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RESEARCH ARTICLE

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

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Abstract:

Background:

Onion is one of the most important crops widely cultivated throughout the world, including Ethiopia. The production of onion is mainly affected by the inadequate application of inorganic fertilizer types and rates.

Objective:

A field experiment was conducted to evaluate the effect of nitrogen and sulfur fertilizers on the growth, yield, quality, and nutrient uptake of onion at Shewa Robit in 2018/19 under irrigation.

Methods:

The experiment consisted of four nitrogen rates (100, 150, 200, and 250 kg N /ha) and five sulfur rates (0, 15, 30, 45, and 60kg S/ha). The treatments were laid out in a factorial arrangement with three replications using randomized complete block design (RCBD). Bombay Red was used as a testing onion variety.

Results:

The interaction effect of nitrogen and sulfur significantly increased plant height, leaf length, leaf diameter, leaf area index, neck diameter, shoot dry weight, bulb fresh weight and bulb dry weight, percent dry matter content, yield, and quality parameters. The application of 200kg N/ha and 45 kg S/ha resulted in the highest yield (42.6 t ha^{-1}), the average weight of bulb (193.6g), and a marketable bulb (99.8%). The highest N uptake (243.3 kg ha^{-1}) and S uptake (31.9kg ha-1) were obtained by the combined application of 200 kgN/ha and 45kg S/ha.

Conclusion:

The application of 200 kgN/ha and 45kgS/ha can be recommended for high yield and quality onion production in the study area.

Keywords: Marketable bulb, Nitrogen, Onion, Sulfur, Yield, Vertisols.

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1. INTRODUCTION

Onion (*Allium cepa* L.) belongs to the genus Allium of the family Alliaceae. It is the most important of the bulb crops cultivated commercially in most parts of the world [1]. Onion contributes a significant nutritional value to the human diet and has medicinal properties. It is primarily consumed for its unique flavor or the ability to enhance the flavor of other foods [2]. Onion is valued for its distinct pungency, and it is an essential ingredient in flavoring varieties of dishes, sauces, soups, sandwiches, and snacks such as onion rings [3].

The average productivity of onions in Ethiopia (9.3 t ha^{-1}) is much lower than other onion producing countries like the Republic of Korea (66.15 t /h^{1-}), USA (56.13 t ha^{-1}), the Netherlands (51.64 t ha^{-1}), Japan (46.64 t ha^{-1}), and Egypt (36.16 t ha^{-1}) [4]. One of the major problems affecting onion production in Ethiopia is the rapid depletion of nutrients in smallholder farmlands [5]. Soil fertility depletion is one of the

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causes of yield decline for most crops in Ethiopia. Abdissa *et al*. [6] reported that the average nutrient depletion in East Africa, particularly Ethiopia, is estimated to be around 47 to 88 kg ha^{-1}/yr. Major factors contributing to such depletion are soil erosion, fixation, and leaching. The problem is further increased by deleterious land use practices resulting from high population pressure. In addition, ATA [7] showed that most of the Amhara regions' soils were deficient in macro (N, P, K, Ca, S, and Mg) and micro-nutrients (Cu, Mn, Zn, B, and Fe).

Though the area has favorable environmental conditions for onion cultivation, limited fertilizer use and sub-optimal application rate of mineral fertilizer are the major constraints for increasing onion yield in the district [6]. Moreover, regardless of the fertility status of the soil and the types of cultivar, the national blanket recommendation of 100 $kgha^{-1}$ urea and 200 kg ha^{-1} DAP (substituted by NPS) is used for onion production in the area [8]. Farmers in the study area are conscious of the response of onion to applied nutrients, but they do not know the type and rate of fertilizers applied to improve yield. Therefore, one of the major problems resulting in lower onion yield in the district is the lack of optimum rate of fertilizer recommendations based on the local soil conditions. Hence, the objectives of this study were to evaluate the effect of different levels of sulfur and nitrogen fertilizer on the growth, yield, and quality of onion and evaluate the economic feasibility of the fertilizer application.

2. MATERIALS AND METHODS

2.1. Description of the Experimental Site

The experiment was conducted at the Shewa Robit Integrated Development Project site of Debre Berhan University (DBU), North Shewa zone, Ethiopia. Shewa Robit is located about 225 km northeast of Addis Ababa. It is located at 11°55' N latitude and 37°20' E longitude and an altitude of 1380 m.a.s.l. The experiment was undertaken during the winter season, from January 2018 to May 2019, with irrigation. The area has a short rainy season between March and April and a long rainy season between June and September [9]. Annual mean minimum and maximum temperatures were 14.0 and 30.4°C, respectively, with sub-humid tropical climate type and a mean rainfall of about 77.0 mm during the cropping season.

Vertisols are the dominant soil type in the district. Crops previously grown on the experimental area were Sorghum (*Sorghum bicolor*), maize (*Zea mays*), Timbaho (Tobacco), teff (*Eragrostis tef*), and Masho (*Vigna radiata*). It has a moderate slope. Mixed crop livestock production is the typical farming system in the Shewa Robit districts [8]. The experimental field was planted with mung bean in the previous cropping season.

