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Original Research

Effect of Nitrogen, Phosphorus, and Sulphur Fertilizers on Growth, Yield, and Economic Returns of Garlic (*Allium sativum* L.)

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Abstract

Garlic (*Allium sativum* L.) is a plant with a major economic importance and has medicinal purposes. Garlic due to poor root system has high demands on soil and fertilizer needs. Andosols and Vertisols, the soils in Debre Zeit area in central Ethiopia, are generally low in organic matter and mineral nitrogen. The aim of the study was to determine effect of applying mineral nitrogen, phosphorus, and sulphur fertilizers on growth, yield, yield attributes, and economic returns of the garlic crop on the two soil types in the study area (Andosols and Vertisols). The treatments consisted of three rates of nitrogen (0, 92, 138 kg N ha^{-1}), three rates of phosphorus (0, 40, 80 kg P ha^{-1}), and three rates of sulphur (0, 30, 60 kg S ha^{-1}). Plant growth parameters, including plant height, leaf number, neck diameter and leaf area index were recorded at 30, 60, 90 and 120 days after planting. There were also marked mean bulb weight, bulb diameter, mean clove weight, harvest index and biological yield. From the results of study, was found that the growth, yield and yield attributes of garlic bulbs increased significantly with the increases in the rates of nitrogen, phosphorus, and sulphur and with further increased growth stages of the plant. A significantly higher bulb yield was obtained from Andosols than Vertisols. Application of nitrogen, phosphorus and sulphur significantly influenced the economic returns of garlic on both soil types in addition to the growth and yields of the crop. Based on the obtained results it was concluded that application of nitrogen, phosphorus, and sulphur at the rates of 92, 40 and 30 kg ha^{-1} led to enhanced production of garlic on both soil types. The results further showed that garlic productivity and profitability was markedly higher on Andosols than Vertisols. Therefore, farmers in the study are could apply 92 kg N ha^{-1} + 40 kg P ha^{-1} + 30 kg S ha^{-1} to attain optimum productivity of the crop for enhanced household income and livelihoods.

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INTRODUCTION

Despite its high importance and expanding production, garlic productivity in many parts of the world is low due to genetic and environmental factors (Potgieter, 2006). In Ethiopia, garlic is one of the main vegetable crops cultivated for both consumption and medicinal purposes. However, in many parts of the country, garlic crop yields are low due to a number of constraints, among which lack of balanced nutrient supply, diseases, and moisture stress are the major ones (FAO, 2003; Potgieter, 2006).

One of the major problems affecting crop production in Africa including Ethiopia is the rapid depletion of nutrients in smallholder farms (Badiane and Delgado, 1995; Achieng *et al*., 2010). In many garlic-producing areas, low availability of nutrients is the major factor limiting garlic production next to soil moisture stress, which constrains liberation of nitrogen, phosphorus and sulphur from soil organic matter and their uptake by plant roots (FAO, 2003). To improve garlic production planting time, balanced fertilizer application, optimal plant population and other cultural practices should be considered (Brewster and Butler, 1989; Potgieter, 2006). According to Luo *et al*. (2000) report, both yield and quality of garlic can also be improved through nitrogen and sulphur fertilization.

In Ethiopia and elsewhere in Sub-Saharan Africa, smallholder farmers generally apply low amounts of mineral fertilizers to crops (Morris *et al*., 2007). Consequently, most of the soils on which farmers produce their crops are deficient in nitrogen and phosphorus (Asnakew and Tekalign, 1991). Moreover, no potassium fertilizer is applied to crops in Ethiopia as soils of the country are supposed to have high contents of available potassium (Achieng *et al*., 2010). Garlic growers in the central highlands of Ethiopia often rely on fertilizer sources that contain only N and P (Urea and Diammonium phosphate), resulting in steadily declining available soil S and K levels (FAO, 2003). Potassium and S uptake imbalance relative to N can predispose the crop to serious disease and insect damages. Under such conditions, the plants will have reduced shoot growth and low yields and quality, consequently reducing the viability of this alternative cash crop.

However, soils (Andosols and Vertisols) in Debre Zeit area in the central highlands of Ethiopia are generally low in organic matter and mineral nitrogen due to continuous cultivation of the land without soil fertility replenishment through the use of crop residues as a source of organic matter (Teklu *et al*., 2004), as compared to the standard nutrients optimum requirements for crops in soils reported by Hazelton and Murphy (2007). Therefore, balanced application of nutrients can improve soil fertility and eliminate the effect of nutrient deficiencies for enhancing garlic productivity (Lujiu *et al*., 2004). This may lead to enhanced household cash income and food security of smallholder farmers in the region. This paper presents the results of a study conducted to elucidate the effect of applying mineral nitrogen, phosphorus, and sulphur fertilizers on growth, yield, and yield attributes, and economic returns of the garlic crop on the two soil types in the study area (Andosols and Vertisols).

MATERIALS AND METHODS

Description of the Experimental Site

Field experiment was conducted at the experimental research station of Debre Zeit Agricultural Research Centre (DZARC), which is located at $08^0 44''$N latitude, $38^0 58''$E longitude, and altitude of 1860-1900 meters above sea level in central Ethiopia. The experiment was undertaken during the main rainy season from July to August 2011 and was supplemented with irrigation after the rains ceased at the end of September. The area has mean annual maximum and minimum temperatures of 26 and 13 ^oC, respectively, with sub-humid tropical climate type and mean rainfall of about 776 mm and mean relative humidity of about 60% during the crop season (Figure 1). The experiment was conducted on two soil types: light grey volcanic ash soil (Andosols) with well-drained and good soil physical property; and black soil (Vertisols) with high water holding capacity, swelling and shrinking properties. The experimental fields were planted to tef [*Eragrostis tef* (Zucc.) Trotter] in the previous two consecutive cropping seasons.

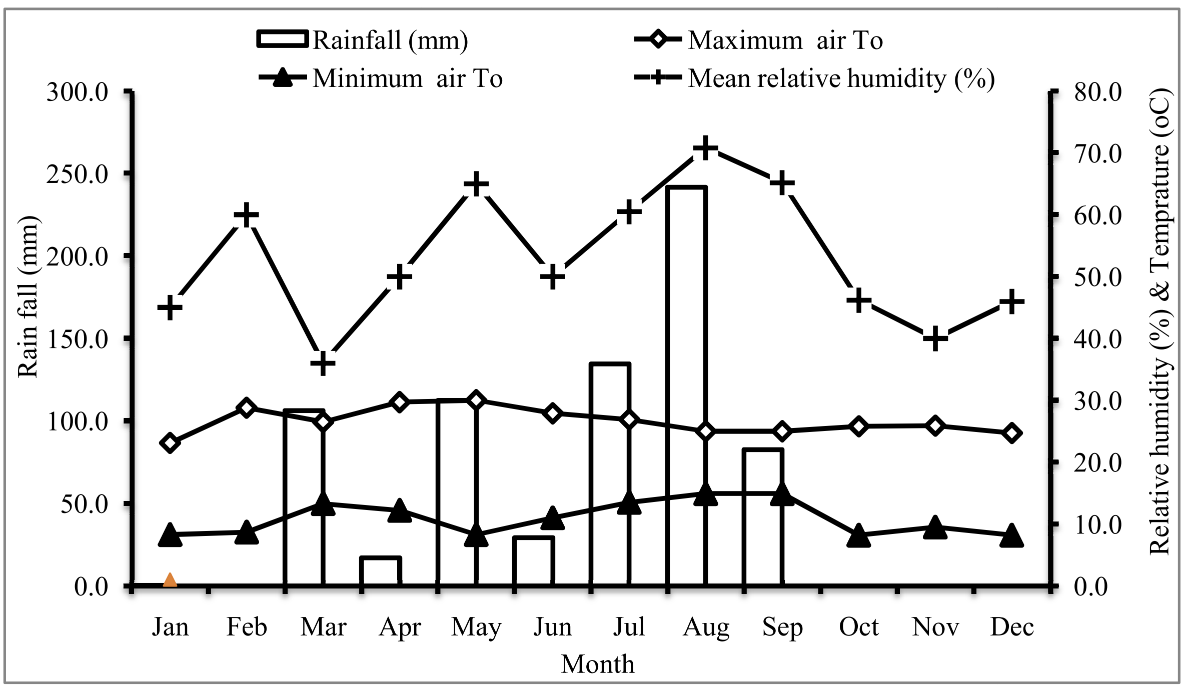

Figure 1: Monthly rainfall, relative humidity, and maximum and minimum temperatures recorded in the experimental area during the cropping year of 2011

