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SOIL & CROP SCIENCES | RESEARCH ARTICLE

Economic and agronomic optimum rates of NPS fertilizer for irrigated garlic (*Allium sativum L*) production in the highlands of Ethiopia

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Abstract: Field experiment has been conducted in Yilmana Densa District during the 2014/2015 irrigation season with the objective of identifying the economical and agronomically optimum rate of the newly introduced NPS fertilizer for garlic production under irrigated smallholder farming system in the Highlands of Northwestern Ethiopia. Twelve NPS fertilizer rates, laid down on Randomized Complete Block Design with three replications were tested on local garlic variety. Accordingly, most of the growth and yield parameters were significantly affected by NPS fertilizer rates where non-fertilized plants were inferior in all parameters. Significantly highest plant height (69.23 cm) and above ground biomass (25.33 g) were recorded on garlic plants supplied with $N:P_2O_5:S$ at the rate of 105:122.6:22.6 kg ha^{-1}. Similarly, the biggest bulb diameter (4.27 cm) and the highest leaf number (13.4) as well as marketable (17.42 *t* ha^{-1}) and total bulb yields (17.8 *t* ha^{-1}) were recorded on plants which were supplied with 140:122.6:22.6 kg ha^{-1} $N:P_2O_5:S$ that were similar with the effects of $N:P_2O_5:S$ at the rate of 140:92:17 kg ha^{-1}. $N:P_2O_5:S$ at the rate of 140:92:17 kg ha^{-1} recorded the highest marginal rate of return that can be recommended to increase the yield of garlic and thus to improve the livelihoods of farmers in the study area.

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PUBLIC INTEREST STATEMENT

Garlic is one of the bulb vegetables widely grown in Ethiopia. It is produced both under rain fed and irrigated production systems. Since garlic is widely utilized as spice and medicinal crop by the people in Ethiopia, its market price is much higher than all other vegetable crops. Despite the multifaceted importance of the crop, its current production is constrained by various problems. Inappropriate agronomic practices are among others the main problems associated with low productivity and quality of garlic produced in Ethiopia. Thus development of location specific agronomic practices such as fertilizer rate, spacing, irrigation frequency, etc. are necessary to boost the productivity of garlic and thus the income of smallholder producers. It will also enhance the expansion of garlic production in the country.

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1. Introduction

Garlic (*Allium sativum L.*) belongs to the family Alliaceae and is the second most widely used *Allium* next to onion (Rubatzky & Yamaguchi, 1997). Garlic is among the most important bulb vegetable crops used as a seasoning or condiment of foods because of its pungent flavor. Garlic adds a taste to foods as well as helps to make them more palatable and digestible (Higdon, 2005). Generally, garlic is a fundamental component of many or most dishes in various countries including Ethiopia.

Garlic grows under a wide range of climatic conditions. However, it grows best at higher elevations ranging from 1800–2800 meters above sea level (m.a.s.l.) where cool weather conditions prevail. Mean temperatures in the range of 12–24°C are generally the best growing condition for garlic production (Edwards, Demissew, & Heberg, 1997; Libner, 1989). As garlic is shallow rooted vegetable and has un-branched root system and low nutrient extraction capacity, it requires relatively high amount of nutrients for best growth and development (Brewster & Butler, 1997). Garlic soils should be therefore fertile, rich in organic matter, well drained and capable of holding adequate moisture. Soil pH ranging from 6.8–7.2 is generally for garlic production. According to Janet (2008), soil pH below 5.0 can lead to the death of garlic plants.

In Ethiopia garlic production and its area coverage is in increasing trend. For instance, the production of garlic in the year 2000 was estimated to be 52,262 tons produced on 4,797 hectares of land (Central Statistic Agency [CSA], 2000). However, currently the annual average production has reached 222,548 t with the average productivity of 10.5 t ha^{-1} (Central Statistic Agency, 2013). More than 50% of the country's garlic production is produced in the western highlands where the Amhara National Regional State (ANRS) is found with the productivity of about 11.13 t ha^{-1}. On the other hand nearly 10% of the garlic produced in ANRS is sourced from the study area Yilmana Densa district with the productivity of about 10.5 t ha^{-1} (Central Statistic Agency, 2013) which is relatively lower than the region`s and as well as world average (16.9 t ha^{-1}) as indicated by Food and Agricultural Organization [FAO], (2012).

The low performance of garlic production both at the country level and regional level can be accounted to the traditional production practices employed by smallholder farmers. One of these practices involve poor application of fertilizer both in terms of rate and type and also lack of evidences on how much to apply for agronomic and economic optimum. Although some farmers are using chemical fertilizers, the rate of application is by far below the national blanket recommendation which is about 105 kg N ha^{-1} and 92 kg P ha^{-1} for garlic production (Ethiopian Institute of Agricultural Research [EIAR], 2007).

