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Effect of Mineral Nitrogen Fertilizer on Growth, Quality and Economic Return of Garlic (*Allium sativum L.*) at Haramaya District, Eastern Ethiopia

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Abstract

Garlic (*Allium sativum L.*) is an important vegetable crop in Ethiopia. The yield of the crop is often constrained by low and unbalanced nutrient supply in the soil. This study was undertaken to assess effect of mineral nitrogen (N) on growth, quality and economic return of garlic variety Chelenko I during 2016 main rainy season. The treatment consisted of five levels of nitrogen (0, 52.5, 80, 105 and 130 kg ha^{-1}) were laid out in a randomized complete block design and replicated three times. Significant maximum total dry matter and total soluble solid were recorded at the rate of 130 kg N ha^{-1}. Due to the application of 130 kg N ha^{-1} fertilizer, the economic analysis showed the highest net benefit cost of 198,701 ETB ha^{-1} and marginal rate of return (1,976.36%) with incurred highest total variable cost of 3,299 ETB ha^{-1}. Therefore, from the results of this study, it can be concluded that, the maximum growth and quality and economic return of garlic was obtained with application of 130 kg N ha^{-1} fertilizer as it gave the highest net benefit cost that leads this investigation to recommend highest rate of 130 kg N ha^{-1} fertilizer for the study area.

Keywords

Chelenko I, Economic, Nitrogen, Quality

1. Introduction

In Ethiopia, the acreage of garlic cultivation decreased from 16,411.19 ha in 2013/14 to 9,257.71 ha in 2,014/15 with a total production of about 1,590,935.75 and 934,868.73 tonnes of bulbs with the productivity of 9.7 and 10.1 t ha^{-1} respectively. Though acreage of garlic, production and productivity were not indicated in Eastern Hararghe, about 27,190 farmers produced garlic [1]. The yield of recently released garlic variety, *Chelenko I*, gave 9.3 t ha^{-1} on research field was appreciated and selected for Eastern and Western Hararghe [2] though its productivity is less than national productivity.

The economic importance of the garlic crop has increased considerably in the entire world in recent years. Despite its importance, growing garlic is faced by various problems during growth period [3]. In Ethiopia, major production constraints include lack of proper planting material particularly shortage of improved varieties, imbalanced fertilizer use, lack of irrigation facilities, lack of proper disease and insect pest management and other agronomic practices, lower soil fertility status in many soil types, and lack of proper marketing facilities [4, 5] all which considerably reduce yield. Among the primary macronutrients, N, P and K are the most commonly reported deficient plant nutrients in most Ethiopian soils [6, 7]. Sub-optimal levels of these nutrients in the soil adversely affect the yield, quality and storability of bulbs of garlic crops [8].

Garlic is heavy feeder and most of the *Allium* species have low nutrient extraction capacity than most crop plants because of their shallow and un-branched root system. Therefore, adequate nutrient supply is essential for healthy crop growth and for attaining higher yield in sustainable way [9, 10]. Optimum application of fertilizers to garlic crop is important for improving growth, yield and marketable bulb proportions as well as bulb quality [11]. Mineral fertilizers of balanced doses increased the leaf area, photosynthetic productivity, yield of garlic plant in particular, and resulted in substantial increases in production in general [12]. Alemu et al. [13] reported that the highest marketable bulb yield with combination application of 46 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} and 23 kg N ha^{-1}. G. Teklemariam and N. Dechassa [14] also reported that increased plant height, mean bulb weight, bulb diameter and dry matter per bulb by 4.9, 23.4, 8.9 and 22.2% with increasing N fertilizer from 0 to 120 kg ha^{-1}. Wolde Tefera Beri [15] reported that the highest mean clove weight (4.42 g) with application of 138 kg N ha^{-1}. Meseret Tadesse Eskezia [16] also reported that the highest mean clove weight (2.83 g) at the rate of 46 kg N ha^{-1} application. Application of N increased dry weight of bulb in comparison to lower dose and nil application of N fertilizer [17].