Soil Sample Preparation and Analysis

The soil samples were taken randomly from the experimental soils before the commencement of the experiments to determine the soil properties and initial fertility status of the soil. The soils were air dried under shade, lightly grounded and screened through a 2 mm sieve to determine variables like soil texture, organic matter, soil pH, cations, extractable and available nutrients. Soil samples were analyzed at Debre Zeit Agricultural Research Centre Soil Laboratory. Physical soil characteristics (particle size distribution) were determined following Bouyoucous hydrometer method (Bouyoucous, 1962). The chemical analysis of the soil samples was conducted to determine the percentage of major elements viz. nitrogen, phosphorus, potassium, sulphur, some cations, and organic carbon, organic matter and pH values. The pH of the soil was measured using pH-water method by making soil to water suspension of 1: 2.5 ration and was measured using a pH meter. The soil organic carbon (OC) was determined by using Rapid Titration Method (Walkley and Black, 1954) and then its content was used to estimate the organic matter (OM) content by multiplying OC by 1.724 (Broadbent, 1953). Total nitrogen content was determined using the modified micro Kjeldhal method (Cottenie *et al.,* 1982), available phosphorus was analyzed by using Olsen's calorimetric method as described by Olsen *et al*. (1954), and potassium available in the soil was extracted with 1 N Ammonium acetate and the value was estimated using a flame photometer (Chapman and Pratt, 1982). The sulphur content in the soil was determined turbidimetrically using a spectrophotometer method (Singh *et al*., 1999) as indicated in Table 1.

Treatments and Experimental Design

The treatments consisted of three rates of nitrogen (0, 92 and 138 kg N ha^{-1}), three rates of phosphorus (0, 40 and 80 kg P ha^{-1}), and three rates of sulphur (0, 30 and 60 kg S ha^{-1}). The respective fertilizer source of the N, P and S were urea ($CO(NH_2)_2$; 46% N), triple super phosphate [$Ca(H_2PO_4)_2$; 20.24% P] and potassium sulphate (K_2SO_4; 43% K + 18% S). Potassium chloride fertilizer adjusted the amount of potassium in each level (KCl; 50% K) to the level of 140 kg ha^{-1}. The entire P, K and S fertilizers were applied at planting. One fourth, half and the remaining one fourth of the N fertilizer was applied as urea at planting, three weeks and six weeks after emergence of the garlic plants, respectively.

Experimental plots were thoroughly pulverized, levelled and ridges of about 20 cm high were prepared. The crop was planted on the ridge of smoothened soil at the spacing of 30 cm between rows and 10 cm between plants on both soil types on plot size of 3.6 m^2 (1.8 m x 2 m). In each trial, a garlic variety called "Tseday" was used. The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement of 27 treatment combinations with three replications on each soil type.

Healthy and uniform medium-sized cloves of 2.0-2.50 g (Fikreyohannes, 2005), were selected and planted at the depth of 2 cm on Vertisols, and 4 cm on Andosols on 30 June 2011 and the matured bulbs were harvested on 25 November 2011. Production management and agronomic practices were kept uniform for all treatments on both soils as per the recommendation of Debre Zeit Agricultural Research Centre (Getachew and Asfaw, 2000).

Data Collection

Plant growth parameters, including plant height, leaf number per plant, neck diameter, and leaf area index were recorded at 30, 60, 90 and 120 days after planting from ten randomly selected plants and the average of these plants was used for analysis. The heights (cm) of ten randomly selected plants from each plot were measured from the plots of each treatment using a ruler. The number of leaves per plant of ten randomly selected plants from each plot was counted. Neck diameter of the plant was measured from ten sample plants using calliper just above the bulb. Leaf area index was calculated from the total leaf area of the plant by dividing to the land area it occupied at each growth stages after the plants were planted.

Mean bulb weight of five bulbs were measured using sensitive balance and mean bulb diameter was measured using calliper at the centre broad diameter of the bulbs. Mean clove weight was calculated as the ratio of total clove weight to the total number of cloves obtained from five sample bulbs. Biological yield was the total weight of garlic plant including above and below ground yield recorded from five plants sampled from the four central rows after matured bulbs were harvested. Harvest index was calculated as the ratio of the bulb weight to total biological yield. Total bulb yield was calculated from total plants harvested from the central four rows of each plot and expressed on a hectare basis. Bulbs were harvested at 90% physiological maturity of the plants. The harvested plants were cured for ten days under ambient condition by thinly spreading them on wooden shelves in a diffused light storehouse constructed from wood whose walls were netted with a wire mesh and roofed with corrugated iron sheets.

To consolidate the statistical analysis of the agronomic and yield data, partial economic analysis was done for each treatment depending on the cost that varies with each treatment. For economic evaluation, cost and returns, and benefit: cost ratio was calculated according to the procedure given by CIMMYT (1988). Benefit to cost ratio (B: C) was calculated as the ratio of net return to total cost. To estimate economic parameters, garlic was valued at an average open market price of 10 birr kg^{-1}, cost of Triple Super Phosphate at 11.50 birr kg^{-1}; Urea at 10.00 birr kg^{-1}; Potassium sulphate at 12.50 birr kg^{-1}; Potassium chloride at 8.50 birr kg^{-1} was used for the adjustment of K in each treatment. Fertilizer application at 120.00 birr/100kg/ha; cost of harvesting and marketing (cleaning, curing and topping, packing) using 2 persons day^{-1} at birr 35.00 per person; packing and its material at 4.00 birr/100kg; transportation of garlic bulb at 5.00 birr/100 kg were used. At the time of dispatch, the price of 1kg garlic was ranged from 10-25 birr and the average (10 birr kg^{-1}) price was used for the calculations. Yield was adjusted by 15% reduction to compromise with the yield produced by farmers. The values of other materials used uniformly for each treatment were not considered in the budget for the partial economic analysis (Table 9).

Data Analysis

Data were subjected to analysis of variance using the Statistic Analysis System (SAS) version 9.0. Treatment means were compared using the Fisher's Least Significant Differences test at 5% level of significance. Moreover, simple Pearson's correlation analysis was done to reveal the magnitudes and directions of relationships between selected growth, yield and quality parameters of the crop.

RESULTS

Status of Nutrients in the Experimental Soils

A close relationship between the plant available nutrients content of the soil and the crop is a prerequisite for crop yields and quality. The total nitrogen contents of Andosols (0.063%) and Vertisols (0.036%) are very low (Table 1) according to the rating of Hazelton and Murphy (2007), who described that N content of soil between 0.15-0.25% as medium and greater than 0.25% as high. Available phosphorus of the Vertisols is low but that of Andosols is medium. However, the exchangeable potassium contents of both soil types are high (Table 1). Landon (1991) stated that a plant response to potassium fertilizer application is likely when a soil has an exchangeable K content of lower than 0.20 Cmol(+) kg^{-1} soil and unlikely when it has exchangeable K content of higher than 0.50 Cmol(+) kg^{-1} soil. Therefore, application of potassium as a treatment to the soils of both experimental sites was not required. The sulphur content of Andosols is lower than that of Vertisols. However, the sulphate-S content of both soils were low according to the rating of Bashour (2001) cited in Bashour and Sayegh (2007), who has categorized the soluble sulphate content of a soil of arid or semi-arid regions to very low, low, medium, high, and very high when the ranges fall between 0 to 10, 10 to 20, 20 to 35, 35 to 45, and above 45 mg kg^{-1} soil, in the order mentioned here. Also both soil types have no salinity problem as the electrical conductivity of both soils are about 1.0 dS m^{-1}; according to Hazelton and Murphy (2007), who described that soil salinity effect below 2.0 dS m^{-1} is mostly negligible for most crops. The contents of organic matter, N, P, K and Zn were higher in Andosols as compared to Vertisols. However, the contents of S and Ca were higher in Vertisols. Moreover, the organic matter and nutrient contents except K were low in both soils for optimum growth and increased yield and quality of the crop (Hazelton and Murphy, 2007).