The type and rate of fertilizer applications, among several agronomic practices are influenced by the crop types. The fact that fertilizer types applied in Ethiopia agriculture system are only urea and di-ammonium phosphate (DAP) which contain only nitrogen and phosphorous however, they may not probably satisfy the nutritional requirements of crop plants such as garlic. To avert this situation the Ministry of Agriculture of the country has recently introduced a new compound fertilizer containing nitrogen, phosphorous and sulfur with the ratio of 19% N, 38% P_2O_5 and 7% S (NPS fertilizer) that substituted DAP in Ethiopian agriculture. The situation is even more challenging for researchers and farmers to understand the impact and identify optimum agronomic and economic threshold of the newly introduced NPS fertilizer that contains sulfur. Therefore, the overarching objectives of the current study were: (i) to evaluate the responses of garlic to the newly introduced fertilizer (NPS) in the study area and; (ii) to track economic and agronomic optimum rates of its application.

2. Materials and methods

2.1. Description of the study area

The experiment was conducted at Yilmana Densa district of Amhara Regional State during the 2014/15 irrigation season. Yilmana Densa district is one of the most important garlic production areas of the region. The experimental site is located at 11°16′N and 37°29′E with an altitude of 2,216

meters above sea level. The minimum and maximum temperatures of the study area during the irrigation season (November–March) are 5.5 and 28.8°C, respectively. The area receives up to 80 mm rain fall during the irrigation season (Office of Agriculture & Rural Development [OARD], 2009). The site has irrigation potential with diverted river as a source of water.

To have insight on some of the physico-chemical properties of the experimental soil, samples were taken randomly from nine spots diagonally at the depth of 20 cm and a composite sample was prepared and analyzed in laboratory. The experimental soil was vertisol and heavy clay in its textural classification (Day, 1965) with the pH value of 6.2.

Salinity of the sample soil was measured as electrical conductivity (EC) and expressed as decisiemens (ds/m) as described by Rhoades, Chanduvi, and Lesch (2002). According to Richards (1954) the sample soil had low salt concentration (0.215 ds/m). The organic carbon (OC) content was determined by oxidation of organic carbon with acid dichromate medium following the Walkley and Black method as described by Dewis and Freitas (1970). Accordingly, the sample soil had low organic matter content (3.32%). Total nitrogen of the sample soil determined by Micro-Kjeldahl method (Dewis & Freitas, 1970) was about 0.16% while the available phosphorous was 9.2 ppm which was determined using Olsen method (Olsen & Dean, 1965). According to Olsen and Dean (1965) the experimental soil has low level of available phosphorous. The soil cation exchange capacity (CEC) of the sample soil was 61.8 (cmol(+)kg) which was determined by ammonium acetate method (Cottenie, 1980). Based on the results of the soil analysis, the experimental soil was generally suitable for the production of garlic as described by Tadese (1991).

2.2. Type of experiment and data collected

2.2.1. Experimental design and treatments
The experiment consisted of 12 NPS fertilizer rates including one unfertilized control (Table 1). There is lack of base line information which is associated with the new entrance of the fertilizer in Ethiopian agriculture. Thus the NPS levels were determined in a way that about 1/3rd of nitrogen and phosphorous concentration was added and subtracted from the blanket DAP recommendation. The treatments were arranged in randomized complete block design (RCBD) with three replications. Prior to the implementation we negotiated with farmers to use their plots for this experiment. Each plot of experiment was 1.5 m wide and 2 m long and accommodates 150 plants with the spacing of 30, 15 and 10 cm between double rows, rows and plants, respectively. Healthy and uniform medium-sized clove of local variety of garlic (*Nechi Shinkurt*) was used. Each plot contains five double rows where each rows contained 15 plants.

The total quantity of phosphorus in the form of DAP and NPS fertilizers was applied at the time of planting, whereas, urea as a main source of nitrogen was applied in two splits of 4 and 8 weeks after planting as indicated by Sendek (2012). Other cultural practices like weeding, irrigation, cultivation and plant protection measures were done uniformly for all plots as required.

2.2.2. Data collection and analysis
Data collected were related to growth and yield parameters. These data were collected from the net plot of each treatment to avoid the border effects. The growth parameters considered in the current study were plant height, number of leaves per plant, above ground biomass per plant and maturity date.

Plant height was collected by measuring from the soil surface to the top of the longest leaf of ten randomly selected plants using a ruler at physiological maturity of the crop and the mean values in cm were computed for further analysis. Number of leaves per plant was recorded by counting the number of leaves of randomly selected ten plants per plot at physiological maturity and the mean value was computed. To determine the average above ground biomass per plant, fresh weights of

Table 1. Rate of nutrients used in the form of NPS, urea and DAP fertilizers in the study	
Treatment number	**N:P_2O_5:S kg ha^{-1}**
T1	0:0:0
T2*	75.69:61.18:0
T3**	105:92:0
T4	70:61.4:11.3
T5	70:92:17
T6	70:122.6:22.6
T7	105:61.4:11.3
T8	105:92:17
T9	105:122.6:22.6
T10	140:61.4:11.3
T11	140:92:17
T12	140:122.6:22.6

*Farmer's practice in the study area.