2.2. Treatments and Experimental Design

The experiment consisted of four nitrogen rates (100, 150, 200, and 250 kg N /ha) and five sulfur rates (0, 15, 30, 45, and 60kg S/ha). The treatments were laid out in a factorial arrangement with three replications using Randomized Complete Block Design (RCBD). Mean separation was made using Duncan's Multiple Range Test (DMRT) at a 5% level of probability. The total number of treatments was 60 (20 treatments* 3 replication) with 1m spacing between blocks and 0.5 m between plots.

2.3. Experimental Procedure

Bombay Red onion variety was used for the study. The variety is well adapted and predominantly produced in the study area. Seeds were sown in a nursery on a well-prepared seedbed. The land was plowed with a depth of 25 cm, pulverized, and leveled by oxen. Ridges and furrows were prepared using hand tools manually. The size of each plot was 3mx2m ($6m^2$). Seedlings were transplanted 45 days after sowing in the experimental field. The planting of onion seedlings was done with a double row (ridge) planting system at the spacing of 20 cm between rows and 10 cm between plants, and 40 cm between double rows (furrow) [8]. Each experimental plot was 8.4 m^2 in size (2.8m x 3m) and accommodated four double rows with 30 plants in each row and 240 plants per plot. The middle six rows were used for data collection.

2.4. Description of the Experimental Materials

Fertilizer sources were urea (46% N) for nitrogen fertilizer and triple superphosphate (46% P_2O_5) for phosphorus. The sulfur fertilizer source was elemental sulfur (99% S). All amounts of P, S, and half of N fertilizer were applied at transplanting time, whereas the half rate of N fertilizer was applied 45 days after transplanting [8]. The experiment was conducted under the furrow irrigation method. A four-day irrigation interval was maintained for the 1st four weeks. Then it was extended to five- to seven-day intervals until 15 days to harvest when irrigation was stopped completely. All other agronomic practices were applied uniformly for all the plots as per the recommendations of the crop [8].

2.5. Soil Sampling, Preparation, and Laboratory Analysis

Soil samples were taken randomly from twenty sampling points for making a composite sample in the depth of 0-30 cm before the commencement of the experiments to determine the initial fertility status of the soil. The soil was air-dried under shade, ground, and screened through a 2 mm sieve to determine particle size distribution. The soil was analyzed for texture, pH, EC (electrical conductivity), organic matter content, exchangeable K, total N, and available S and P. Furthermore, the samples were crushed to pass through a 0.5 mm diameter sieve for analysis of Organic Carbon (OC) and total N. Analyses of both physical and chemical soil characteristics were done at Debre Berhan Agricultural Research Centre Soil Laboratory. Standard laboratory procedures were followed for the analysis of the selected physicochemical properties considered in the study.

2.6. Data Collection and Measurements

2.6.1. Growth Parameters

Plant growth parameters, including plant height, leaf length, leaf diameter, leaf number per plant, neck diameter, leaf area index, and shoot dry weight, were recorded at physiological maturity.

Plant height (cm) was measured from 10 randomly selected plants in each plot at maturity from the ground level and averaged per plant.

Leaf Length (cm) was measured from the longest leaf of ten randomly selected plants in each plot and averaged per plant.

Leaf number per plant was counted from 10 randomly selected plants in the plot and averaged per plant.

Leaf diameter (cm) was considered from 10 randomly selected plants. One leaf from each sample plant was measured at the widest part leaf.

Neck diameter (cm) was determined from 10 randomly selected plants. It was measured by using a caliper just above the ground.

Leaf area index (LAI) was calculated from the total leaf area of the plant proportional to the land area that was occupied.

Shoot dry weight (g) was taken from adjacent rows and oven-dried at a temperature of 65 ^{O}C to a constant weight, and its dry matter yield was determined.

2.6.2. Yield and Yield Components

Bulb length (cm) was determined from ten randomly selected plants of the six central rows at physiological maturity. It was measured longitudinally by using a caliper after curing.

Bulb diameter (cm) was determined from ten randomly selected plants. It was measured at the middle cross-section of the bulb by using a caliper after curing.

Yield per hectare (t/ha) was weighed after curing for 10 days under shade in ambient condition and converted to t/ha.

Fresh weight of bulb (g) was determined by taking ten randomly selected plants. Then the root, leaf, and stem parts were removed and weighed by digital sensitive balance.

Bulb dry matter (g) five bulbs were randomly taken from each plot and chopped into small 1-2 cm cubes, mixed thoroughly, and two sub-samples each weighing 25 gram were weighed. The exact weight of each sub-sample was determined and recorded as fresh weight. Each subsample was placed in a paper bag and placed in an oven until the constant dry matter was attained. Each sub-sample was then immediately weighed and recorded as dry matter yield.

Dry weight of bulb (g) was the dry mass of the above bulb fresh weight after oven drying the bulb at a temperature of 65 ^{O}C until constant weight.