Table 1: Selected physical and chemical properties of the experimental soils before planting the garlic cloves

Soil physical and chemical properties	Soil Types		Soil physical and chemical properties	Soil Types	
	Andosols	Vertisols		Andosols	Vertisols
Texture	Sandy Loam	ClayLoam	Exchangeable cations (Cmol(+) kg^{-1}): -K	2.55	1.47
Clay (%)	11.52	27.02	-Na	0.87	0.53
Silt (%)	21.78	20.99	-Ca	33.74	47.66
Sand (%)	66.70	51.99	-Mg	11.05	12.31
Organic matter (%)	2.23	1.40	Micronutrients (ppm): -Cu	0.23	0.22
C:N Ratio	20.6:1	22.5:1	- Fe	0.26	0.31
Total N (%)	0.063	0.036	- Mn	0.77	0.74
Available P (ppm)	41.51	14.48	- Zn	0.60	0.46
Available SO_4 (mg kg^{-1})	13.40	19.20	EC (dS m^{-1})	1.064	1.033
			pH (1:25 H_2O)	7.17	6.91

Effect of Fertilizers and Soil Type on Growth Parameters of Garlic

The main effect of nitrogen significantly ($P \le 0.01$) influenced all growth parameters of the garlic crop, i.e., plant height, leaf number, neck diameter and leaf area index (LAI) except at 30 days after planting (DAP). The main effect of phosphorus significantly ($P \le 0.05$) influenced both plant height and LAI at 60, 90 and 120 DAP, and neck diameter at both 90 and 120 DAP, but leaf number per plant was only affected at 90 days. In addition, the main effect of sulphur significantly ($P \le 0.01$) influenced both plant height and LAI at 90 and 120 DAP. However, it did not affect leaf number and neck diameter at all growth stages. Soil type significantly influenced all these growth parameters except LAI at 30 DAP (Table 2). However, the interaction effects of fertilizers on both soil types did not significantly influence these growth parameters.

Table 2: Effect of nitrogen, phosphorus and sulphur rates and soil types on plant height and number of leaves per plant of garlic at different growth stages during the 2011 rainy season

Treatments	Days after planting							
	Plant height (cm)				Number of leaves per plant			
	30	60	90	120	30	60	90	120
Nitrogen (kg ha^{-1})								
0	22.46^a	33.60^c	41.65^b	44.01^c	4.63^a	5.42^b	7.89^b	9.59^b
92	22.95^a	37.87^a	44.26^a	47.51^a	4.69^a	5.76^a	8.21^a	9.78^b
138	23.41^a	36.45^b	43.63^a	46.08^b	4.76^a	5.75^a	8.24^a	10.18^a
F-test	ns	**	**	**	ns	**	**	**
Phosphorus (kg ha^{-1})								
0	22.86^a	34.93^b	42.42^b	44.57^b	4.69^a	5.61^a	7.98^b	9.75^a
40	22.92^a	36.0^{ab}	43.3^{ab}	46.20^a	4.72^a	5.68^a	8.06^b	10.00^a
80	23.04^a	36.97^a	43.80^a	46.83^a	4.68^a	5.65^a	8.29^a	9.79^a
F-test	ns	*	*	**	ns	ns	*	ns
Sulphur (kg ha^{-1})								
0	22.76^a	35.18^a	42.07^b	44.56^b	4.68^a	5.65^a	8.08^a	9.93^a
30	22.80^a	36.45^a	43.73^a	46.69^a	4.70^a	5.61^a	8.24^a	9.82^a
60	23.26^a	36.29^a	43.74^a	46.34^a	4.70^a	5.68^a	8.02^a	9.80^a
F-test	ns	ns	**	**	ns	ns	ns	ns
Soil type								
Andosols	23.3^a	35.48^b	43.77^a	47.24^a	4.58^b	5.10^b	9.01^a	10.48^a
Vertisols	22.6^b	36.47^a	42.60^b	44.49^b	4.80^a	6.19^a	7.22^b	9.22^b
F-test	*	*	**	**	**	**	**	**
Fertilizer-LSD (5%)	**0.82**	**1.19**	**0.96**	**0.98**	**0.13**	**0.21**	**0.20**	**0.35**
Soil-LSD (5%)	**0.62**	**0.97**	**0.79**	**0.81**	**0.11**	**0.17**	**0.16**	**0.29**
CV (%)	**8.63**	**8.63**	**5.81**	**5.59**	**7.37**	**9.59**	**6.41**	**9.57**

Means followed by the same letter within a column are not significantly different at 5% level of significance; CV - coefficient of variation; LSD - least significant difference

Plant Height

Thirty days after planting, plant height remained similar in response to the application of the three fertilizers, which indicated that the nutrient uptake capacity of the crop was very low because of small growth of roots at the initial stage. But, 60 days after planting, garlic plants grew significantly taller in response to increasing the rates of applied nitrogen and phosphorus. However, increasing the rate of sulphur did not increase the height of plants at this stage of growth. Application of 92 kg ha^{-1} nitrogen increased plant height by about 12% as compared to 0 kg N ha^{-1}, however, an increase in the rate of the fertilizer beyond this level significantly depressed plant height. At this stage of growth, application of 40 kg P ha^{-1} enhanced plant height than the control plot, but it remained unchanged at 80 kg P ha^{-1} (Table 2). Ninety and 120 days after planting, application of 92 kg N ha^{-1} and 40 kg P ha^{-1} increased plant heights, respectively. However, at higher rates of each fertilizer, the height of the plants remained unchanged or was even depressed. However, 120 days after planting, application of sulphur at 30 kg S ha^{-1} enhanced plant height significantly by about 5% as compared to 0 kg S ha^{-1} (Table 2). Taller garlic plants were produced on Andosols at all growth stages than Vertisols except at 60 days after planting. Garlic plant height significantly increased up to 120 days after planting on Andosols, but on Vertisols a slight change was obtained after 90 days of growth.

Leaf Number

Except 30 days after planting, 92 kg ha^{-1} nitrogen application significantly increased leaf number at both at 60 and 90 days, and up to 138 kg N ha^{-1} at 120 days of growth stages after planting. However, application of phosphorus increased leaf number only at 90 days after planting. Increasing the rate of sulphur did not increase leaf number per plant at all stages of growth (Table 2). Soil types also significantly influenced garlic leaf number per plant. Many more leaves were produced on Vertisols at 30 and 60 days and on Andosols at 90 and 120 days after planting the crop (Table 2).

Neck Diameter

Application of nitrogen fertilizer increased neck diameter of garlic at all stages of growth, with the highest neck diameter being recorded at the highest two rates of the fertilizer at all stages of growth. This parameter responded to the increased rate of phosphorus only at 90 and 120 days after planting. However, neck diameter did not respond to the increased application rates of sulphur (Table 3). Soil type significantly increased the neck thicknesses with growth periods up to 120 days after planting with thick diameters from Andosols at 30 and 120 days and from Vertisols at 60 and 90 days after planting (Table 3).

Table 3: Effect of nitrogen, phosphorus and sulphur fertilizer rates and soil types on neck diameter and leaf area index of garlic at different growth stages during the 2011 rainy season

Treatments	Days after planting							
	Neck diameter (mm)				Leaf area index			
	30	60	90	120	30	60	90	120
Nitrogen (kg ha^{-1})								
0	3.97^{a}	4.71^{c}	6.02^{b}	7.08^{b}	1.72^{b}	4.33^{b}	4.85^{b}	5.37^{c}
92	4.15^{a}	5.65^{a}	7.21^{a}	8.67^{a}	1.62^{b}	5.20^{a}	5.99^{a}	7.51^{a}
138	4.24^{a}	5.42^{b}	7.29^{a}	8.70^{a}	1.91^{a}	5.35^{a}	6.11^{a}	7.12^{b}
F-test	ns	**	**	**	**	**	**	**
Phosphorus (kg ha^{-1})								
0	4.10^{a}	5.21^{a}	6.62^{b}	7.84^{b}	1.70^{a}	4.56^{b}	5.42^{b}	6.03^{b}
40	4.12^{a}	5.25^{a}	6.91^{a}	8.27^{a}	1.75^{a}	5.19^{a}	5.81^{a}	6.91^{a}
80	4.14^{a}	5.32^{a}	6.98^{a}	8.35^{a}	1.80^{a}	5.14^{a}	5.73^{ab}	7.06^{a}
F-test	ns	ns	*	**	ns	**	*	**
Sulphur (kg ha^{-1})								
0	4.21^{a}	5.11^{a}	6.76^{a}	7.95^{a}	1.70^{a}	4.91^{a}	5.15^{b}	6.08^{b}
30	4.08^{a}	5.30^{a}	6.90^{a}	8.25^{a}	1.76^{a}	4.96^{a}	5.75^{a}	6.91^{a}
60	4.07^{a}	5.36^{a}	6.85^{a}	8.26^{a}	1.80^{a}	5.02^{a}	5.05^{a}	7.00^{a}
F-test	ns	ns	ns	ns	ns	ns	**	**
Soil type								
Andosols	4.21^{a}	5.04^{b}	6.72^{b}	8.33^{a}	1.82^{a}	5.14^{a}	5.91^{a}	6.96^{a}
Vertisols	4.03^{b}	5.48^{a}	6.96^{a}	7.97^{b}	1.68^{a}	4.78^{b}	5.39^{b}	6.08^{b}
F-test	*	**	*	**	ns	*	**	**
Fertilizer-LSD (5%)	**0.19**	**0.21**	**0.23**	**0.31**	**0.182**	**0.325**	**0.380**	**0.315**
Soil-LSD (5%)	**0.16**	**0.17**	**0.19**	**0.25**	**0.149**	**0.265**	**0.310**	**0.257**
CV (%)	**12.6**	**10.50**	**8.93**	**9.92**	**27.30**	**17.20**	**17.60**	**12.40**