**Blanket recommendation (Ethiopian Institute of Agricultural Research, 2007).

ten randomly selected plants from each plot were measured at the time of harvesting and the mean values per plant in gram were recorded for further analysis.

Maturity date in each plot was recorded by recording the number of days elapsed from the time of planting up to the time when 75% of plants in the plot became dry and collapsed at the neck as described by Guesh (2015).

Yield parameters such as bulb size, marketable bulb yield, unmarketable bulb yield and total bulb yield were recorded in this study. Average bulb size was recorded by measuring the diameter at the middle of ten randomly selected bulbs in each plot using caliper. Bulbs which were free of mechanical, disease and insect pest damages, uniform in color and medium to large in size were considered as marketable bulbs and the weights of such bulbs obtained from net plot area of each plots was measured in kilogram using scaled balance and expressed as *t* ha^{-1}. Bulbs which are damaged, undersized, misshaped, and decayed were sorted and considered as unmarketable. The weights of such bulbs obtained from net plot areas of each plots were measured in kilogram using scaled balance and expressed as *t* ha^{-1}. Finally the total bulb yield was obtained from the sum of marketable and unmarketable yields.

Variable costs incurred for the production of garlic and local market price of garlic were also recorded for the economic analysis of NPS fertilizer application. Filially, collected data were subjected to the analysis of variance (ANOVA) by using Statistical Analysis System (SAS) version 9.0 and mean separations were carried out using Least Significance Difference (LSD) at 5 or 1% significance level based on the results of the ANOVA. Moreover, the economic benefits of nutrient application were analyzed following the procedures described by CIMMYT (1988).

3. Results and discussion

3.1. Growth parameters of garlic as influenced by NPS fertilizer application rate

3.1.1. Plant height and leaf number
Plant height was highly significantly ($p < 0.01$) affected by NPS fertilizer rates (Table 2). The highest mean plant height (69.2 cm) was recorded by the application of 105:122.6:22.6 kg ha^{-1} N:P_2O_5:S fertilizer followed by 140:122.6:22.6 kg ha^{-1} N:P_2O_5:S with the mean value of 68.5 cm. However no

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Table 2. Effects of different rates of nutrients on growth parameters of garlic					
Treatments (N:P$_2$O$_5$:S (kg ha^{-1}))	Garlic growth parameters				
	PHT	LNO	MD	FWB	DWB
T1 (0:0:0)	55.27d	12.1c	135.0	13.30d	2.76d
T2 (75.69:61.18)	64.13bc	13.1ab	135.0	18.10bcd	3.70bcd
T2 (105:92:0)	62.17c	12.6bc	135.0	16.67cd	3.32cd
T4 (70:61.4:11.3)	64.17bc	13.1ab	134.0	18.50bc	3.68bcd
T5 (70:92:17)	66.00abc	13.3ab	136.0	18.17bcd	3.57bcd
T6 (70:122.6:22.6)	66.60ab	13.1ab	134.3	17.33cd	4.12abc
T7 (105:61.4:11.3)	66.00abc	13.1ab	136.0	18.67bc	3.83bc
T8 (105:92:17)	64.13bc	12.9ab	136.0	22.50ab	4.23abc
T9 (105:122.6:22.6)	69.23a	13.0ab	135.3	25.33a	5.05a
T10 (140:61.4:11.3)	63.17bc	13.2ab	135.3	17.17cd	3.31cd
T11 (140:92:17)	65.63abc	13.3ab	135.3	19.17bc	3.79bc
T12 (140:122.6:22.6)	68.50a	13.4a	136.0	22.67ab	4.51ab
Mean	64.58	13.0	135.3	18.97	3.82
CV	3.67	3.04	0.99	15.95	14.98
Level of significance	**	*	NS	**	**

Notes: PHT = plant height (cm); LNO = leaf number; MD = maturity date (days after planting); FWB = fresh weight of above ground biomass (g/plant); DWB = dry weight of above ground biomass (g/plant); CV = coefficient of variation; NS = non significant.

*Significant ($p < 0.05$).