However, the crop nutrient requirements vary with species, variety, soil type and season, a blanket recommendation of 105 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} each of N and P fertilizer are being used for garlic variety *Tseday* production in many areas of a country [18]. This is also used for *Chelenko I* [2] without research recommendation. This is one of the gaps addressed for the study area. Nitrogen (N) deficiency is probably the most common nutritional problem affecting in plants worldwide [19]. The available form of N can be made unavailable or lost via plant uptake, immobilization, denitrification, volatilization, leaching and ammonium fixation [20]. The loss of available N through natural processes is believed to suppress the gain [21, 20]. This fact has made fertilizer management an important aspect of crop production practices [22]. Consequently, N is applied relatively in large quantities all over the World [21].

Use of chemical fertilizers has pushed up the agricultural production [23], therefore; most smallholder farmers in Africa appreciate the value of fertilizers [24]. In Ethiopia, fertilizers applied are based on blanket recommendation without considering soil fertility levels of specific areas leading to uneconomic fertilizer application [25].

Extensive use of N-based fertilizers worldwide has resulted insignificant environmental problems associated with high-input agricultural production systems [26]. This indicates as mineral N fertilizer is crucial to increase productivity of plants with reduced pollution of environment. Possibilities to enhance garlic productivity in the Eastern Hararghe, Ethiopia have been the domain of investigation of recent years though nationally expected yield is not achieved yet. Farmers around the study area, Haramaya produce the local varieties of garlic crop in homesteads. However, recently Haramaya University has released new garlic variety *Chelenko I* [2]. Varieties may also differ in their response to source and rate of applied fertilizers [12]. Moreover, no work has been done on effect of mineral nitrogen fertilizer on the performance of garlic in the area. Therefore, the study was initiated with the following objective:

- To assess the effect of mineral nitrogen fertilizer on growth, quality and economic return of garlic.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted at Haramaya University main campus, Rare Research Field during the main crop growing season (August-December) of 2016. The Area is geographically located eastern part of the country at 20 km northwest of Harartown, altitude of about 2006 meters above sea level, 9°24"Nlatitude and 42°03"Elongitude. The site has a bimodal rainfall distribution pattern and is representative of a sub-humid, mid-altitude agro-climatic zone. The short rainy season extends from March to April and constitutes about 25% of the annual rainfall whereas the long rainy season extends from June to October for about 45% of total rainfall. The mean annual rainfall and temperature are 790 mm and 17^0, respectively [27, 28]. The minimum and maximum temperatures are 3.8 and 25^0C, respectively [29]. However, in this crop growing season, from May to December 2016, the total annual rainfall was 566.1 mm, mean maximum and minimum temperature were 24.04 and 13.14^oC, respectively (Appendix Table 1). Thus, the rainfall and maximum temperature were low during crop growing season whereas minimum temperature was high. During the previous crop growing season, maize was grown at the site. The soil of the experimental site is a well-drained deep alluvial [30] with sandy loam texture [28].

2.2. Experimental Materials

Garlic variety *Chelenko I* was used which was released in 2014 for mid to high altitude garlic growing areas of eastern and western Hararghe Zones by Haramaya University. Its yield is stable over seasons and locations in the eastern highlands of the country. It is well adapted with productivity of 9.3 t ha^{-1}andmoderately susceptible to garlic rust in Eastern Ethiopia. It takes about 132 days to mature [2].

2.3. Treatments and Experimental Design

The treatments consisted of five mineral nitrogen fertilizer rates (0, 52.5, 80, 105 and 130 kg N ha^{-1}), thus, the total treatments five. The experiment was laid out in randomized complete block design with three replications.