Means followed by the same letter within a column are not significantly different at 5% level of significance; CV - coefficient of variation; LSD - least significant difference

Leaf Area Index

Across all growth stages, leaf area index of the crop increased significantly as a result of the applied N, P and S fertilizers. However, the optimum leaf area indices were recorded at 92 kg N ha^{-1}, 40 kg P ha^{-1}, and 30 kg S ha^{-1} (Table 3). The lowest leaf area index was obtained from garlic plants grown on the unfertilized (control) plots on both soils (Table 3). Also higher leaf area indices were produced on the Andosols as late as 60, 90 and 120 days after planting whereas this occurred on Vertisols as early as 30 days after planting. Nitrogen fertilization significantly increased the leaf area index with its rates at 30 days after planting but both at 60 and 90 days after planting the LAI were at par due to 92 and 138 kg N ha^{-1} and highest due to 92 kg N ha^{-1} at 120 days after planting. Application of P and S fertilizers significantly increased the LAI of plant without significant differences observed due to the application of 40 and 80 kg P ha^{-1}, and 30 & 60 kg S ha^{-1}.

Effect of the Applied Fertilizers on Yield and Yield Attributes of Garlic

Mean Clove Weight

The main effects of N, P and S fertilizers on both soils significantly affected the mean clove weight; in addition, the interaction effects of N and P as well as P and S significantly influenced the mean clove weight on Andosols (Table 4). Application of nitrogen significantly increased the mean clove weight up to the rate of 138 kg N ha^{-1} on Vertisols but increased on Andosols with N application without significant variation between 92 and 138 kg N ha^{-1}. Fertilization of the crop by 138 kg N ha^{-1} on Vertisols increased the mean clove weight by 29.51% and 9.22% as compared to control and 92 kg N ha^{-1}, respectively (Table 4). Phosphorus application on both Andosols and Vertisols at the rate of 40 kg P ha^{-1} led to the production of heavier cloves. However, unlike in Vertisols further increased the rate of P depressed the weight of cloves on both soils. The application of phosphorus on Vertisols at both rates resulted in the production of heavier cloves without significant variation (Table 5). Application of sulphur at 30 kg S ha^{-1}, increased clove weight significantly on both soils. As the rate of S was increased from 30 to 60 kg ha^{-1}, the clove weight did not change statistically on both soils. Application of 30 kg S ha^{-1} produced heavier cloves on both soil types, which exceeded the weight of cloves, obtained from the control plots by 35% and 10% on Andosols and Vertisols, respectively (Table 5).

Combined application of 138 kg N ha^{-1} + 40 kg P ha^{-1} and 40 kg P ha^{-1} + 60 kg S ha^{-1} led to the production of the heaviest cloves on Andosols. Plants not supplied with the N and P as well as P and S fertilizers interactions produced the lightest cloves. The mean clove weights produced by plants treated with the combinations of 138 kg N + 40 kg P ha^{-1} and 40 kg P + 60 kg S ha^{-1} exceeded the control treatment by about 105% and 130%, respectively on Andosols (Table 6).

Table 4: Mean square values of yield components and bulb yield of garlic as influenced by the main and interaction effects of inorganic nitrogen (N), phosphorus (P) and sulphur (S) fertilizers on both Andosols and Vertisols

Parameters	Soil	N	P	S	N x P	N x S	P x S	NxPxS
Bulb weight	Andosols	232.93^{***}	46.28^{***}	23.24^{***}	1.14^{ns}	17.19^{***}	0.86^{ns}	22.30^{***}
	Vertisols	585.08^{***}	44.32^{***}	207.79^{***}	38.28^{***}	28.86^{***}	32.97^{***}	16.94^{***}
Bulb diameter	Andosols	6.09^{***}	4.18^{***}	3.29^{***}	0.33^{**}	0.49^{***}	0.272^{*}	0.389^{***}
	Vertisols	9.66^{***}	1.61^{***}	2.34^{***}	0.61^{*}	0.344^{ns}	0.486^{*}	0.211^{*}
Mean clove weight	Andosols	2.56^{***}	4.67^{***}	3.01^{***}	0.222^{*}	0.064^{ns}	0.218^{*}	0.032^{ns}
	Vertisols	2.01^{***}	0.817^{**}	0.545^{*}	0.202^{ns}	0.094^{ns}	0.029^{ns}	0.046^{ns}
Biological yield	Andosols	96647.6^{***}	2757.7^{***}	624.65^{***}	295.88^{**}	266.74^{**}	581.38^{***}	642.59^{***}
	Vertisols	16866.2^{***}	1119.6^{***}	14447.0^{***}	1090.8^{***}	2488.4^{***}	2404.0^{***}	1474.3^{***}
Harvest index	Andosols	0.0103^{ns}	0.0054^{ns}	0.0142^{ns}	0.0087^{ns}	0.0150^{*}	0.0284^{***}	0.0286^{***}
	Vertisols	0.1046^{***}	0.0149^{*}	0.0127^{*}	0.0045^{ns}	0.0060^{ns}	0.0094^{*}	0.0079^{*}
Bulb yield	Andosols	45.91^{***}	19.14^{***}	9.10^{***}	9.98^{***}	2.35^{ns}	5.27^{***}	2.51^{*}
	Vertisols	178.22^{***}	26.21^{***}	79.36^{***}	6.25^{***}	10.73^{***}	6.31^{***}	3.39^{***}

Where, ns = indicate non-significant, and *, **, ***, indicate significant at P < 0.05, 0.01 and 0.001 LSD tests, respectively

Table 5: Main effect of N, P and S fertilizers on mean clove weight of garlic on two soils

Treatment		Mean clove weight (g)	
Fertilizer	**Levels (kg ha^{-1})**	**Andosols**	**Vertisols**
Nitrogen	0	1.51^{b}	1.83^{c}
	92	1.97^{a}	2.17^{b}
	138	2.09^{a}	2.37^{a}
	LSD	0.15	0.19
Phosphorus	0	1.39^{c}	1.93^{b}
	40	2.20^{a}	2.27^{a}
	80	1.98^{b}	2.16^{a}
	LSD	0.15	0.19
Sulphur	0	1.47^{b}	1.96^{b}
	30	1.99^{a}	2.16^{a}
	60	2.10^{a}	2.24^{a}
	LSD	0.15	0.19
	Mean	**1.85**	**2.12**
	C.V.(%)	**14.80**	**16.30**

Means followed by the same letter within a column are not significantly different at 5% LSD

Table 6: The effects of N and P as well as P and S fertilizers interaction on mean clove weight (g) of garlic on Andosols

Treatment	P (kg ha^{-1})				P (kg ha^{-1})		
N (kg ha^{-1})	**0**	**40**	**80**	**S (kg ha^{-1})**	**0**	**40**	**80**
0	1.22^{e}	1.78^{c}	1.52^{d}	0	1.12^{e}	1.61^{d}	1.69^{d}
92	1.52^{d}	2.29^{ab}	2.10^{b}	30	1.51^{d}	2.39^{ab}	2.09^{c}
138	1.44^{de}	2.51^{a}	2.31^{ab}	60	1.55^{d}	2.58^{a}	2.15^{bc}
LSD = 0.26 ; C.V. (%) = 14.80							

Means followed by the same letter within a column are not significantly different at 5% level of significance

Bulb Weight

All main and interaction effects of the applied nitrogen, phosphorus and sulphur fertilizers on both soil types except the two factor interactions of N and P as well as P and S on Andosols significantly influenced the bulb weight of garlic (Table 4). Significantly higher garlic bulb weights were obtained from the Andosols in response to the combined application of 92 kg N ha^{-1} + 40 kg P ha^{-1} + 60 kg S ha^{-1} and 138 kg N ha^{-1} + 40 or 80 kg P ha^{-1} + 30 kg S ha^{-1}. Similarly, the combined application of 138 kg N ha^{-1} + 40 or 80 kg P ha^{-1} + 60 kg S ha^{-1} on Vertisols produced highest bulb weight (Table 7). The mean bulb weight did not significantly differ due to the effect of soil types, but the heaviest bulb produced on Vertisols in response to 138 kg N ha^{-1} + 40 kg P ha^{-1} + 60 kg S ha^{-1} was increased by about 64% as compared to the bulb weight produced on Andosols. However, at the combined application of 138 kg N ha^{-1} + 40 kg P ha^{-1} + 30 kg S ha^{-1} the bulb weight produced on Andosols was increased by about 19% than the bulb weight produced on Vertisols (Table 7). On the other hand, the lightest bulbs were obtained from the control plots of both soil types.