**Highly significant ($p < 0.01$).

significant difference in plant height was observed between the two treatments. The lowest mean plant height of 55.27 cm was recorded from the control plot where no fertilizer was applied. Therefore, sulfur, nitrogen and phosphorus nutrients in NPS fertilizer enhanced garlic plant height. The highest plant height of garlic was recorded from high level of P$_2$O$_5$ and S applications since the experimental soil exhibited low available phosphorous as indicated in the results of composite soil analysis (9.2 ppm). The results of the present study are in conformity with the findings of Balasubramonium, Raman, and Moort (1979) where application of sulfur increased plant height, as high levels of P$_2$O$_5$ and S contribute to the metabolic processes such as formation of nucleic acids, phospholipids, co-enzymes, and chlorophyll which intern enhance the growth and development of garlic plants as described by El-Shafie and El-Gamaily (2002), Tucker (1999) and Nasiruddin, Farooque, and Baten (1993). Eshetu and Tulu (2014) also reported that the highest garlic plant height was obtained by the application of 100 kg N ha^{-1} + 120 kg P$_2$O$_5$ ha^{-1}. Similarly, Farooqui, Naruka, Rathore, Singh, and Shaktawat (2009) observed significantly increased plant height with combined application of 200 kg ha^{-1} nitrogen and 60 kg ha^{-1} sulfur. Moreover, Zaman, Hashem, Jahiruddin, and Rahim (2011) reported the gradual increase of plant height with increasing the levels of sulfur up to 45 kg ha^{-1}.

Garlic leaf number was also significantly ($p \leq 0.05$) influenced by different rates of NPS fertilizers application (Table 2). The highest number of garlic leaves (12.1) was observed on plants that received the highest nitrogen rate (140:122.6: 22.6 kg ha^{-1} of N:P$_2$O$_5$:S). However the number of garlic leaves was on par with plants treated with all treatments except T1 and T3.

The increment in leaf number with higher level of NPS fertilizer application may be attributed to *N* availability, which enhances the number as well as length of leaves by its simulative effect on cell division and cell enlargement. It also enhances protein synthesis leading to an increase in buildup of carbohydrates and increase of plant growth parameters (Zaman et al., 2011).

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Phosphorus plays a pivotal role in metabolic processes and is a main constituent of energy compounds like nucleic acids, phospholipids and co-enzymes. Also it may be attributed to favorable effects of phosphorus on root development and formation of carbohydrate. The application of sulfur helps to enhance the availability and uptake of other nutrients which promote growth and development of plants (El-Shafie & El-Gamaily, 2002; Nasiruddin et al., 1993; Tucker, 1999).

The results obtained in this experiment are generally in agreement with the findings of various researchers where the application of nitrogen, phosphorous and sulfur alone or in combination increased the growth and development of garlic including the number and size of garlic leaves (Assefa, Mesgina, & Abrha, 2015; Balasubramonium et al., 1979; Eshetu & Tulu, 2014; Farooqui et al., 2009; Geleta, 2014; Mulatu, Tesfaye, & Getachew, 2014; Reddy, Suryanarayana, Reddy, & Reddy, 2000; Zaman et al., 2011). As NPS fertilizer used in this experiment is a combined fertilizer, it was not however possible to identify the effects of individual nutrients on garlic plants which requires further study.

3.1.2. Above ground biomass
The above ground biomass of garlic was highly significantly ($p < 0.01$) affected by NPS fertilizer rates (Table 2). The highest above ground biomass per plant (25.33 g) was recorded at $N:P_2O_5:S$ rate of 105:122.6:22.6 kg ha^{-1} followed by plants (22.67 g) in the plot treated with 140:122.6:22 kg ha^{-1} $N:P_2O_5:S$ which were not however statistically different. The lowest above ground biomass (13.3 g) was recorded from plants which were not received any type of fertilizer.

The results in above ground biomass also clearly indicated that the application of NPS fertilizer which contains nitrogen, phosphorous and sulfur promotes the growth and development of garlic which is in agreement with the findings reported by other scholars (Assefa et al., 2015; Balasubramonium et al., 1979; Eshetu & Tulu, 2014; Farooqui et al., 2009; Mulatu et al., 2014; Zaman et al., 2011).

3.2. Yield related traits of garlic as affected by NPS application rates

3.2.1. Bulb diameter
Data on yield related traits of garlic as affected by fertilizer application rates are presented on Table 3. Plants supplied with the highest nutrient rate (T12) produced the biggest bulb with the diameter of 4.27 cm which was however statistically ($p < 0.05$) similar with bulbs obtained from other treatments except those from the control plants (3.48 cm). The biggest bulb diameter of garlic was generally obtained from those garlic plants supplied with the highest combination of phosphorous and sulfur. This is probably due to the combined positive effects of phosphorous and sulfur existed in NPS fertilizer on metabolic processes of garlic plants as indicated by Arif et al. (2016) and Assefa et al. (2015). Furthermore sulfur and nitrogen in NPS fertilizer stimulate the enzymatic actions and chlorophyll formation which contribute to an increase in bulb sizes of garlic (El-Shafie & El-Gamaily, 2002). The results obtained in this study are in conformity with the findings of Assefa et al. (2015), Hariyappa (2003) and Nasiruddin et al. (1993) who reported an increase of garlic bulb diameters with the application of sulfur containing fertilizers.

