. Patil, "Effect of inorganic and organics on growth and yield of onion (*Allium cepa* L.)," *Karnataka Journal of Agricultural Sciences*, vol. 25, pp. 112–115, 2012.

[4] G. Griffiths, L. Trueman, T. Crowther et al., "Onions: a global benefit to health," *Phytotherapy Research*, vol. 16, no. 7, pp. 603–615, 2002.

[5] V. I. Nemtinov, Y. N. Kostanchuk, V. S. Pashtetskiy et al., "Biochemical and cytological features of onion bulbs and leaves collected from various ecogeographical origins," *SABRAO Journal of Breeding and Genetics*, vol. 53, no. 4, pp. 543–560, 2021.

[6] FAOSTAT (Food and Agriculture Organization Statistics), "Corporate statistical data base," 2020, http://www.fao.org/faostat//en//#data/QC/visualize.

[7] G. Tekle, "Growth, Yield, and Quality of Onion (Allium cepa L.) as Influenced by Intra- Row Spacing and Nitrogen Fertilizer Levels in Central Zone of Tigray, Northern Ethiopia," MSc. Thesis, Haramaya University, Haramaya, Ethiopia, 2015.

[8] O. Nikus and F. Mulugeta, *Onion Seed Production Techniques, A Manual for Extension Agents and Seed Producers*, FAOCDMDP, Asella, Ethiopia, 2010.

[9] Central Statistical Agency (CSA) of Ethiopia, "Agricultural Sample Survey 2020/21 (2013 E.C.) Report on Area and Production of Major Crops, Private Peasant Holdings," 2021, https://www.statsethiopia.gov.et/wp-content/uploads/2021/06/2020_21-2013-E.C-AgSS-Main-Season-Agricultural-Farm-Management-Report.pdf.

[10] Y. Yeshiwas, M. Alemayehu, and E. Adgo, "The rise and fall of onion production; its multiple constraints on pre-harvest and post-harvest management issues along the supply chain in northwest Ethiopia," *Heliyon*, vol. 9, no. 5, 2023.

[11] N. Tekeste, N. Dechassa, K. Woldetsadik, L. Dessalegne, and A. Takele, "Effect of Integrated Nitrogen, Phosphorus, and Farmyard manure on post-harvest quality and storability of onion (*Allium cepa* L.)," *Journal of Postharvest Technology*, vol. 5, no. 4, pp. 25–37, 2017.

[12] A. Yohannes, T. Tsegaw, and L. Pant, "Growth, bulb yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and phosphorus on vertisol of Shewa Robit District," *African Journal of Agricultural Research*, vol. 6, no. 14, pp. 3252–3258, 2011.

[13] M. Tilahun, W. Tena, and B. Desta, "Effects of different nitrogen and sulfur fertilizer rates on growth, yield, quality and nutrient uptake of onion (*Allium cepa* L.) at Shewa Robit, North Shewa, Ethiopia," *The Open Biotechnology Journal*, vol. 15, no. 1, pp. 59–67, 2021.

[14] Ethiopian Institute of Agricultural Research (EIAR), "Guideline of Crop Production Technologies," 2007, https://www.eiar.gov.et/.

[15] M. Alemayehu and M. Jemberie, "Optimum rates of NPS fertilizer application for economically profitable production of potato varieties at Koga Irrigation Scheme, Northwestern Ethiopia," *Cogent Food & Agriculture*, vol. 4, no. 1, Article ID 1439663, 2018.

[16] ATA (Agricultural Transformation Agency), "Soil fertility status and fertilizer recommendation, atlas for Amhara Regional State, Ethiopia," *Addis Ababa*, 2016.

[17] BoA (Bureau of Agriculture), "Kewet woreda agriculture development office," *Annual Report*, USAID, Washington, DC, USA, 2000.

[18] EARO (Ethiopian Agricultural Research Organization), *Directory of released crop varieties and their recommended cultural practice*, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia, 2004.