Table 7: Interaction effect of inorganic nitrogen (N), phosphorus (P) and sulphur (S) fertilizers on yield components and bulb yield of garlic on both Andosols and Vertisols soil types (N x P x S)

Fertilizer rates (kgha^{-1})			Bulb weight (g)		Bulb diameter (cm)		Biologica yield (g)		Harvest index		Total bulb yield (t ha^{-1})	
N	P	S	Andosols	Vertisols	Andosols	Vertisols	Andosols	Vertisols	Andosols	Vertisols	Andosols	Vertisols
0	0	0	9.09^{l}	9.91^{m}	2.59^{e}	2.84^{h-k}	71.80^{m}	69.4^{k-n}	0.65^{d}	0.55^{i}	6.53^{h}	4.36^{l}
		30	12.13^{k}	11.51^{lm}	3.21^{cd}	2.82^{h-k}	74.10^{m}	92.0^{k-m}	0.83^{b}	0.62^{f-i}	6.67^{h}	5.94^{h-l}
		60	15.33^{f-i}	9.97^{m}	3.17^{d}	2.50^{k}	97.00^{h-k}	75.6^{n}	0.79^{bc}	0.63^{f-i}	7.61^{gh}	4.98^{kl}
	40	0	14.67^{h-j}	10.88^{lm}	3.38^{cd}	2.67^{i-k}	93.50^{i-l}	77.6^{mn}	0.78^{b-d}	0.70^{b-g}	8.70^{fg}	4.48^{l}
		30	12.47^{jk}	11.63^{lm}	3.22^{cd}	2.72^{h-k}	79.30^{lm}	97.0^{j-l}	0.79^{b-d}	0.60^{g-i}	9.58^{c-f}	6.25^{h-k}
		60	16.37^{d-h}	14.68^{i-k}	3.36^{cd}	3.03^{g-k}	111.90^{e-h}	104.0^{i-k}	0.74^{b-d}	0.71^{b-g}	9.65^{c-f}	6.50^{h-k}
	80	0	15.06^{g-i}	10.23^{m}	3.48^{cd}	2.57^{jk}	89.60^{kl}	73.8^{n}	0.84^{b}	0.69^{b-g}	11.07^{bc}	5.30^{j-l}
		30	12.84^{i-k}	11.21^{lm}	3.29^{cd}	2.75^{h-k}	88.30^{kl}	96.8^{j-l}	0.73^{b-d}	0.58^{hi}	10.43^{b-f}	5.57^{i-l}
		60	14.79^{h-j}	14.28^{jk}	3.54^{cd}	3.07^{g-k}	93.80^{i-l}	117.1^{f-i}	0.79^{bc}	0.61^{g-i}	9.63^{c-f}	5.58^{i-l}
92	0	0	17.62^{c-f}	15.58^{h-j}	3.41^{cd}	3.25^{e-i}	112.00^{e-h}	99.5^{j-l}	0.79^{bc}	0.79^{a-d}	11.08^{bc}	6.71^{h-j}
		30	17.37^{c-g}	19.55^{d-f}	3.58^{cd}	3.62^{d-g}	114.00^{d-g}	140.3^{c-e}	0.76^{b-d}	0.70^{b-g}	10.49^{b-f}	9.29^{de}
		60	15.24^{f-i}	21.25^{b-d}	3.48^{cd}	3.75^{d-f}	92.60^{j-l}	147.9^{bc}	0.82^{b}	0.72^{b-f}	10.86^{b-d}	9.50^{c-e}
	40	0	16.03^{e-h}	16.76^{g-i}	3.44^{cd}	3.37^{e-h}	106.40^{g-j}	111.9^{g-j}	0.76^{b-d}	0.75^{a-e}	9.66^{c-f}	7.54^{f-h}
		30	18.55^{cd}	22.57^{b}	4.71^{ab}	4.17^{a-d}	126.80^{c-e}	143.2^{cd}	0.73^{b-d}	0.79^{a-d}	13.87^{a}	11.09^{b}
		60	22.47^{a}	19.96^{c-e}	4.82^{ab}	3.90^{b-e}	145.50^{a}	128.4^{d-g}	0.77^{b-d}	0.78^{a-d}	14.58^{a}	10.90^{bc}
	80	0	19.29^{bc}	15.33^{ij}	3.63^{cd}	3.26^{e-i}	144.50^{ab}	96.7^{j-l}	0.67^{cd}	0.79^{a-c}	10.58^{b-f}	7.29^{f-h}
		30	18.57^{cd}	15.30^{ij}	4.80^{ab}	3.87^{b-f}	127.80^{cd}	105.9^{h-k}	0.73^{b-d}	0.73^{a-f}	10.07^{c-f}	10.3^{b-d}
		60	21.55^{ab}	21.85^{bc}	4.88^{ab}	4.26^{a-d}	138.10^{a-c}	160.3^{b}	0.78^{b-d}	0.68^{c-h}	12.12^{b}	11.20^{b}
138	0	0	17.89^{c-e}	15.30^{ij}	3.50^{cd}	3.26^{e-i}	114.90^{d-g}	109.6^{h-j}	0.78^{b-d}	0.70^{b-g}	8.92^{e-g}	7.40^{f-h}
		30	16.44^{d-h}	17.86^{e-g}	3.48^{cd}	3.33^{e-i}	108.60^{g-i}	131.9^{c-f}	0.76^{b-d}	0.68^{d-h}	10.75^{b-e}	8.72^{ef}
		60	18.51^{c-e}	17.75^{f-h}	3.67^{c}	3.23^{f-j}	107.50^{g-j}	122.2^{f-h}	0.86^{b}	0.73^{a-f}	10.32^{b-f}	8.39^{e-g}
	40	0	18.50^{c-e}	12.99^{kl}	3.61^{cd}	3.06^{g-k}	124.90^{c-f}	86.0^{mn}	0.74^{b-d}	0.76^{a-e}	9.05^{d-g}	7.41^{f-h}
		30	23.00^{a}	19.23^{d-f}	4.98^{a}	4.49^{ab}	106.40^{g-j}	120.0^{f-i}	1.09^{a}	0.80^{ab}	10.64^{b-e}	13.53^{a}
		60	17.35^{c-g}	28.59^{a}	4.80^{ab}	4.75^{a}	131.10^{bc}	220.0^{a}	0.66^{cd}	0.65^{e-i}	11.03^{bc}	14.76^{a}
	80	0	16.35^{d-h}	20.82^{b-d}	3.51^{cd}	3.81^{c-f}	108.80^{g-i}	126.4^{e-g}	0.75^{b-d}	0.83^{a}	10.64^{b-e}	7.06^{g-i}
		30	22.61^{a}	20.19^{cd}	4.56^{ab}	4.47^{a-c}	148.10^{a}	132.8^{c-f}	0.76^{b-d}	0.76^{a-e}	10.71^{b-e}	10.89^{bc}
		60	19.53^{bc}	29.73^{a}	4.42^{b}	4.57^{a}	127.30^{cd}	211.3^{a}	0.77^{b-d}	0.71^{b-g}	10.65^{b-e}	14.51^{a}
Mean			**17.02**	**16.83**	**3.80**	**3.46**	**110.55**	**119.17**	**0.77**	**0.70**	10.22	8.35
LSD (5%)			**2.49**	**2.20**	**0.48**	**0.67**	**13.26**	**14.68**	**0.117**	**0.092**	1.58	1.43
C.V.(%)			**8.90**	**8.00**	**7.70**	**11.80**	**7.30**	**7.50**	**9.20**	**8.00**	9.50	10.50

Means followed by the same letter within a column are not significantly different at 5% (*) or 1% (**) levels of significance

Bulb Diameter

Similar to mean bulb weight, garlic bulb diameter was significantly affected by the main and all interaction effects of the three fertilizers applied on both soil types, except the interaction effect of N and S on Vertisols (Table 4). Increased in the rate of nitrogen, phosphorus and sulphur application led to markedly increased bulb diameter on both soils. The highest bulb diameter was obtained from plot treated with the combined rates of 138 kg N ha^{-1} + 40 kg P ha^{-1} + 30 kg S ha^{-1} on Andosols, and with the combined rates of 138 kg N ha^{-1} + 40 kg P ha^{-1} + 60 kg S ha^{-1} on Vertisols (Table 7). The mean bulb diameter of the crop was higher on Andosols as compared to that produced on Vertisols by about 9.8%. The lowest bulb diameter was produced on the control plot of Andosols and in all treatments not supplemented by nitrogen in Vertisols.