3.2.2. Bulb yield
Table 3 shows the marketable and unmarketable bulb yields of garlic as influenced by fertilizer application rates. The highest marketable yield of garlic was obtained from T12 followed by T11 and T9 with the mean values of 17.42, 16.16 and 15.81 t ha^{-1}, respectively, whereby the mean values were statistically similar ($p < 0.05$) when compared each other. The lowest significant ($p < 0.05$) marketable bulb yield (9.97 t ha^{-1}) was recorded from the control treatment where no fertilizer was applied. In case of unmarketable yield, the highest unmarketable yield was obtained from T7 followed by T1 and T2 with the mean values of 1.08, 0.85 and 0.71 t ha^{-1}, respectively. The reason for unmarketable bulb yield may be the low level of phosphorus and sulfur application. Similar trend was also observed in total bulb yield of garlic with the mean values of 17.80, 16.74, and 16.42 t ha^{-1} in above mentioned

order (T12, T11 and T9). Statistically significant ($p < 0.05$) lowest total bulb yield of garlic (10.82 t ha^{-1}) was obtained from control plot where no fertilizer was applied.

The results of the present study generally revealed that growth, yield and yield parameters of garlic were positively influenced with the application of NPS fertilizer. The improved growth and development of garlic with the highest rates of sulfur is probably associated with the sulfur loving nature of garlic (Assefa et al., 2015; Rai & Yadav, 2005). Garlic contains high proportion of sulfur containing metabolites such as organosulfur compounds (Higdon, 2005) which are responsible for its flavor and aroma, as well as for its potential health benefits (Block, 1985). According to Trio et al. (2014), the organosulfur compounds prevent as well as treat chronic diseases such as cancer and cardiovascular diseases.

Furthermore sulfur and nitrogen stimulate the enzymatic actions and chlorophyll formation that promote the growth and development leading to high yield of plants (El-Shafie & El-Gamaily, 2002). Thus an adequate supply of nutrients to plants is associated with vigorous vegetative growth resulting higher productivity of crops (Farooqui et al., 2009; Naruka & Dhaka, 2001; Yadav, 2003). The results obtained in this study also substantiate the findings of Nasiruddin et al. (1993) who reported the application of sulfur increased plant height, number of leaves, bulb diameter, and bulb yield of garlic. They are also in agreement with the findings of Zaman et al. (2011) where the bulb yield of garlic was increased with increasing sulfur level up to 45 kg ha^{-1}. Hariyappa (2003) also recorded a significant increase in yield and bulb diameter of garlic with the application of sulfur.

Sulfur has also the ability to improve the availability of plant micronutrients by amending the soil pH (Marschner, 1995). Moreover the findings of various researches indicated that sulfur improved the physico-chemical qualities of garlic including Alliin content, storability, pungency, protein and nutrient content (Bloem, Haneklaus, & Schnug, 2005; Brown & Noah, 2014; Geleta, 2014).

Table 3. Yield and yield parameters of garlic as affected by different rates of nutrients				
Treatments (N:P$_2$O$_5$:S (kg ha^{-1}))	Yield and yield parameters of garlic			
	BD	MYT	TYT	UMYT
T1 (0:0:0)	3.48b	9.97f	10.82e	0.85
T2 (75.69:61.18)	4.01a	13.60cde	14.31cd	0.71
T3 (105:92:0)	4.16a	14.81bcde	15.16bcd	0.34
T4 (70:61.4:11.3)	3.95a	12.49e	13.08de	0.59
T5 (70:92:17)	4.10a	13.68cde	14.21cd	0.53
T6 (70:122.6:22.6)	4.17a	14.36bcde	14.81bcd	0.45
T7 (105:61.4:11.3)	3.93a	13.08de	14.17cd	1.08
T8 (105:92:17)	4.20a	15.03bcd	15.67abc	0.65
T9 (105:122.6:22.6)	4.22a	15.81abc	16.42abc	0.61
T10 (140:61.4:11.3)	4.06a	14.24bcde	14.90bcd	0.66
T11 (140:92:17)	4.20a	16.16ab	16.74ab	0.57
T12 (140:122.6:22.6)	4.27a	17.42a	17.80a	0.38
Mean	4.06	14.22	14.84	0.62
CV	5.38	9.89	9.38	39.90
Level of significance	*	**	**	NS

Notes: BD = bulb diameter (cm); MYT = marketable bulb yield (t ha^{-1}); UMYT = unmarketable bulb yield (t ha^{-1}); TYT = total bulb yield (t ha^{-1}); CV = coefficient of variation; NS = non significant.
*Significant ($p < 0.05$).
**Highly significant ($p < 0.01$).