2.4. Experimental Procedures and Crop Management

Experimental field was ploughed by a tractor. The plots were leveled and ridge of about 20 cm high was prepared. The gross plot size was 2.0 m x 1.5 m (3.0 m^2). In between blocks and plots, 0.75 m and 0.5 m space was left, respectively. Healthy and uniform medium-sized cloves of 1.5-2.50 g [31], were selected and planting was done on 11 August 2016 at the depth of 3-4 cm. The cloves were planted on the ridge at a spacing of 30 cm between rows and 10 cm between plants. Thus, there were five rows in each plot and 20 plants in a row. The outer most one row on each side of a plot and 20 cm on both ends of each row were considered as border. Thus, the net plot size was 0.9 m x 1.8 m = 1.62 m^2. Mancozeb was applied at the rate of 3.5 kg ha^{-1} mixing with water in a ratio of 2 gm L^{-1} [32]. This was done after a month from planting when fungus (garlic rust) symptom appeared on garlic leaf. All other recommended cultural practices to produce the crop such as weeding, harrowing and watering were applied uniformly and regularly to the entire plots throughout the experiment time as per the recommendation of Debre Zeit Agricultural Research Centre [33]. When 70% of the plants showed neck fall [4, 17], harvesting of bulbs was done on starting from 16 Dec 2016.

2.5. Soil Sample Analysis

Soil sampling was done before planting. The samples were taken randomly using an auger in a zigzag pattern from the entire experimental field. Before planting, ten soil samples were taken from the top soil layer to a depth of 20 cm and composited in a bucket to represent the site. The soil was broken into small crumbs and thoroughly mixed. From this mixture, a composite sample weighing 1 kg was filled into a plastic bag. The sample was air-dried and sieved through a 2 mm sieve. It's EC and pH was determined from the filtered suspension of 1: 2.5 soils to water ratio using a glass electrode attached to a digital EC meter and pH meter [34]. Sample was analyzed for electric conductivity (EC), total N, available P, exchangeable K, organic matter and organic carbon. Total N was determined using the Kjeldhal method [35]. Available P was determined by extraction with 0.5 M sodium bicarbonate ($NaHCO_3$) according to the methods of [36]. Exchangeable potassium was determined with a flame photometer after extraction with 0.5 ammonium-acetate according to [37]. Organic carbon of soil was determined by the Walkley-Black method [38]. Soil texture was determined by Bouyocous hydrometer method [39].

2.6. Data Collection and Measurements

2.6.1 Days emergency

Day's emergency: was determined by counting when about 50% of the plants emerged.

2.6.2 Growth Parameter

Leaf area: was determined using leaf area formula from 10 randomly taken plants from the central rows.

LA = LL*LW*0.733

Where: LAm = mean leaf area of the plant

LL = leaf length

LW = maximum leaf width

0.733 = conversion factor for leaf area

Leaf area index: was determined using the value of the leaf area divided by the area of the land occupied by the plants according to [40] using the following formula:

Leaf area index (LAI) = LAm× N/A

LA = LL*LW*0.733

Where: LAm = mean leaf area of the plant

LL = leaf length

LW = maximum leaf width

0.733 = conversion factor for leaf area

A = the area (cm^2) occupied by one plant in the cropping area

N = number of leaves on the plant

Total fresh biomass yield (g/plant): was determined by taking the total weight of five randomly sampled plants from the four central rows of fresh bulbs, leaves, stems and roots using a sensitive balance.

2.6.3 Quality Parameters

Total soluble solid: This was measured by taking 100 g juice and diluting it in 50% of distilled water, and then refractometer was used for evaluation.

Total dry matter (%): The average dry matter weight (g) of total biomass after curing were measured by drying 10 randomly sampled plants in an oven with a forced hot air circulation at 70^0C until a constant weight was obtained. The percent of bulb dry matter calculated by taking the ratio of the dry weight to the fresh weight of the sampled plants and multiplying it by 100.

$$\%\ \text{BDM} = \frac{\text{Weight of total dry matter}}{\text{Total fresh weight}} \times 100$$

2.7. Data Analysis

Data collected was subjected to analysis of variance (ANOVA) using SAS software version 9.0 and the means separated by using Turkey's Method at 0.05 level of significant if treatments found significant.

2.8. Partial Economic Analysis

The partial budget analysis as described by CIMMYT [41] was done to determine the economic feasibility of the garlic production using the prevailing market prices for inputs at planting and for the outputs at the time of crop harvest. It was calculated by taking into account the additional input and labor cost involved due to additional input and the gross benefits obtained from garlic production. Average yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could obtain under their management practices as described by CIMMYT [41]. The field price of garlic was calculated as (sale price minus the costs of harvesting, cleaning, bagging and transportation). The net benefit was calculated as the difference between the gross field benefit (ETB ha^{-1}) and the total variable costs (ETB ha^{-1}).