Biological Yield

Both the main and interaction effects of nitrogen, phosphorus and sulphur fertilizers on both Andosols and Vertisols significantly influenced biological yield of the garlic crop (Table 4). The lowest biological yield was obtained from the control treatment on both soils (Table 7). The highest biological yield was obtained at the combined application of 138 kg N, 40 kg P, and 60 kg S ha^{-1} followed by the application of 138 kg N, 80 kg P, and 60 kg S ha^{-1} on Vertisols. The biological yields obtained at these combined rates of the three fertilizers exceeded the lowest biological yield produced on the same soil by 198% and 186%, respectively. On the other hand, the highest biological yield on the Andosols was produced in response to the combined application of 138 kg N, 80 kg P, and 30 kg S ha^{-1} that was followed by 92 kg N, 40 kg P, and 60 kg S ha^{-1} (Table 7). The highest mean biological yield on Vertisols exceeded the one produced on Andosols by about 7.80%.

Harvest Index

The interaction effects of N, P and S on both Andosols and Vertisols significantly influenced harvest index (Table 4). Lowest harvest index was produced from the control plots (0 kg NPS ha^{-1}) on both soil types. On the other hand, with the increase in the rate of nitrogen, phosphorus and sulphur led to higher harvest indices. The highest harvest index was obtained at the combined application of 138 kg N + 40 kg P + 30 kg S ha^{-1} on Andosols and 138 kg N + 80 kg P + 0 kg S ha^{-1} on Vertisols (Table 7). Similarly, the application of N, P and S significantly increased garlic harvest index on Andosols, which was higher by 10% than the HI produced on Vertisols (Table 7).

Total Bulb Yield

All main and interaction effects of N, P and S fertilizers significantly affected total bulb yield of garlic on both soil types except the interaction effect of N and S on Andosols (Table 4). The interaction of the three factors significantly increased the total bulb yield with the application of the three nutrients together on both soils (Table 7). The highest bulb yield on the Andosols was obtained in response to the combined application of 92 kg N + 40 kg P + 60 kg S ha^{-1}. However, it was statistically in parity with the combination of same levels of N and P with 30 kg S ha^{-1}. Similarly, on Vertisols the highest bulb yield was obtained at the combined application of 138 kg N + 40 kg P + 60 kg S ha^{-1} which did not significantly different from 138 kg N + 40 kg P + 30 kg S ha^{-1} as well as 138 kg N + 80 kg P + 60 kg S ha^{-1} combinations. The lowest bulb yield was obtained from the control plot (0 kg NPS ha^{-1}) on both soils. The higher bulb yields obtained from Vertisols in response to 138 kg N ha^{-1} + 40 kg P ha^{-1} along with 30 or 60 kg S ha^{-1} exceeded the lowest bulb yield obtained from the same soil at 0 kg NPS ha^{-1} by about 210% and 238%, respectively. Similarly, the higher bulb yields obtained from Andosols at 92 kg N + 40 kg P ha^{-1} along with 30 or 60 kg S ha^{-1} exceeded the one obtained from the same soil in the control plot by about 112% and 123%, respectively (Table 7).

Similarly, the highest bulb yield obtained at 92 kg N + 40 kg P ha^{-1} along with 30 and 60 kg S ha^{-1} from Andosols exceeded the one obtained from Vertisols by about 25% and 34%, respectively. Consequently, a comparison of mean bulb yields from the two independent soil types showed statistically significant ($P \leq 0.01$) differences, with higher mean yield of garlic from Andosols (10.22 t ha^{-1}) compared to Vertisols (8.35 t ha^{-1}) (Table 7). Therefore, the null hypothesis of no difference should be rejected and the hypothesis of different means of garlic yields on the two soil types should be upheld.

Relationships between Growth and Yield Attributes

Correlation coefficient values (r) computed to display the relationships between and within main growth and yield attributes of garlic showed apparent relationship on both soil types (Table 8). The result of correlation analysis on both Andosols and Vertisols indicated that growth and yield parameters had a positive and significant correlation with each other (Table 8). Mean clove weight was significantly and positively correlated with only neck diameter, bulb weight and total bulb yield on Andosols, but correlated positively with all growth and yield parameters on Vertisols. As the growth of garlic height, neck diameter, and leaf area index become increased, the bulb weight and yields of garlic bulb also increased on both soils.

Table 8: Correlation coefficient for the growth and yield attributes considered on Andosols and Vertisols

Parameters	Soil	ND	LAI	BW	MCW	TBY	BDM
PH	A	0.385**	0.617***	0.394**	0.208	0.242*	0.330**
	V	0.639***	0.713***	0.614***	0.582***	0.691***	0.071
ND	A		0.522***	0.384**	0.214*	0.254*	0.365**
	V		0.719***	0.758***	0.697***	0.817***	0.117
LAI	A			0.423***	0.122	0.302**	0.460***
	V			0.606***	0.608***	0.718***	0.081
BW	A				0.412**	0.590***	0.274*
	V				0.879***	0.841***	0.042
MCW	A					0.357**	0.130
	V					0.757***	0.116
TBY	A						0.367**
	V						0.174

Where no asterisk indicates non significant, and * , **, indicate significant difference at 5% and 1%, levels of probability, respectively. PH= Plant height; ND= Neck diameter; LAI= Leaf area index; BW= Bulb weight; MCW= Mean clove weight; TBY= Total bulb yield; A = Andosols and V = Vertisols

Economic Returns

Garlic production in two different soil types under fertilizer management involved different costs, which affected the total production cost that varied within each treatment (Table 9). The treatments that received N:P:S fertilizers at the rates of 92:40:60, 92:80:60 and 138:80:60 kg ha^{-1} led to the higher total variable cost of 20216, 20621 and 20516 birr ha^{-1} on Andosols. Also the combined rates of 138:40:60 and 138:80:60 NPS kg ha^{-1} led to the higher variable cost of 21414 and 23565 birr ha^{-1} on Vertisols, while the control treatments incurred the lowest costs of 7780 and 6065 birr ha^{-1} on both soils, respectively. The adjusted average bulb yields obtained from a hectare of land were highest at the rates of 92:40:30 and 92:40:60 kg ha^{-1} NPS on Andosols (12,640 and 12,393 kg ha^{-1}) and at the rates of 138:40:60 and

138:80:60 kg ha^{-1} NPS on Vertisols (12,546 and 12,334 kg ha^{-1}). The lowest yield was obtained at lowest rate of fertilizers applied on both soils.

Therefore, this investigation led to the determination of 92:40:30 kg ha^{-1} NPS as the best combination for optimum bulb yield of garlic for Andosols since it produced the maximum net return with benefit cost ratio of 6.44 (Table 9). However, the fertilizer N, P and S combinations at the rates of 92:40:30, 138:40:30 and 138:40:60 kg ha^{-1} had a promising effect on increasing the net returns over the remaining treatments with the higher benefit cost ratios on Vertisols even though the highest net return was recorded from plot treated with 138:40:60 kg ha^{-1} NPS (Table 9).

Table 9: Effect of different levels of nitrogen, phosphorus and sulphur fertilizers on cost of production, average yield, gross return, net benefit and benefit: cost ratio of garlic (var. Tseday) production on Andosols and Vertisols soil types