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3.3. Economically optimum rate of NPS application on garlic for higher marginal rate of return

The fertilizer related cost-benefits and associated marginal rate of returns are depicted in Tables 4 and 5, respectively. Over all the benefits of application of fertilizer exceed the traditional practices both in yield and rate of return. The highest net benefit of fertilizer application was recorded from garlic plants in T12 (Table 4). Based on the procedures described by CIMMYT (1988), the highest marginal rates of returns were however obtained from T11 followed by T3 with $N:P_2O_5:S$ application rates of 140:92:17 and 105:92:0 kg ha^{-1}, respectively (Table 5). T5 and T8 recorded the relatively least marginal rate of returns.

Table 4. Variable costs and gross incomes of garlic production as influenced by application of different rates of nutrients								
Treatments ($N:P_2O_5:S$ (kg ha^{-1}))	**Variable cost (ha^{-1})**					**Income (ha^{-1})**		
	Fertilizer cost (Eth-Birr)			**LC (Eth-Birr)**	**TVC (Eth-Birr)**	**MY (t ha^{-1})**	**GI (Eth-Birr)**	**NB = GI-TVC (Eth-Birr)**
	DAP	**NPS**	**Urea**					
T1 (0:0:0)	0.00	0.0	0.0	0.0	0.0	9.97	299,100.00	299,100.00
T2 (75.7:61.2:0)	1,862.00	0.0	1,264.50	2,400.00a	5,526.50	13.60	408,000.00	402,473.50
T3 (105:92:0)	2,800.00	0.0	1,686.00	2,400.00	6,886.00	14.81	444,300.00	437,414.00
T4 (70:61.4:11.3)	0.00	2,261.00	960.60	2,400.00	5,621.60	12.49	374,700.00	369,078.40
T5 (70:92:17)	0.00	3,388.00	586.70	2,400.00	6,374.70	13.68	410,400.00	404,025.30
T6 (70:122.6:22.6)	0.00	4,516.40	212.40	2,400.00	7,128.80	14.36	430,800.00	423,671.20
T7 (105:61.4:11.3)	0.00	2,261.00	1,815.80	2,400.00	6,476.80	13.08	392,400.00	385,923.20
T8 (105:92:17)	0.00	3,388.00	1,442.10	2,400.00	7,230.10	15.03	450,900.00	443,669.90
T9 (105:122.6:22.6)	0.00	4,516.40	1,067.80	2,400.00	7,984.20	15.81	474,300.00	466,315.80
T10 (140:61.4:11.3)	0.00	2,261.00	2,670.60	2,400.00	7,331.60	14.24	427,200.00	419,868.40
T11 (140:92:17)	0.00	3,388.00	2,296.30	2,400.00	8,084.30	16.16	484,800.00	476,715.70
T12 (140:122.6:22.6)	0.00	4,516.40	1,922.00	2,400.00	8,838.40	17.42	522,600.00	513,761.60

Notes: LC = labor cost; TVC = total variable cost; MY = marketable yield; GI = gross income; NB = net benefit.

Price of garlic at farm gate = 30 Birr kg^{-1}; labor cost = 50 BIRR Man-day^{-1}; Price of NPS, DAP and urea fertilizer = 14, 14 and 11.24 Eth-Birr kg^{-1}.

1 USD = 23.00 Eth-Birr.

Table 5. Economical benefits of garlic as influenced by application of different rates of nutrients				
Treatments ($N:P_2O_5:S$ (kg ha^{-1}))	**TVC (Eth-Birr)**	**NB (Eth-Birr)**	**MRR (%)**	**Rank**
T1 (0:0:0)	0	299,100.0	–	–
T2 (75.7:61.2:0)	5,526.5	402,474.0	1,870.5	5
T5 (70:92:17)	6,374.7	404,025.0	182.9	7
T3 (105:92:0)	6,886.0	437,414.0	6,530.4	2
T8 (105:92:17)	7,230.1	443,670.0	1,818.1	6
T9 (105:122.6:22.6)	7,984.2	466,316.0	3,003.0	4
T11 (140:92:17)	8,084.3	476,716.0	10,386.4	1
T12 (140:122.6:22.6)	8,838.4	513,762.0	4,912.5	3

Notes: TVC = total variable cost; NB = net benefit; MRR = marginal rate of return (%) after CIMMYT (1988); 1 USD = 23.00 Eth-Birr.