Marginal rate of return (MRR %): was calculated by dividing change in net benefit or gross benefit by change in cost which was the measure of increasing in return by increasing input. This means by subtracting gross benefit of nil from gross benefit of each treatment and divide by total variable cost of each treatment and multiplying each value by 100%.

$$\text{Marginal rate of return (\%)} = \frac{\text{Change in net benefit}}{\text{change in total cost}} \times 100$$

3. Results and Discussion

3.1. Physical and Chemical Properties of the Soil

The result of laboratory analysis of selected physical and chemical properties of soils of the experimental area is presented in Table 1. The textural class of the soil was sandy clay loam based on the soil textural triangle of the International Society of Soil Science system [39, 42]. The pH of the experimental soil was 7.4 which is moderately alkaline on the basis of pH limit (7.4 to 7.8) described by [34]. The pH is in the range of 6.5 to 7.5 favorable for garlic production [43].

Table 1. Physical and chemical properties of the soil of the experimental site at Haramaya, Eastern Ethiopia

Soil property	Value	Rating	Reference
Sand (%)	61		
Clay (%)	23		
Silt (%)	16		
Textural class	Sandy clay loam		[39, 42]
pH 1: 2.5 (H_2O)	7.4	Moderately alkaline	[34]
OC	1.48	Moderate	[44]
OM (%)	2.55	Low	[47]
Total N (%)	0.18	Medium or moderate	[45] and [44]
Available P (mg kg^{-1})	5.58	Low	[44]
Exchangeable K (Cmolc kg^{-1})	0.32	Medium	[44]
CEC (cmol (+) kg^{-1})	18.61	Medium	[46]

Where: OC, organic carbon; OM, organic matter; VC, vermicompost; ppm, parts per million; EC, electric conductivity; The organic matter (OM) of the experimental soil was 2.55%. According to [47], OM ranging from 0.86 to 2.59 is low, hence the soil might respond to the applied VC, as its organic matter content was low.

As per the rating (0.12 to 0.25%) described by [45], the total N content of the soil (0.18%) was medium. This value showed that the crop might respond to the applied VC (Table 1) due to increased soil fertility with application of fertilizers. According to the rating (5 to 9 mg P kg^{-1}) suggested by [48], the available P of the soil was low (Table 1). This may be because of low percent of OM content of the soil (Table 1) which is also in agreement with the suggestion of [49] who indicated that soil OM influences P availability to crops directly by contributing to P pool. However, Toung et al. [50] reported that P response is likely in soils that have less than 20 mg kg^{-1} extractable P. The cation exchange capacity (CEC) of the experimental soil was 18.61 (cmol (+) kg^{-1}). This value was medium according to the rating (15 to 25) suggested by Berhanu Debele [46], P. Hazelton and B. Murphy [44] cation exchangeable soil potassium contents of 0.3-0.7 Cmolc kg $soil^{-1}$ as medium. In accordance with this category, the exchangeable soil potassium content of the experimental soil is in medium category. This indicates external application of mineral and/or organic fertilizers containing potassium is important for enhancing the fertility of the crop and yield of the crop.

3.2. Days to Emergency

Nitrogen (N) application significantly influenced days to emergence. With the increase in the rates of N application, the number of days required by the garlic sprouts to emerge above the soil surface was decreased. This means that plants that were not treated with the N emerged from the soil later than plants that were treated with the N. Thus, increasing the rate of N from nil to 130 kg ha^{-1} hastened the emergence of garlic sprouts from the soil by 24%. The hastened duration for emergence due to the increased application of the N may be attributed to the influence of mineral N on root initiation and development which might lead to early shoot emergence.

3.3. Growth parameters

Fresh biomass

Analysis of variance showed that application of N very highly significant affects (0.001) on fresh biomass. With increased N from 0 to 130 kg ha^{-1}, fresh biomass increased by 73.80% over control.