Fertilizers (kg ha^{-1})			Andosols						Vertisols					
N	P	S	Total cost that vary (Birr ha^{-1})	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1})	Gross return (Birr ha^{-1})	Net benefit (Birr ha^{-1})	Benefit cost ratio (B:C)	Total cost that vary (Birr ha^{-1})	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1})	Gross return (Birr ha^{-1})	Net benefit (Birr ha^{-1})	Benefit cost ratio (B:C)
0	0	0	7780	6530	5551	55510	47730	7.13	6065	4360	3706	37060	30995	6.11
		30	8700	6670	5670	56700	48000	6.52	8123	5940	5049	50490	42367	6.22
		60	10252	7610	6469	64690	54438	6.31	8174	4980	4233	42330	34156	5.18
	40	0	11842	8700	7395	73950	62108	6.24	8508	4480	3808	38080	29572	4.48
		30	13346	9580	8143	81430	68084	6.10	10716	6250	5313	53130	42414	4.96
		60	14212	9650	8203	82030	67818	5.77	11723	6500	5525	55250	43527	4.71
	80	0	16063	11070	9410	94100	78037	5.86	11504	5300	4505	45050	33546	3.92
		30	16366	10430	8866	88660	72294	5.42	12527	5570	4735	47350	34823	3.78
		60	16544	9630	8186	81860	65316	4.95	13344	5580	4743	47430	34086	3.55
92	0	0	13484	11080	9418	94180	80696	6.98	10032	6710	5704	57040	47008	5.69
		30	13829	10490	8917	89170	75341	6.45	12881	9290	7897	78970	66089	6.13
		60	14929	10860	9231	92310	77381	6.18	13855	9500	8075	80750	66895	5.83
	40	0	14710	9660	8211	82110	67400	5.58	13036	7540	6409	64090	51054	4.92
		30	19637	14870	12640	126400	106763	6.44	16651	11090	9427	94270	77619	5.66
		60	20216	14580	12393	123930	103714	6.13	17309	10900	9265	92650	75341	5.35
	80	0	17785	10580	8993	89930	72145	5.06	15187	7290	6197	61970	46783	4.08
		30	18193	10070	8560	85600	67407	4.71	18398	10330	8781	87810	69412	4.77
		60	20621	12120	10302	103020	82399	4.99	19894	11200	9520	95200	75306	4.79
138	0	0	12833	8920	7582	75820	62987	5.91	11632	7400	6290	62900	51268	5.41
		30	15089	10750	9138	91380	76291	6.06	13485	8720	7412	74120	60635	5.50
		60	15559	10320	8772	87720	72161	5.64	14035	8390	7132	71320	57285	5.08
	40	0	15284	9050	7693	76930	61646	5.03	13988	7410	6299	62990	49002	4.50
		30	17350	10640	9044	90440	73090	5.21	19633	13530	11501	115010	95377	5.86
		60	18468	11030	9376	93760	75292	5.08	21414	14760	12546	125460	104046	5.86
	80	0	18888	10640	9044	90440	71552	4.79	16059	7060	6001	60010	43951	3.74
		30	19753	10710	9104	91040	71287	4.61	19896	10890	9257	92570	72674	4.65
		60	20516	10650	9053	90530	70014	4.41	23565	14510	12334	123340	99775	5.23

Cost of TSP=11.50 Birr kg^{-1}; Urea=10.00 Birr kg^{-1}; Potassium sulphate=12.50 Birr kg^{-1}; Potassium chloride= 8.50 Birr kg^{-1} used for the adjustment of K in each treatment; Fertilizer application=120.00 Birr/100kg/ha; cost of harvesting and marketing (cleaning, curing and topping, packing) = 2 person day^{-1} at Birr 35.00 per person; packing & its material=4.00Birr/100kg; transportation=5.00Birr/100kg. At the time of dispatch, the price of 1kg garlic ranged from 10-25 Birr and the average (10 Birr kg^{-1}) was used for the calculations. Yield was adjusted by 15% reduction to compromise with the yield produced by farmers.

DISCUSSION

The physical and chemical analysis of the experimental fields showed that, the Andosols and Vertisols have low organic matter content, which is below the rate (3.74%) reported by Roy *et al*. (2006), indicating that low potential of the soils to supply N to plants since organic matter can be used as an index of N availability. Moreover, the organic matter and nutrient contents except K were low in both soils for optimum growth and increased yield and quality of the crop (Hazelton and Murphy, 2007). The exchangeable potassium values of the soils are also in accord with the ratings of Landon (1991) and that of Bashour (2001) cited in Bashour and Sayegh (2007). The higher sand content of Andosols is more important for bulb growth and easily expansion in the soil, but it has a characteristic of fixing nutrients particularly phosphorus, which led to unavailability of the nutrient for the crop (Wakene *et al*., 2002). Such findings further signified that the soils required external application of the certain nutrients according to the requirement of the crops. This confirmed the findings of Voncir *et al*. (2007) who reported that soil reaction has a great influence on the availability of plant nutrients, which is generally highest between pH 6.0 and 7.5. These properties indicated that the experimental soil had some limitations with regard to its use for crop production.

Application of inorganic N, P and S fertilizers significantly influenced the growth of plant height, leaf number, neck diameter and leaf area index of garlic, and better growth of these parameters were obtained at the rates of 92 kg N, 40 kg P and 30 kg S ha^{-1}, respectively. However, application of these fertilizers beyond these rates did not show a significant difference on many of these parameters at different growth stages. The increased growth and number of leaves in response to N application may be attributed to the role nitrogen plays in cell division, elongation and leaf growth as suggested by Hewitt and Smith (1974). Consistent with the results of this study, Kakar *et al*. (2002) and Kilgori *et al*. (2007) reported an increased garlic height and leaf number up to 100 kg N ha^{-1}. Similarly, Melaku (2010) found significantly higher growth of onion plant in response to the application of 120 kg N ha^{-1} and 40 kg P ha^{-1}. However, Grad *et al.* (1993) and Singh and Singh (1999) obtained the tallest garlic plants at the rates of 90 and 80 kg P ha^{-1}, respectively. In contrast, Gebrehaweria (2007) reported that P application did not significantly increase garlic plant height. Kesik *et al*. (2011) also reported that, N nutrition had no clear influence on morphological traits of garlic. Jana and Kabir (1990) reported that the tallest onion plants with the application of 30 kg S ha^{-1}. The present results are in conformity with the results of Farooqui *et al.* (2009) who reported that application of 60 kg S ha^{-1} significantly increased garlic plant height at 30 days after planting.

During the later growth stages, the enhanced plant height because of N fertilization could be ascribed to optimum nutrient supply and enhanced uptake for promoting different physiological processes that could have improved root growth, foliage growth, photo assimilation, and better growth of the crop. Similar results were observed by Mudziwa (2010) who reported that garlic plant height at 112, 140 and 175 days after planting increased significantly with the increase in the supply of ammonium sulphate and calcium nitrate from 50 to 200 kg ha^{-1}. The increase in plant height with the increased application of sulphur might be due to its role in the growth and physiological functioning of plants, thus improving its quality by increasing the dry matter contents of the crop (Barker and Pilbeam, 2007). Taller garlic plants were produced on Andosols at all growth stages than Vertisols except at 60 days after planting and the garlic plant height significantly increased up to 120 days after planting on Andosols, but on Vertisols a slight change was obtained after 90 days of growth, possibly because of higher nitrogen and phosphorus content of Andosols than Vertisols. Similarly, the tallest onion plants were produced on sandy loam soil as reported by Poornima (2007).

Soil types also significantly influenced plant height and leaf number per plant. Taller plant and many more leaves were produced on Vertisols at 60 days and on Andosols at 90 and 120 days after planting the crop. This indicated that during the later growth stages, at the time of optimum nutrient uptake of plants, Andosols had more conducive soil physic-chemical properties than Vertisols to supply optimum amount of nutrients for the crop. However, earlier crop growth stages, Vertisols may provide a better soil condition for growth of the plant particularly through its better supplying power of moisture to the plant than Andosols. This in turn, may enhance the nutrient uptake of the young plants.

The significant increment in neck diameter at the latter growth stages might be due to increased nutrient uptake capacity of roots and P availability, resulting from applied nutrients. Neck diameter of garlic is an important parameter that determines the uptake of available macronutrients in the soil for its production (Potgieter, 2006). Mudziwa (2010) also reported that garlic plant height and neck diameter were significantly increased along with growth stages from 54 to 175 days after planting with the increase in the rate of ammonium sulphate and calcium nitrate from 50 to 200 kg ha^{-1} application. The results of the present study are also in conformity with the findings of Syed *et al.* (2000) and Melaku (2010) who reported that increasing the rate of nitrogen up to 120 kg ha^{-1} resulted in greater thick neck onion bulbs. Thick neck of bulbs usually occurs when a proportion of bulbs fail to complete bulb formation in which the leaves continue growing (Lemma and Shimeles, 2003), due to added nitrogen which facilitates more cell division and thus results in continued growth of leaves that keeps the neck wide.

Leaf area index is a very good indicator of a plant's photosynthetic capacity and is very important in determining the levels of photosynthetic activity and yield. The LAI growth is influenced by many factors, of which plant density (Moravcevic *et al*., 2011) and fertilization with balanced nutrients are the foremost to obtain favourable growth and high yields with good quality (Dawar *et al*., 2005). In this study, all the fertilizers applied had positive influence on the leaf area index particularly at late growth stages. Application of N improved the leaf area index as it might have played an important role in plant photosynthesis (Murata, 1969). Availability of optimum N, especially at optimum growth stages, with other fertilizers increases the photosynthetic rate of plant, as it increases the chlorophyll content of plant cells (Girarden *et al*., 1985). Application of P and S fertilizers significantly increased the LAI of plant without significant differences observed due to the application of 40 and 80 kg P ha^{-1}, and 30 and 60 kg S ha^{-1}. This indicated that application of 40 kg P ha^{-1} and 30 kg S ha^{-1} to the crop along with optimum nitrogen level led to produce good leaf area index of the crop.