Total dry biomass (g) was determined by taking the total biomass weight of 10 randomly selected plants which included dried bulbs, leaves, stems, and roots, after drying in an oven at 65 ^{O}C until a constant weight was attained.

$$TDM = (BDW+SDW+RDW) \quad (1)$$

where: DW = Bulb dry weight, SDW = Shoot dry weight, and RDW = Root dry weight

Harvest index (%) was the ratio of dry bulb yield to dry biological yield, and biological yield was the total weight of onion plant including above and below ground yield (total biomass) recorded from ten plants sampled after bulbs were harvested. This was calculated as:

$$HI= (EY/BY)*100 \quad (2)$$

where EY = weight of dry bulb (Economic Yield); BY = weight of biological yield (above and below ground dry weight).

2.6.3. Quality Parameters

Marketable bulb percentage (%MB) refers to the weight of healthy and marketable bulbs that range as oversized (above 160g), large (100-160g), and medium (50-99g) [10]. This parameter was determined from the net plot at the final harvest and expressed in percentage.

$$\text{Marketable bulbs (\%)} = \text{(weight of marketable bulbs)/(total weight of bulbs)} \times 100 \quad (3)$$

Unmarketable bulb percentage (% UMB) was recorded as the total weight of damaged, small bulbs (<20g), splitter, thick-necked, doubles, rotten, off-color and discolored bulbs after curing, which was obtained by converting the discarded unmarketable bulbs in percentage.

$$\text{Unmarketable bulbs (\%)} = \text{(weight of unmarketable bulbs)/(total weight of bulbs)} \times 100 \quad (4)$$

Average weight of the bulb was determined by measuring bulb weights of 10 randomly selected plants from the central six rows, curing, and dividing by the number of bulbs.

2.7. Plant Tissue Analysis

Samples of the bulbs from the center rows of each plot were taken at maturity. Bulbs were chopped into pieces to facilitate drying. For plant sample analysis, 0.50g dry bulb samples were taken and digested with a 2:1 mixture of nitric (HNO_3) and per chloric acids ($HClO_4$). The nitrogen contents in matured bulbs were determined by Micro Kjeldahl's method [11]. The concentration of S in the extract was determined turbidmetrically using a spectrophotometer [11]. Total uptakes of N and S were determined by multiplying the concentration with its yield weight.

2.8. Data Analysis

Data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) of the SAS statistical package [12] version 9.4. Duncan's Multiple Range Test (DMRT) at 0.05 probability level was used to separate treatment means.

3. RESULTS AND DISCUSSION

3.1. Soil Analysis

Major soil physico-chemical properties of the experimental site are presented in Table **1**. The result of the laboratory analysis showed that the soil of the study area had a particle size distribution of 34% sand, 22% silt, and 44% clay, which put the soil in the texture class of clay at the depths (0-30cm).

According to the soil requirements of onion, the soil was found to be suitable for onion production [10]. The soil pH (H_2O) was 7.4, which was a moderately alkaline condition [13]. Favorable soil pH is about 6.5–8.0 in mineral soils [3]. The total N content of the soil (0.08%) was rated as low [13]. Available phosphorus and exchangeable potassium content of the soil were 10.20 (mg/kg) and 1.07 cmol (+)/kg, respectively (Table **1**). Landon [14] stated that plant response to potassium fertilizer application is likely when soil has an exchangeable K content of lower than 0.20 cmol (+)/kg soil and unlikely when it has exchangeable K content of higher than 0.40 cmol (+)/kg soil. The available content of K in the soil indicated that the soil contains a sufficient amount of K for onion cultivation. The amount of phosphorus in soil was low. Olsen *et al.* [15] showed that in irrigated area phosphorus content of the soil is classified as < 12 mg/kg low, 12-17 mg/kg marginal, 18-25 mg/kg adequate and > 25 mg/kg high. The sulfur content of the soil was 5.4 mg/kg, which was very low. The content of organic matter was very low [13]. The soil analysis result shows no salinity problem as the electrical conductivity of soils was about 0.34 d S m^{-1}. Hazelton and Murphy [16] described that the soil salinity effect below 2.0 d S m^{-1} is mostly negligible for most crops. Therefore based on the soil analysis result, the study area soil is deficient in N, P, and S nutrients but sufficient in available K.

3.2. Effect of Nitrogen and Sulfur Rate on Growth Parameters of Onion

3.2.1. Plant Height

Plant height was significantly affected by nitrogen and sulfur application ($P < 0.001$) (Table **2**). The tallest plant height (68.93 cm) was recorded by the combined application of 200kg N ha^{-1} and 45 kg S ha^{-1}. However, the shortest plant height (49.67cm) was recorded by the application of 100 kg N/ha with no S application. In line with this, Chattoo *et al*. [17] reported that the application of nitrogen at the rate of 150 kg ha^{-1} and sulfur at the rate of 45 kg ha^{-1} produced the highest value (76.40 cm) for plant height of onion.