[19] A. Zeleke and E. Derso, *Production and Management of Major Vegetable Crops in Ethiopia*, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia, 2015.

[20] L. A. Gererufael, N. T. Abraham, and T. B. Reda, "Growth and yield of onion (*Allium cepa* L.) as affected by farmyard manure and nitrogen fertilizer application in Tahtay Koraro District,Northwestern Zone of Tigray, Ethiopia," *Vegetos*, vol. 33, no. 4, pp. 617–627, 2020.

[21] D. Manna, "Growth, yield and bulb quality of onion (*Allium cepa* L.) in response to foliar application of boron and zinc,"

SAARC Journal of Agriculture, vol. 11, no. 1, pp. 149–153, 2014.
[22] A. Mehlich, "Mehlich 3 soil test extractant: a modification of Mehlich 2 extractant," *Communications in Soil Science and Plant Analysis*, vol. 15, no. 12, pp. 1409–1416, 1984.
[23] H. Murphy, "A report on fertility status and other data on some soils of Ethiopia. In College of Agriculture HSIU," *Experimental Station Bulletin*, vol. 551, 1968.
[24] P. Hazelton and B. Murphy, *Interpreting Soil Test Results: What Do All the Numbers Mean?*, CSIRO Publishing, Australia, 2007, http://www.publish, 2nd edition.
[25] J. Potgieter, *Verbal Communication on Macro-Elements Application Time*, Researcher, Limpopo Department of Agriculture, 2006.
[26] J. Landon, *Tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics*, vol. 474, Long man scientific and technical, Essex, NY, USA, 1991.
[27] S. R. Olsen, *Estimation of available phosphorus in soils by extraction with sodium bicarbonate*, US Department of Agriculture, vol. 939, 1954.
[28] I. Bashour, *Fertility and Fertilizer Requirements in Rural Integrated Development of the Mountains of Northern Lebanon*, FAO report to Ministry of Agriculture, Beirut, Lebanon, 2001.
[29] J. Jones, *Agronomic Handbook: Management of Crops, Soils, and Their Fertility*, vol. 482, CRC Press LLC, Boca Raton, FL, USA, 2003.
[30] L. Desalegn and S. Aklilu, *Research Experiences in Onion Production*, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia, 2003.
[31] SAS, Institute Inc., "SAS/STAT User‟s guide," *SAS Online Document 9.1.3*, SAS Institute, Inc, Cary, NC, USA, 2009.
[32] K. A. Gomez and A. A. Gomez, *Statistical Procedures of Agricultural Research*, John Wily and Sons, New York, NY, USA, 1984.
[33] CIMMYT, "From agronomic data to farmer recommendations," *An Economics Training Manual*, 1988.
[34] M. Assefa, "Effects of liming and NPS fertilizer rates on yield and yield components of onion Allium cepa L.) in Koga Irrigation Scheme, Mecha District of North West Ethiopia," MSc. Thesis, Bahir Dar University, Bahir Dar, Ethiopia, 2019.
[35] C. Kitila, A. Abraham, and S. Shuma, "Growth and bulb yield of some onion (*Allium cepa* L.) varieties as influenced by NPS fertilizer at Dambi Dollo, Western Ethiopia," *Cogent Food & Agriculture*, vol. 8, no. 1, 2022.
[36] S. Arora and M. Singh, "Interactive effect of zinc and nitrogen on growth and yield of barley on typic ustipsamments," *Asian Journal of Plant Science*, vol. 3, no. 1, pp. 101–103, 2004.
[37] S. Tisdale, W. Nelson, and J. Beaton, "Micronutrients and other beneficial elements in soils and fertilizers," in *Soil Fertility and Fertilizers, Zinc*, vol. 10022, pp. 387-388, Macmillan Publishing Company, New York, NY, USA, 1985.