Leaf Area

Nitrogen (N) fertilization significantly ($P < 0.01$) affected the mean leaf area per plant of garlic. Optimum mean leaf area per plant (36.03 cm^2) was achieved at 105 kg N ha^{-1} while the lowest was obtained from the unfertilized plots. Therefore; increasing N resulted in increased leaf area of garlic.

Leaf Area Index

Leaf area index was significantly affected by application of N ($P < 0.001$). Nitrogen supplement at a rate of 130 kg ha^{-1} increased leaf area index of garlic by 71.6% compared to control.

3.4. Quality Parameters

Total Dry Matter

Bulb dry matter percent was significantly influenced Nitrogen ($P < 0.001$). However, bulb dry matter percent did not significantly affected by all interaction effects. Garlic bulb dry matter percent was increased by 18.27% due to N application at 130 kg ha^{-1} rate over the control.

Total soluble solid

Total soluble solid was significantly influenced by N ($P < 0.001$). Application of 130 kg N ha^{-1} increased TSS by 18.27% compared to control. It might be due to more accumulation of reserve substances in the bulbs.

Table 2. Effect of application of nitrogen on days to emergency, fresh biomass, total dry matter, leaf area, leaf area index and total soluble solid

Factor	Treatment	Days to emergency (days	FB (gm)	Tot Dry M (%)	Leaf Area (cm^2)	LAI	TSS ($Brix^o$)
N (kg ha^{-1})	0	9.92a	55.84d	27.70d	27.69d	0.81e	11.60e
	52.5	9.25b	57.68cd	28.90cd	31.38c	0.94d	11.89d
	80	9.17b	58.69bc	29.90bc	33.92bc	1.09c	12.25c
	105	8.50c	60.63ab	31.07ab	36.03ab	1.23b	12.72b
	130	8.00c	63.24a	32.76a	38.15a	1.39a	13.24a
CD (0.05)		0.6	2.73	1.78	2.96	0.11	0.09
CV %		5.76	3.96	5.09	7.57	8.79	0.67

3.5. Economic Analysis

As indicated in Table 4, economic analysis was done for effects of N as it shows significant effect on marketable bulb yields. The variable cost considered was mineral N fertilizer cost with its application cost as well as extended days for gardener [60 ETB per (day + night)] of each treatment over control was considered. Even though there is no variable cost (the costs of fertilizer requirements and application were not included) in absolute control or nil application of N fertilizer, the lowest benefit cost was obtained. On the other hand treatment with application of N is economically sound full than over control. The study undertaken on two soils types by Alemu, Nigussie, and Fikreyohannes [13] also showed that the growth, yield and economic potential of garlic were increased in response to fertilizer application.

Maximum net benefit (398,701 ETB ha^{-1}) was obtained with application of 130kg N ha^{-1} fertilizer while the least net benefit cost (336,800 ETB ha^{-1}) was obtained with unfertilized. Verma et al. [51] also reported that application fertilizer was superior with respect to net returns of garlic. As to this finding, it is profitable to cultivate garlic with application of 130 kg N ha^{-1}. Marginal rate of return percent was increased with increased rate of N. Maximum marginal rate of return percent (1,976.36%) was obtained with application of 130 kg N ha^{-1} while the least (336,800, 1,127.07%) was recorded with nil application of N. This was due to increased yield potential of garlic with increased levels of mineral N fertilizer.

Table 4. Partial budget analysis of the economic performance of garlic under mineral N fertilization

Factors	Treatments	Average yield (t ha^{-1})	Adjusted yield (t ha^{-1})	Gross benefit (ETB ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	%MRR
N (kg ha^{-1})	0	9.36	8.42	336,800	0	336,800	--
	52.5	9.92	8.93	357,200	1,810	355,390	1,127.07
	80	10.38	8.34	333,600	2,587	371,013	1,422.50
	105	11.17	10.05	402,000	3,299	398,701	1,976.36

Price of N = 26.09 ETB kg^{-1} N + application cost of 320.00 ETB per ha^{-1}. Garlic selling price = 40.00 ETB kg^{-1} (Garlic selling price at Haramaya district, 2017).