Table 1. Physico-chemical characteristics of soil in the experimental area.

Soil Properties	Values	Rating	Source
pH	7.40	Moderately alkaline	Tekalign [13]
Sand (%)	34.00	-	-
Silt (%)	22.00	-	-
Clay (%)	44.00	-	-
Textural class	clay	-	Hazelton and Murphy [16]
Electrical conductivity (ds /m)	0.34	Non-saline	Hazelton and Murphy [16]
Organic matter (%)	1.00	Very low	Tekalign [13]
Total nitrogen (%)	0.08	Low	Tekalign [13]
Total Available phosphorus (mg/kg)	10.20	Medium	Olsen *et al*. [15]
Total available potassium (cmol (+)/kg)	1.07	Medium	Hazelton and Murphy [16]
Available S (ppm)	5.4	Low	Hazelton and Murphy [16]

Table 2. Effect of nitrogen and sulfur application on plant height (PH), leaf number (LN), leaf diameter (LD), leaf length (LL), leaf area index (LAI), and neck diameters (ND) of onion.

N kg ha^{-1}	S kg ha^{-1}	PH (cm)	LN	LD (cm)	LL (cm)	LAI	ND (cm)
100	0	49.67^{l}	8.33^{h}	0.63^{j}	31.67^{j}	1.63^{g}	0.76^{i}
	15	50.80^{k}	10.00^{f-h}	0.70^{g-j}	35.17^{g-j}	1.64^{g}	0.78^{hi}
	30	51.37^{jk}	11.00^{d-g}	0.72^{f-j}	35.83^{f-j}	1.65^{g}	0.79^{hi}
	45	54.40^{h}	13.00^{a-d}	0.69^{f-j}	34.67^{g-j}	1.78^{dg}	0.80^{hi}
	60	51.96^{j}	13.33^{a-c}	0.73^{f-i}	36.67^{e-g}	1.67^{g}	0.81^{hi}
150	0	53.40^{hi}	9.67^{gh}	0.68^{h-j}	34.17^{h-j}	1.79^{d-g}	0.83^{fh}
	15	56.07^{fg}	9.67^{gh}	0.78^{d-h}	38.67^{b-h}	1.87^{d-g}	0.92^{d}
	30	55.43^{g}	11.00^{d-g}	0.83^{a-d}	41.50^{a-c}	1.99^{cde}	0.92^{d}
	45	60.77^{c}	12.00^{c-f}	0.83^{a-d}	41.67^{a-c}	2.17^{ab}	1.01^{c}
	60	57.27^{ef}	9.33^{gh}	0.82^{a-e}	41.00^{a-e}	1.87^{d-g}	0.93^{cd}
200	0	62.80^{bc}	14.67^{a}	0.87^{ab}	42.67^{ab}	2.29^{a}	1.08^{b}
	15	55.20^{gh}	9.33^{gh}	0.76^{c-f}	36.50^{e-g}	1.85^{d-g}	0.91^{d}
	30	59.03^{d}	10.33^{e-g}	0.79^{a-f}	39.33^{b-g}	1.96^{c-f}	0.92^{d}
	45	68.93^{a}	15.00^{a}	0.88^{a}	43.83^{a}	2.30^{a}	1.67^{a}
	60	57.53^{e}	13.00^{a-d}	0.80^{a-f}	40.00^{a-f}	1.85^{d-g}	0.91^{e}

(Table 2) contd.....

N kg ha^{-1}	S kg ha^{-1}	PH (cm)	LN	LD (cm)	LL (cm)	LAI	ND (cm)
250	0	52.20^{ij}	9.33^{gh}	0.65^{ij}	32.50^{j}	1.71^{f}	0.78^{hi}
	15	52.73^{i}	9.33^{gh}	0.71^{f-i}	35.00^{f-j}	1.79^{d-g}	0.85^{eh}
	30	58.60^{de}	10.67^{e-h}	0.75^{d-h}	37.33^{c-i}	1.80^{d-g}	0.90^{ef}
	45	63.07^{b}	12.33^{b-e}	0.87^{ab}	43.33^{ab}	2.07^{a-c}	0.97^{c}
	60	56.17^{f}	14.33^{ab}	0.75^{d-h}	36.83^{e-i}	2.02^{a-c}	0.88^{fe}
CV		2.23	11.00	6.41	6.77	8.1	4.8
Sign. Difference		***	***	**	***	*	***

Means followed by the same letter within a column are not significantly different at a 5% level of significance by DMRT. *, **, and ***showed significant differences at 0.05, 0.01, and 0.001 probability levels, respectively.

3.2.2. Leaf Number Per Plant

Leaf number per plant was significantly affected by nitrogen and sulfur application ($P < 0.001$) (Table **2**). The highest leaf number (15.00) was recorded in response to the combined application of 200kg N ha^{-1} and at 45 kg S ha^{-1}. On the other hand, plants with the lowest number of leaves per plant (8.33) were recorded in response to the application of 100 kg N ha^{-1} with no S application. These results are in conformity with Al-Fraihat *et al.* [18], who reported that the highest (10.48) number of leaves per plant was obtained by the application of 200 kg N/h^{1-} and 50 kg S/h^{-1}. Rizk *et al.* [19] also reported that the application of 200 kg N/h^{1-} and 50 kg S/h^{1-} showed a significant effect on the number of leaves (10.70) of onion.