4. Conclusions

The current study was initiated with the objectives to assess the economic and agronomic optimum rate of the newly introduced compound NPS fertilizer on garlic (*A. sativum L*) under irrigated garlic production system in the Highlands of Ethiopia. The study illustrated that application of mineral fertilizer like NPS is necessary to improve the production and productivity of garlic in the study area since almost all growth and yield parameters of garlic were significantly influenced by NPS fertilizer rates. Accordingly, most growth parameters were significantly highest at 105:122.6:22.6 $N:P_2O_5:S$ kg ha^{-1} (T9). The highest yield of garlic was obtained from plants treated with 140:122.6:22.6 $N:P_2O_5:S$ kg ha^{-1} (T12) which was statistically similar with the yield obtained from those plants treated with the $N:P_2O_5:S$ rate of 140:92:17 kg ha^{-1} (T11) and 105:122.6:22 kg ha^{-1} (T9). Based on the results of the present study, NPS fertilizer at the rate of 140:92:17 $N:P_2O_5:S$ kg ha^{-1} can be recommended for the production of garlic in the study area under irrigated production system since the rate resulted the highest marginal rate of return. As the NPS fertilizer is a compound fertilizer the recommendation made here is specific for his fertilizer type. Therefore, the use of fertilizers that contain individual nutrient is recommended in future researches to come up with the best composition of nutrients specific for garlic production in the study area.

Competing Interests
The authors declare no competing interest.

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References
Arif, U., Hussain, S., Shah, S. Z. A., Hamid, A., Yaqoob, A., Arif, A. A., … Muneer, N. (2016). Interactive effect of phosphorus and zinc on the growth, yield and nutrient uptake of garlic (*Allium sativum* L.) variety Gulabi. *Asian Journal of Agricultural and Food Sciences, 4*, 278–284.

Assefa, A. G., Mesgina, S. H., & Abrha, Y. W. (2015). Effect of inorganic and organic fertilizers on the growth and yield of garlic crop (*Allium sativum* L.) in Northern Ethiopia. *Journal of Agricultural Science, 7*, 80–86.

Balasubramonium, A., Raman, G., & Moort, K. (1979). Effect of sulfur application in the yield and quality of onion (*Allium cepa* L.). *Agricultural Research Journal of Kerala, 17*, 138–140.

Block, E. (1985). The chemistry of garlic and onions. *Scientific American, 252*, 114–118.
https://doi.org/10.1038/scientificamerican0385-114

Bloem, E., Haneklaus, S., & Schnug, E. (2005). Influence of nitrogen and sulfur fertilization on the alliin content of onions and garlic. *Journal of Plant Nutrition, 27*, 1827–1839.
https://doi.org/10.1081/PLN-200026433

Brewster, J. & Butler, H. (1997). Effects of nitrogen supply on bulb development in onions (*Allium cepa* L.). *Journal of Experimental Botany, 40*, 1155–1162.

Brown, R., & Noah, L. C. (2014). *Effect of sulfur amendments on yield and quality in alliums. Rhode Island agricultural experiment station bulletin paper 14*. Retrieved from http://digitalcommons.uri.edu/riaes_bulletin/14

Central Statistic Agency. (2000). *Report on area and production of major crops. Vol. I. Bulletin No. 227*. Retrived from http://www.csa.gov.et

Central Statistic Agency. (2013). *Report on area and production of major crops. Vol. I. Bulletin No. 532*. Retrived from http://www.csa.gov.et

CIMMYT. (1988). *From agronomic data to farmer recommendations: An economics training manual*. Retrieved from http://repository.cimmyt.org/xmlui/bitstream/handle/10883/830/13803.pdf

Cottenie, I. (1980). *Soil and plant testing as a base for fertilizer recommendation: Soils bulletin No. 38/2*. Retrieved from www.fao.org/docrep/018/ar118e/ar118e.pdf

Day, P. R. (1965). Hydrometer method of particle size analysis. In C. A. Black (Ed.). *Methods of soil analysis: American society of agronomy no. 9. Part 2* (pp. 562–563). Milwaukee: Wisconsin Argon.

Dewis, J., & Freitas. P. (1970). *Physical and chemical methods of soil and water analysis. Bulletin no. 10*. Rome: Food Agriculture Organization of the United Nations.

Edwards, S., Demissew, S., & Heberg, I. (1997). *Flora of Ethiopia and Eritrea: National Herbarium*. Addis Ababa: Addis Ababa University.

El-Shafie, F., & El-Gamaily, E. (2002). Effect of organic manure, sulfur and microelements on growth, bulb yield,

storability and chemical composition of onion plants. *Minufiya Journal of Agricultural Research, 27*, 407–424.

Eshetu, B., & Tulu, S. (2014). Evaluating the role of nitrogen and phosphorus on the growth performance of garlic (*Allium Sativum* L.). *Asian Journal of Agricultural Research, 8*, 211–217.