4. Summary and Conclusion

The research was conducted to study the response of garlic to nitrogen (N) fertilizer application rates with the objectives of assessing the effect of mineral N fertilizer on growth and quality of garlic, and to estimation of economic return of N fertilizer for higher yield of garlic. This experiment was conducted at Haramaya University main campus, Rare Research Field during 2016 meher season. Garlic variety, *Chelenko I* was used for the study. The experiment was laid out in randomized complete block design with three replications. Five levels of N (0, 52.5, 80, 105 and 130 kg ha^{-1}) were used as treatment. The analysis of variance indicated that effect of N show significant effects on days to emergency, leaf area, leaf area index, fresh biomass, total dry matter percent and bulb quality. The highest net benefit and marginal rate of return was recorded with application of highest rate of N fertilizer (130 kg N ha^{-1}).

The early emergency (8 days) was recorded with application of maximum rate of N (130 kg ha^{-1}) while late emergency (9.92 days) was with nil application of N. Growth parameters such as leaf area, leaf area index and fresh biomass had significantly influenced by the applied N fertilizers. Maximum leaf area (38.15 cm^2) was recorded with application of maximum rate of N (130 kg ha^{-1}) fertilizer. The highest leaf area index (1.39) and fresh biomass (63.24 gm) were recorded from 130 kg N ha^{-1} application. Total dry matter and soluble solid traits showed significant differences in response to the application of N fertilizer. Maximum total dry matter (32.76%) and total soluble solid (13.24 Brix^{o}) were recorded at the rate of 130 kg N ha^{-1}. The economic analysis showed the highest net benefit cost of 398,701 ETB ha^{-1} and highest marginal rate of return (1,976.36%) with incurred highest total variable cost of 3,299 ETB ha^{-1} with application of 130 kg N ha^{-1} fertilizer. The least net benefit cost of 336,800 ETB ha^{-1} was obtained with nil application of N fertilizer.

Thus, it can be reasonably generalized that on short time basis, the application of high amounts of mineral N fertilizers can result higher economic return than the low dose of mineral N fertilizer. However, the results of the experiment have revealed that growth, quality and economic return did not reach to the optimum since all significantly increased in response to the application of mineral N fertilizer. Therefore, there is a possibility that significantly more growth characters, quality and economic return of the garlic could have been obtained if the rates of the N fertilizers had been increased. Therefore, for a time being for this specified area, from the results of this study, it can be concluded that, the maximum growth and quality and economic return of garlic was obtained with application of 130 kg ha^{-1} fertilizer as it gave the highest net benefit cost. However, since the experiment was done only once and at one location, similar experiments should be carried out using additional higher rates of mineral N fertilizer over several seasons and locations to make a conclusive recommendation.

5. Abbreviations

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
C: N	Carbon nitrogen ratio
CSA	Central Statistical Agency
CV	Coefficient of variation
DZARC	Debrezeit Agricultural Research Center
EARO	Ethiopian Agriculture Research Organization
HU	Haramaya University
MoARD	Ministry of Agriculture and Rural Development

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Appendix

Appendix Table 1. Monthly total rainfall (mm) and mean maximum and minimum air temperature (oc) of Rare, the Haramaya University Research and farm during the cropping season of 2016.

Months	Total Rainfall (mm)		Temperature (°C) Mean	
			Maximum	Minimum
May	149.2		24.3	16.6
June	38.7		23.5	17.5
July	165.8		24.3	13.7
August	1.0		25.2	14.7
September	23.5		24.0	4.21
October	0.0		23.2	4.3
November	149.2		24.3	16.6
December	38.7		23.5	17.5
Total	566.1	Mean	24.04	13.14

Source: Jijiga Meteorology Station (JMS) 2017

Source of Variation	Mean squares						
	Df	Days to mergency (days)	FB (gm)	Tot Dry M (%)	Leaf Area (cm^2)	LAI	TSS (Brix°)
Replication	2	0.2667	21.0908	43.5619	0.8062	0.0007	0.4805
Vermicompost	3	11.3111	76.7494	94.2833	120.8625	0.6137	1.6890
Nitrogen	4	6.5250	96.8297	45.7657	199.2925	0.6414	0.0056
Error	38	0.2667	5.4891	2.3398	6.4097	0.0091	0.0068