[38] A. Assefa, M. Solomon, and A. Yirga, "Response of onion (*Allium cepa* L.) growth and yield to different combinations of N, P, S, Zn fertilizers and compost in Northern Ethiopia," *International Journal of Science and Research*, vol. 4, no. 2, pp. 985–989, 2015.
[39] M. Nigatu, M. Alemayehu, and A. Haile Sellassie, "Optimum rate of NPS fertilizer for economical production of irrigated onion (*Allium cepa* L) in Dembyia District of Amhara Region, Ethiopia," *Ethiopian Journal of Science and Technology*, vol. 11, no. 2, pp. 113–127, 2019.
[40] T. A Bhat, M. Chattoo, F. Mushtaq et al., "Effect of zinc, boron and their interaction on growth and yield of onion under temperate conditions," *International Journal of Current Microbiology and Applied Sciences*, vol. 7, no. 4, pp. 3776–3783, 2018.
[41] H. P. Mishra, K. P. Singh, and J. P. Yadav, "Influence of Zn, Fe, B and Mn and their uptake on onion grown in calcareous soil," *Haryana Journal of Horticultural Sciences*, vol. 19, no. 1&2, pp. 153–159, 1990.
[42] M. Nigatu, "Assessment of Onion production practices and effects of N: P2O5: S fertilizer rates on yield and yield components of onion (*Allium cepa* L.) under irrigated farming system in Dembiya District, Amhara Region, Ethiopia," *MSc Thesis, Bahirdar University, Bahirdar, Ethiopia*, 2016.
[43] A. Arshad, M. Zubair, A. Bari, and M. Fazal, "Response of onion (*Allium cepa* L) Growth and yield to different levels of nitrogen and zinc in Swat Valley," *Sarhad Journal of Agriculture*, vol. 23, no. 4, pp. 77–79, 2007.
[44] B. Gashaw, "Evaluation of different rates of NPS on growth and yield performances of garlic (*Allium sativum* L.) in Cheha District, Gurage Zone, Ethiopia," *International Journal of Agronomy*, vol. 2021, pp. 1–5, 2021.
[45] D. Shiferaw, *Response of Garlic (Allium Sativum L.) to Fertilizer Management in Ada'a District, Central Highland of Ethiopia*, PhD. Dissertation, Haramaya University, Haramaya, Ethiopia, 2014.
[46] S. Babaleshwar, Ainrp on Onion and Garlic Dept Soil Science Uas Dharwad Karnataka India, P. Dharmatti, and K. Math, "Impact of micronutrients on growth, yield and quality of onion (*Allium cepa* L)," *International Journal of Pure & Applied Bioscience*, vol. 5, no. 6, pp. 1205–1209, 2017.
[47] F. Kibebew, D. Belew, and A. Nebiyu, "Effects of blended (NPSB) fertilizer rate of growth, yield, and yield component of onion (*Allium cepa* L.) varieties at Jimma condition by Wolkite, Ethiopia," *Agricultural Pre*, vol. 37, no. 4, pp. 152–157, 2021.
[48] R. Yadav, N. Sen, and B. Yadav, "Response of onion to nitrogen and potassium fertilization under semi-arid condition of Rajasthan," *Indian Journal of Horticulture*, vol. 60, no. 2, pp. 176–178, 2003.
[49] K. Mukesh, T. K. Chattopadhyay, D. K. Das, P. S. Munsi, and M. Kumar, "Interaction between sulphur and zinc on the yield and yield attributes of onion (*Allium cepa* L.)," *J. Interacademicia.*, vol. 1, no. 4, pp. 295–300, 1997.
[50] U. Acharya, K. Venkatesan, T. Saraswathi, and K. S. Subramanian, "Effect of zinc and boron application on growth and yield parameters of multiplier onion (*Allium cepa* L. var aggregatum Don.) var. CO (On)5," *International Journal of Research*, vol. 2, pp. 757–765, 2015.