3.2.3. Leaf Diameter

The interaction of N and S showed a significant effect on the leaf diameter of onion ($P < 0.01$) (Table **2**). Application of N at the rate of 200 kg ha^{-1} and S at the rate of 45 kg ha^{-1} recorded the widest (0.88cm) leaf diameter but statistically similar with the application rate of 250 N kg ha^{-1} with 45 kg S ha^{-1}, 150 kg N ha^{-1} with the application of S rate at (45 and 60 kg ha^{-1}) and 200 N kg ha^{-1} with (0, 30 and 60 S kg ha^{-1}). On the other hand, the narrowest (0.63cm) leaf diameter was recorded in response to the application of N at a rate of 100 kg ha^{-1} with no S application ($P < 0.001$). The increment of leaf diameter with the addition of a higher level of N and S might enhance protein synthesis and cell enlargement leading to increased leaf diameter of onion. The obtained results are in conformity with that of Magray *et al*. [20], who reported that 150 kg ha^{-1} nitrogen with the application of 45 kg S/ha resulted in maximum leaf diameter in onion.

3.2.4. Leaf Length

The interaction effects of N and S fertilizer application significantly affected leaf length ($P < 0.001$) (Table **2**). The combined application of N at the rate of 200 kg ha^{-1} and S at the rate of 45 kg/ha recorded the longest leaf length (43.83 cm) compared to the other treatments. On the other hand, the shortest leaf length (39.53 cm) was recorded by the application of N at the rate of 100 kg ha^{-1} with no S application. Zaman *et al*. [21] reported the application of N at a rate of 200 kg and S at the rate of 45 kg ha^{-1} resulted in maximum leaf length.

3.2.5. Leaf Area Index

The interaction effects of N and S significantly affected the leaf area index ($P < 0.05$) (Table **2**). The combined application of 200 kg N ha^{-1} and 45 kg S ha^{-1} recorded the largest (2.30) LAI, but it was statistically similar with the application at the rate of 250 kg N ha^{-1} with 45 and 60 S kg ha^{-1}, 150 N kg ha^{-1} with the application of S rate at 45 kg ha^{-1} and 200 kg N ha^{-1} with 0 kg S ha^{-1}. However, a small LAI was recorded in response to the application of N at the rate of 100 kg ha^{-1} and 0 kg S ha^{-1}. The increase in LAI might be due to the impact of nitrogen and sulfur application on improving the vegetative growth, which led to the increment in leaf length and leaf diameter and resulted in an increased LAI. Similarly, Diriba [22] reported that the leaf area index of the garlic plant increased significantly as a result of the applied 138 kg N ha^{-1}and 60 kg S ha^{-1} fertilizers.

3.2.6. Neck Diameter

The interaction effects of N and S significantly affected leaf length ($P < 0.001$) (Table **2**). The combined application of N at the rate of 200 kg ha^{-1} and S at the rate of 45 kg ha^{-1} recorded the widest (1.67cm) neck diameter of onion. Nitrogen application at the rate of 100 kg N/ha with 0kg S/ha recorded the narrowest (0.76 cm) neck diameter. Kumar *et al*. [23] reported that increasing the application of N and S fertilizer rate increased neck diameter.

3.3. Effect of Nitrogen and Sulfur Rate on Yield and Yield Components of Onion

3.3.1. Shoot Dry Weight

The interaction effect of N and S application significantly influenced the shoot dry weight of onion ($P < 0.01$) (Table **3**). The combined application of N (200 kg N/ha) and S (45 kg /ha) resulted in the highest (12.57g) shoot dry weight while the application of N at the rate of 100 kg /ha and S at the rate of 0 kg ha^{-1} resulted in the lowest (6.83 g) shoot dry weight. In line with the present finding, Zaman *et al*. [21] reported the highest fresh and dry weight of onion leaves with the application of 200N kg ha^{-1} with 45 kg S ha^{-1}.

Table 3. Effect of nitrogen and sulfur application on Shoot Dry Weight (SDW), Bulb Fresh Weight (BFW), Bulb Dry Weight (BDW), percent Dry Matter content (DM%), Bulb Length (BL) and Bulb Yield (BY) of onion.