Ethiopian Institute of Agricultural Research. (2007). *Guideline of crop production technologies*. Retrieved from www.eiar.gov.et/

Farooqui, M., Naruka, I., Rathore, S., Singh, P., & Shaktawat, R. (2009). Effect of nitrogen and sulfur levels on growth and yield of garlic (*Allium sativum* L.). *Asian Journal of Food and Agro-Industry, 2*, S18–23

Food and Agricultural Organization. (2012). *Global review of area and production of garlic*. Retrieved from https://en.wikipedia.org/wiki/Garlic

Geleta, D. S. (2014). *Response of garlic (Allium sativum L.) to fertilizer management in Ada'a District, Central Highland of Ethiopia* (PhD dissertation). Haramaya University, Ethiopia. Retrieved from 13.55.85.90/.../Diriba%20Sh%20PhD%20Dissertation%20%20May%202014.pdf

Guesh, T. (2015). *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* (M.Sc. thesis). Haramaya University, Haramaya, Ethiopia. Retrieved from 213.55.85.90/bitstream/handle/123456789/.../Guesh%20Final%20Thesis.pdf.

Hariyappa, N. (2003). *Effect of potassium and sulfur on growth, yield and quality parameters of onion (Allium cepa L.)* (M. Sc. thesis). University of Agricultural Sciences, Dharwad, India

Higdon, J. (2005). *Garlic and organosulfur compounds*. Linus Pauling Institute, Macronutrient Information Center, Oregon State University. Retrieved from http://lpi.oregonstate.edu/mic/food-beverages/garlic

Janet, B. (2008). *Garlic: Organic production*. Retrieved from www.eduinca.net/elibrary/en/book/download/id/7777

Libner, N. (1989). *Vegetable production*. New York: Van Nostrand Rein hold.

Marschner, H. (1995). *Mineral nutrition of higher plants* (2nd ed.). London: Academic Press.

Mulatu, A., Tesfaye, B., & Getachew, E. (2014). Growth and bulb yield of garlic varieties affected by nitrogen and phosphorus application at Mesqan districts, South Central Ethiopia. *Journal of Agricultural Research, 3*, 249–255.

Naruka, I., & Dhaka, R. (2001). Effect of row spacing and nitrogen fertilization on growth, yield and composition of bulb in garlic (*Allium sativum* L.) cultivars. *Journal of Spices and Aromatic Crops, 10*, 111–117.

Nasiruddin, K., Farooque, M., & Baten, A. (1993). Effect of potassium and sulfur on growth and yield of onion. *Bangladesh Journal of Agricultural Science, 20*, 35–40.

Office of Agriculture and Rural Development. (2009). *Annual crop yield assessment report of Yilmana Densa District* (Report No 18). Adet: Yilmana Densa District Office of Agriculture.

Olsen, S. R., & Dean, L. A. (1965). Phosphorous. In C. A. Black (Ed.), *Methods of soil analysis—Part 2: Chemical and microbiological properties*, (Vol. 9, pp. 1035–1049). Madison: American Society of Agronomy.

Rai, N., & Yadav, D. S. (2005). *Advances in vegetable production*. New Delhi: Researchco Book Centre.

Reddy, G. S., Suryanarayana, K., Reddy, K. M., & Reddy, K. C. (2000). Effect of different levels of nitrogen and phosphorus on yield and yield components in garlic (*Allium sativum* L.). *The Journal of Research ANGRAU, 28*, 56–59.

Rhoades, J. D., Chanduvi, F., & Lesch, S. M. (2002). *Soil salinity assessment: Methods and interpretation of electrical conductivity measurement*. Rome: Food and Agriculture of the United Nations (FAO).

Richards, L. A. (1954). *Agriculture handbook no. 60: Diagnosis and improvement of saline and alkali soils*. Washington: US Government Printing Office.

Rubatzky, V., & Yamaguchi, M. (1997). *World vegetable: Principles, production and nutritive values* (2nd ed.). New York: Chapman and hall International Thomson publishing. https://doi.org/10.1007/978-1-4615-6015-9

Sendek, F. (2012). *Fruit and vegtable production and management manual*. Bahir Dar: GIZ-SLM Amhara Sustainable Land Management Project (SLMP).

Tadese, T. (1991). *Soil, plant, water, fertilizer, animal manure and compost analysis*. (Working Document No. 13). Retrieved from https://cgspace.cgiar.org/handle/10568/4448

Trio, P. Z., You, S., He, X., He, J., Sakao, K., & Hou, D. X. (2014). Chemo-preventive functions and molecular mechanisms of garlic organosulfur compounds. *Food Function, 5*, 833–844. https://doi.org/10.1039/c3fo60479a

Tucker, M. R. (1999). *Essential plant nutrients: Their presence in North Carolina soils and role in plant nutrition*. Retrieved from http://cdm16062.contentdm.oclc.org/cdm/ref/collection/p249901coll22/id/461718

Yadav, P. (2003). Effect of nitrogen and potassium on growth and yield of garlic (*Allium sativum* L.) in western Rajasthan. *Haryana Journal of Horticultural Science, 32*, 290–291.

Zaman, M., Hashem, M., Jahiruddin, M., & Rahim, M. (2011). Effect of nitrogen for yield maximization of garlic in old brahmaputra flood plain soil. *Bangladesh Journal of Agricultural Research, 36*, 357–367.