The applied fertilizers significantly influenced bulb yield and yield components. The main effect of nitrogen, phosphorus and sulphur significantly influenced the mean clove weight on both soil types with heavier cloves at the rates of 92 kg N ha^{-1}, 40 kg P and 30 kg S ha^{-1}. The increased clove weight with the application of N, P and S on both soils might be due to enhanced uptake of the nutrients and the production and translocation of higher dry matter to the cloves. The clove weight advantage was achieved through greater nutrients uptake as S application may have improved the nutrient use efficiency of the garlic plants; as a result of synergistic effect between S and N, P, and K nutrients, resulting in increased crop product quality and marketability, which might have led to the increased clove weights (Kumar and Singh, 1994; Fan and Messick, 2007). The interactions of N and P as well as P and S also significantly affected the mean clove weight of garlic on Andosols. The clove weights may have been increased due to availability of N as well as S along with P for the uptake by the plants, whereby the nutrients may have improved the vegetative growth and accelerated translocation of photosynthates in storage organs of bulbs, resulting in an increased diameter and weight of the bulb through the synergistic effect of nutrients as also suggested by Sharma (1992). Similarly, development of lateral roots and fibrous rootlets, which are responsible for nutrients uptake from the soil, might have been encouraged by phosphorus as availability of P with both N and S nutrients increased markedly the mean clove weight as also reported by Barker and Pilbeam (2007).

Bulb weight, bulb diameter, harvest index and biological yield were significantly affected by the three way interaction of N, P and S fertilizers on both soil types. This may have attributed to the synergistic role played by the three nutrients in providing balanced supply of nutrients to the crop. This is consistent with the findings of (Amin *et al*., 2007) who observed that application of 100 kg N, 80 kg P and 30 kg S ha^{-1} along with 50 kg K ha^{-1} significantly increased yield components of weight of onion over the lower rates and control treatment. Higher rate of nitrogen (138 kg N ha^{-1}) was required on Vertisols than on Andosols to produce higher bulb weight and diameter, and biological yield. This seemed that increasing the amount of nutrients on nutrient deficient Vertisols increased both overall growth of the crop and allocation of the produced organic food to both leaf and bulb growth, which led to increase in bulb yields. The bulb weight obtained on Andosols was not significantly increased over that of Vertisols, which is supported by the result obtained by Nori *et al*. (2012), who reported that with high levels of nitrogen and organic matter, nutrient allocation to leaf production and vegetative growth reduced growth and weight of garlic bulb. This result is also in agreement with the findings of Gebrehaweria (2007) and Islam *et al.* (2007) who obtained the heaviest bulb of garlic with the application of 120:60 and 120:92 kg NP ha^{-1}, respectively. The increase in garlic bulb diameter and harvest index was due to the cumulative effect of N and P on the growth and dry matter production, which is also supported by the report of Gebrehaweria (2007), who indicated that significantly increased garlic bulb diameter in response to a combined application of N and P up to the rates of 120 kg N and 60 kg P ha^{-1}. Consistent with the results of this study, Nasreen *et al*. (2007) and Melaku (2010) reported that there were significant increases in diameter and weight of onion bulbs due to application of nitrogen up to 120 and 80 kg ha^{-1}, respectively.

Higher production of biological yield on Vertisols than Andosols might be attributed to suppression of bulb growth on the former than the latter whereby more biomass may have been produced at the expense of bulbs. This is consistent with the results of Agbede and Adekiya (2009) who reported that planting sweet potato on loose sandy-loam soil on ridges rather than on flat compact soil led to increased production of biomass but reduced production and bulking of tuberous roots of the crop. Similarly, the heavy Vertisols that have compact structure may have depressed the sink strength of the garlic crop thereby reducing translocation of carbohydrate to the bulbs and re-directing it rather to the shoots, thereby increasing biomass production at the expense of bulbs. Nitrogen application at the highest level in combination with P and S played a prominent role in increasing harvest index of the crop, and the Vertisols responded to the highest level of P fertilizer to produce highest harvest index. Application of balanced amount of N, P and S have a cumulative positive effect on crop growth, as nitrogen improves the vegetative growth and accelerates the photosynthates in storage organs of bulbs resulting in an increased diameter and weight of the bulb (Sharma, 1992). In addition, phosphorus encourages the growth of lateral roots and fibrous rootlets that facilitates nutrient uptake (Barker and Pilbeam, 2007), and sulphur facilitates the uptake of other nutrients by the crop (Tisdale and Nelson, 1985).

The higher bulb yields obtained from Vertisols in response to 138 kg N ha^{-1} + 40 kg P ha^{-1} along with 30 or 60 kg S ha^{-1} exceeded the lowest bulb yield obtained from the same soil at 0 kg NPS ha^{-1} by about 210% and 238%, respectively. Similarly, the higher bulb yields obtained from Andosols at 92 kg N + 40 kg P ha^{-1} along with 30 or 60 kg S ha^{-1} exceeded the one obtained from the same soil in the control plot by about 112% and 123%, respectively. This yield advantage achieved appeared to be through greater nutrient uptake by garlic plants, resulting in an increased diameter and weight of cloves that cumulatively increased the total bulb yield because of balanced nutrition. Similarly, Amin *et al*. (2007) reported that onion yield and its profit were maximized by the nutrient doses of 107-72-90-33 and 95-50-70-32 kg NPKS ha^{-1}, respectively.

The results showed that combining the three nutrients had synergistic effect on garlic bulb yields perhaps through enhanced balanced nutrition of the three major nutrients. The results also indicated that the Andosols required less level of the combined fertilizers to produce higher yields than Vertisols. This could also be attributed to the overall good soil texture and structure of Andosols for growth of plants as suggested by Amberger (2006). Moreover, the increase in bulb yield with application of higher levels of S might be due to increased uptake of N, P, K and S by the crop which may have enhanced the synthesis of assimilate and its allocation to the bulbs. Generally, the availability of one nutrient influences the availability and up-take of other nutrients, which interact to enhance growth and yields of the crop. According to the report of Reddy *et al*. (2000), the interaction of N and P produced higher garlic yield (11.19 t ha^{-1}) than the yield obtained due to N alone (10.75 t ha^{-1}) and P alone (7.46 t ha^{-1}). Similarly, the combined application of 120 kg N + 22 kg P ha^{-1} resulted in good yield of garlic (Kilgori *et al*., 2007). Consistent with the results of this study, Nasreen and Hossain (2004) reported significantly increased onion bulb yields with the application of 100 kg N + 44 kg P + 83 kg K + 20 kg S + 5 kg Zn ha^{-1}. Similarly, Nasreen *et al*. (2007) obtained the highest onion yields in response to the combined application of 120 kg N + 40 kg S ha^{-1} with a blanket dose of 40 kg P, 75 kg K, 5 kg Zn ha^{-1} and 5 t ha^{-1} of cow manure.

The result of correlation analysis on both Andosols and Vertisols indicated that growth and yield parameters had a positive and significant correlation with each other. As the growth of garlic height, neck diameter, and leaf area index become increased, the bulb weight and yield components of garlic bulb also increased on both soil types; which indicated that as the nutrient uptake increases both the yield and yield components of the crop increased. In addition, application of sulphur along with both nitrogen and phosphorus significantly increased the growth and yield attributes of bulb on both soils. Thippeswamy (1993), and Nasreen and Hossain (2004), also observed a similar increase of onion bulb qualities, as fertilization of the crop with sulphur fertilizer significantly improved the pungency, TSS and protein contents of the bulbs.

CONCLUSIONS

From the results of this study, it may be inferred that the growth, yield and yield attributes of garlic bulbs increased significantly with the application of NPS and with further increased growth stages of the plant, especially after 60 days of growth. Soil types also significantly influenced the growth parameters of garlic at different stages of the plant growth. The combined application of fertilisers significantly improved the relationships between the growth and yield attributes on both Andosols and Vertisols of the area. The growth, yield and economic potential of garlic were increased in response to the combined application of 92 kg N + 40 kg P + 30 kg S ha^{-1} with a benefit cost ratio of 6.44:1 on Andosols and 138 kg N + 40 kg P + 60 kg S ha^{-1} with a benefit cost ratio of 5.86:1 on Vertisols. It could thus be concluded that application of 92 kg N + 40 kg P + 30 kg S ha^{-1} on both soils are optimum and economical to attain maximum productivity of the crop for enhanced household income and livelihoods of the farmers in the study area.

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Conflict of Interest

Authors declared no conflict of interest.

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