N kg ha^{-1}	S kg ha^{-1}	SDW (g)	BFW (g)	BDW (g)	DM%	BL (cm)	BY (t ha^{-1})
100	0	6.83^{i}	124.63^{m}	12.06^{h}	18.90^{h}	4.94^{k}	28.07^{g}
	15	7.00^{i}	138.71^{l}	11.97^{h}	18.97^{h}	5.07^{k}	29.57^{fg}
	30	7.10^{hi}	148.73^{l}	12.23^{hg}	19.33^{gh}	5.43^{j}	29.63^{fg}
	45	8.27^{g-i}	160.74^{k}	12.40^{hg}	20.67^{fg}	6.33^{h}	30.40^{ef}
	60	7.27h^{i}	175.97^{j}	12.17^{hg}	19.43^{gh}	5.71^{i}	30.53^{ef}
150	0	7.57^{hi}	193.09^{i}	12.50^{g}	20.07^{gh}	6.37^{h}	30.73^{ef}
	15	9.90^{d-f}	204.37^{h}	14.43^{e}	24.33^{d}	6.38^{h}	33.62^{d-f}
	30	11.03^{bc}	213.45^{h}	15.3^{de}	26.33^{c}	6.44^{h}	36.93^{bc}
	45	10.97^{bc}	253.31^{e}	16.57^{b}	27.53^{bc}	7.45^{dc}	38.97^{b}
	60	10.10^{c-e}	242.15^{fg}	14.57^{e}	24.67^{d}	6.80^{g}	36.20^{c}
200	0	11.50^{a-c}	286.65^{d}	14.90^{de}	26.40^{c}	7.14^{ef}	33.10^{d}
	15	10.23^{cde}	300.13^{bc}	16.03^{bd}	26.27^{c}	7.21^{d-f}	37.17^{bc}
	30	11.03^{b-d}	305.28^{b}	16.06^{bd}	27.10^{c}	7.53^{c}	38.70^{b}
	45	12.57^{a}	334.50^{a}	18.60^{a}	31.17^{a}	8.36^{a}	42.60^{a}
	60	10.37^{cd}	285.13^{d}	16.55^{b}	26.92^{c}	7.58^{c}	37.03^{bc}
250	0	8.57^{gh}	236.53^{g}	13.37^{g}	21.93^{ef}	7.37^{ce}	30.79^{ef}
	15	8.87^{e-g}	247.81^{ef}	14.50^{e}	23.37^{de}	7.56^{c}	32.20^{de}
	30	10.03^{c-e}	290.25^{cd}	16.43^{b}	24.47^{d}	6.99^{fg}	37.82^{bc}
	45	12.03^{ab}	327.97^{a}	16.73^{b}	28.77^{b}	7.85^{b}	41.37^{a}
	60	11.50^{a-c}	293.32^{cd}	16.43^{b}	27.73^{bc}	7.60^{C}	36.06^{c}
CV		8.32	2.55	4.56	3.65	2.16	3.44
Sign.Difference		**	***	**	***	**	***

Means followed by the same letter within a column are not significantly different at a 5% level of significance by DMRT. **, and *** showed significant differences at 0.01 and 0.001 probability levels, respectively.

3.3.2. Bulb Fresh Weight

The interaction effect of N and S fertilizer application significantly influenced bulb fresh weight ($P < 0.001$) (Table **3**). The combined application of 200 kg N ha^{-1} with 45 kg S ha^{-1} resulted in the highest (334.50 g) Bulb Fresh Weight (BFW) of onion but it was statistically similar with the application of 250kgN/ha with 45 kg S ha^{-1}. However, the application of N at 100kg /ha with 0kg S/ha resulted in the lowest (124.63g) bulb fresh weight. This might be due to the role of N and S in improving the vegetative growth and accelerating the photosynthesis in storage organs of bulbs, ultimately resulting in an increased bulb fresh weight. These results are in agreement with those of Mishu [24] and Zaman [21], who reported that an increased level of N and S fertilizer rate resulted in increased bulb fresh weight.

3.3.3. Bulb Dry Weight

The bulb dry weight was significantly influenced by the interaction effect ($P < 0.01$) of N and S rate Table **3**. The combined application of N (200 kg ha^{-1}) and S (45kg ha^{-1}) resulted in the highest (18.60 g) bulb dry weight. On the other hand, the application of N at the rate of 100 kg ha^{-1} with 15kg S/ha resulted in the lowest (11.97 g) bulb dry weight, but it was statically similar with the application of 100 kg N/ha and 0 kg S/ha. Improvements in bulb dry weight could be attributed to an increased photosynthetic area in response to N and S fertilization that may have enhanced assimilate production and partitioning to the bulbs that led to increased bulb dry weight. Thus an adequate supply of nutrients to plants is associated with a vigorous vegetative growth that resulted in higher productivity of crops [25].

3.3.4. Percent Dry Matter Content

Percent Dry Matter content (DM%) was significantly influenced by the interaction effect of N and S rate ($P < 0.001$) (Table **3**). The combined application of N at the rate of 200 kg ha^{-1} with S at the rate of 45 kg ha^{-1} resulted in the highest percent Dry Matter content (DM%) (31.17%) (Table **4**). However, 100 kg N/ha with 0kg S/ha resulted in the lowest percent dry matter content (18.9), which was statistically similar with the application of 100kg N/ha with 15kgS/ha. Rizak *et al.* [19] stated that the application of N and S plays a vital role in all living tissues of the plant and promotes bulb formation and translocation of nutrients from leaf to bulb, which in turn increases percent dry matter content.

Table 4. Effect of N and S on Average Bulb Weight (AWB), percent Marketable Bulb (%MB), percent Unmarketable Bulb (%UMB), N and S uptake of onion.

N (kg ha^{-1})	S (kg ha^{-1})	ABW (g)	MB %	UMB%	N uptake (kg ha^{-1})	S uptake (kg ha^{-1})
	0	65.00^{o}	97.75^{i}	2.25^{c}	127.66^{q}	13.20^{t}
	15	85.47^{n}	97.82^{i}	2.18^{c}	131.67^{p}	14.00^{s}
	30	91.50^{m}	97.86^{i}	2.14^{c}	140.66^{o}	15.25^{r}
	45	111.96^{l}	98.06^{h}	1.94^{d}	150.33^{n}	15.70^{q}
100	60	122.33^{k}	98.28^{gf}	1.72e	151.00^{m}	16.25^{p}
	0	146.00^{j}	97.46^{j}	2.54^{b}	157.66^{l}	19.85^{o}
	15	160.80^{i}	98.27^{g}	1.73^{e}	165.67^{l}	20.55^{n}
	30	163.50^{hi}	98.38^{f}	1.62^{f}	171.33^{k}	20.95^{m}
	45	164.17^{hi}	98.74^{e}	1.26^{g}	185.33^{j}	21.65^{l}
150	60	163.30^{hi}	98.94^{d}	1.06^{h}	187.00^{i}	22.35^{k}
	0	167.00^{gh}	98.99^{dc}	1.01^{hi}	187.67^{i}	22.60^{j}
	15	169.17^{fg}	99.02^{dc}	0.98^{hi}	196.33^{h}	23.60^{i}
	30	170.27^{fg}	99.07^{bc}	0.93^{ij}	198.67^{g}	24.00^{h}
	45	193.63^{a}	99.77^{a}	0.23^{k}	243.33^{a}	31.90^{a}
200	60	172.77^{ef}	99.10^{bc}	0.85^{j}	200.67^{f}	24.30^{g}
	0	174.65^{de}	97.06^{k}	2.94^{a}	201.67^{f}	25.80^{f}
	15	175.43^{cd}	98.06^{h}	1.94^{d}	208.66^{e}	26.50^{e}
	30	176.61^{c}	99.07^{bc}	0.93^{ij}	214.67^{d}	27.60^{d}
	45	182.00^{b}	99.18^{b}	0.82^{j}	218.67^{c}	29.15^{c}
250	60	178.60^{bc}	99.16^{b}	0.84^{j}	225.33^{b}	31.75^{b}
CV		1.39	0.1	4.26	3.7	5
Sign. Difference		***	***	***	***	***

Means followed by the same letter within a column are not significantly different at a 5% level of significance by DMRT, *** showed significant differences at 0.001 probability levels.

3.3.5. Bulb Length

The bulb length was significantly influenced by the interaction effect of N and S ($P < 0.01$) (Table **3**). The application of N at the rate of 200kg ha^{-1} and S at the rate of 45 kg /ha significantly increased the bulb length by 69% compared to the application of 100kg N/ha with 0 kg S/ha. The increased bulb length with N and S fertilization in the current study could be attributed to the increase in plant height, the number of leaves produced, leaf length, and neck diameter, which may have increased assimilate production and allocation to the bulb. In line with this, Diriba *et al*. [22] reported that the application of N and S increased bulb length. Magray *et al*. [20] also reported that a higher bulb length was observed by the application of 150 kg N with 60 kg S ha^{-1}.

3.3.6. Bulb Yield

Bulb yield was significantly influenced by the interaction effect of N and S rate ($P < 0.001$) (Table **3**). The combined application of N at the rate of 200 kg /ha with S at the rate of 45 kg ha^{-1} resulted in the highest bulb yield (42.60 t ha^{-1}), which was statistically similar with the application of N at the rate of 250 kg ha^{-1} with S at the rate of 45 kg ha^{-1}. However, N application at the rate of 100 kg ha^{-1} with no S application recorded the lowest yield (28.07 t/ha). The application of S at 15, 30, and 45 kg ha^{-1} with 200 kg N/ha increased the bulb yield by 32%, 38%, and 52%, respectively, compared to the application of 100kg N/ha with no S application. Similarly, Zaman *et al*. [21] indicated that 200 kg N/ha with S at the rate of 45 kg ha^{-1} produced 54.5% and 54.9% higher yield over control treatment on two consecutive years.

3.4. Effect of Nitrogen and Sulfur Rate on Quality Parameters of Onion

3.4.1. Average Bulb Weight

The average bulb weight (ABW) was significantly ($P<0.001$) influenced by the interaction effect of N and S fertilizer rate application (Table **4**). The application of 200kg N/ha with 45 kg S ha^{-1} increased the average bulb weight by 198% compared to 100kg N ha^{-1} with 0 kg S ha^{-1}. Cecilio *et al.* [26] described that the application 200 kg ha^{-1} N and 45 kg S ha^{-1} resulted in the highest average bulb weight. Diriba *et al*. [22] also reported that higher garlic bulb weights (29.73g) were obtained from the combined application of 200 kg N ha^{-1} and 60 kg S ha^{-1}.

3.4.2. Marketable Bulb

The percent marketable bulb (%MB) was significantly ($P<0.001$) influenced by the interaction effect of N and S fertilizer rate (Table **4**). The combined application of N at the rate of 200kg/ha and S at the rate of 45 kg ha^{-1} resulted in the highest marketable bulb (99.77%). However, the combined application N at the rate of 100 kg ha^{-1} with S at the rate of 0 kg ha^{-1} recorded the lowest MB (97.75%). The influence of N and S on the marketable yield of the onion bulb could be attributed to the important role of N and S in plant protein and some hormone formation; hence it helps to have a good marketable bulb. In line with this, Magray *et al*. [20] reported that nitrogen (150 kg ha^{-1}) and sulfur (45 kg ha^{-1}) application improves the bulb yield.

3.4.3. Unmarketable Bulb (%UMB)

The Unmarketable Bulb (%UMB) was significantly ($P<0.001$) influenced by the interaction effect of N and S rate (Table **4**). The combined application of N (100 kg ha^{-1}) and S at the rate of 0 kg ha^{-1} resulted in the highest UMB (2.94%). However, N application at the rate of 200 kg ha^{-1} and S at the rate of 45 kg ha^{-1} resulted in the lowest UMB (0.23%). This might be due to the application of under sub-optimal supply of N and S that promotes poor bulb size formation. Magray *et al*. [20] reported that 150 kg N ha^{-1} and S at the rate of 45 kg ha^{-1} application results in a low unmarketable bulb.

3.4.4. Uptake of Nitrogen and Sulfur

The interaction effect of N and S fertilizer application significantly ($P<0.001$) affected N and S uptake (Table **4**). The combined application of N at the rate of 200kg $ha^{-1}$and S at the rate of 45 kg ha^{-1}resulted in the highest N uptake (243.33 Kg ha^{-1}). However, the combined application N at the rate of 100 kg N/ha with no S application recorded the lowest value of N uptake (127.66 kg ha^{-1}). The combined application of N at the rate of 200kg ha^{-1} and S at the rate of 45 kg ha^{-1} resulted in the highest S uptake (31.90 Kg ha^{-1}). The combined application of N at the rate of 100 kg ha^{-1} with no S application recorded the lowest value of S uptake (13.20 kg ha^{-1}). In line with this result, Tripathy *et al.* [27] showed that the application of 150kg N ha^{-1} with 45 kg S ha^{-1} resulted in a higher N and S uptake. The increase in N uptake might be due to the vital role of S that increased the availability of N to plant, which promotes the production of higher amounts of dry matter content that could have led to the higher acquisition of nutrients, ultimately resulting in higher total N and S uptake [28]. Cecilio *et al*. [26] also indicated that the positive relation of S with nutrients such as N might promote the uptake of other essential nutrients.

CONCLUSION AND RECOMMENDATION

Onion is one of the most important crops widely cultivated throughout the world, including Ethiopia. In Ethiopia, the onion production area is increasing from time to time mainly due to its high profitability per unit area. However, the yield is very low. Different production constraints are responsible for such low bulb yield. The yield is reduced due to many factors, of which limited application of inorganic fertilizer type and rate are the major constraints for onion yield in Ethiopia. Lack of N and S application in N and S deficient soils often results in poor utilization of macro and micronutrients, which may lead to low yield and poor quality of onion. The present study was undertaken to evaluate the effect of four levels of nitrogen fertilizer (100, 150, 200, and 250 kg N /ha) and five sulfur levels (0, 15, 30, 45, and 60 kg S /ha) on growth, yield and quality of onion at Shewa Robit Integrated Research and Development Project site in 2018/19 under irrigation. The soil analysis results of the experimental site revealed that the total nitrogen contents of the soil was very low. The soil contains a low amount of phosphorous and sufficient K for onion cultivation. The sulfur content of the soil was deficient for crop production. The interaction effect of nitrogen and sulfur application showed significant effects on plant height, leaf length, leaf diameter, leaf area index, neck diameter, shoot dry weight, bulb fresh weight, bulb dry weight and % TDM, yield, and quality of onion. The combined application of 200kg N/ha with 45 kg S/ha increased the bulb yield and average weight of bulb by 52% and 198%, respectively as compared to the application of 100kg N/ha with 0 S/ha. The combined application of 200kg N/ha with 45 kg S/ha increased the uptake of nitrogen and sulfur by 90.61 and 141.67%, respectively, as compared to 100kg N/ha with 0 S/ha. Hence, the application of 200kg N/ha with 45kg S/ha can be recommended for higher yield and quality onion production in the study area.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

FUNDING

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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