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Bulb quality of Garlic (*Allium sativum* L.) as influenced by the application of inorganic fertilizers

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Garlic is an important cash crop for smallholder farmers in Ethiopia. Bulb quality is an important attribute that adds to the use and marketability of the crop. However, garlic bulb quality is constrained by several factors in the country among which imbalanced and low availability of nutrients in the soil is prominent. Therefore, a study was conducted on two soil types (Andosol and Vertisol) with the objective of elucidating the effect of nitrogen, phosphorus, and sulphur application on the quality of the crop. The treatments consisted of three levels of nitrogen (0, 92, 138 kg N ha^{-1}), three levels of phosphorus (0, 40, 80 kg P ha^{-1}), and three levels of sulphur (0, 30, 60 kg S ha^{-1}). The experiment was laid out as a randomized complete block design in a factorial arrangement with three replications on each soil type. The results revealed that the main as well as the interaction effects of N, P, and S fertilizers on both soil types significantly ($P \leq 0.05$) influenced bulb quality, namely, dry matter percentage, total soluble solids, pungency, bulb protein content, and bulb weight loss in storage, and concentrations of major nutrients in the bulb tissues. The bulb quality indices studied on both soil types correlated positively and significantly with each other but had a negative correlation with bulb weight loss. This result indicates favorable effects of integrated application of nitrogen, phosphorus and sulphur on garlic bulb quality. Combined applications of 92 kg N + 40 kg P + 30 kg S ha^{-1} and 138 kg N + 40 kg P + 60 kg S ha^{-1} led to the attainment of optimum bulb quality attributes on Andosol and Vertisol, respectively. However, it was application of 92 kg N + 40 kg P + 30 kg S ha^{-1} that was found to be economical for farmers.

Key words: Andosol, bulb quality, inorganic fertilizer, nutrient concentration, soil type, Vertisol.

INTRODUCTION

The composition of a garlic bulb varies greatly depending on cultivar, agronomic practices, climate, soil fertility, and postharvest storage conditions that determine the quality and intensity flavor as well as nutritional and nutraceutical values of the crop. Soil nutrient management plays a significant role in improving productivity and quality of crops (Zhou et al., 2005). Garlic (*Allium sativum* L.), is a nutrient exhaustive crop and removes a good amount of nitrogen, phosphorus, and sulphur from the soil. Uptake of sufficient nutrient by the garlic crop is important to improve growth, yield and marketable proportions as well as quality of the crop (Nai-hua et al., 1998).

Different types of soils have different characteristics that influence growth and yield of crops. Both macro and micro-nutrients have various levels of availability in different soils and their removal by different crops varies

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at different seasons and areas (Teklu et al., 2004). Kakara et al. (2002) reported that N accounts for a higher percentage of variation in plant height, leaf area, leaf count, and fresh and dry plant mass when its application increased from 50 to 200 kg ha^{-1}.

Garlic growers in the central high lands of Ethiopia tend to rely on fertilizer sources that contain only nitrogen (N) and phosphorus (P), resulting in steady decline in other nutrients in the soil. Smaller potassium (K) and sulphur (S) uptake relative to N uptake can predispose the crop to serious disease and insect damage (ENAIA, 2003).

Balanced fertilizer application is essential for the vegetative growth and, thus, for producing crops with top quality and high yields especially on soils that are cultivated continuously. Improved management of nitrogen, phosphorus, potassium and other inputs in the soil could improve yields and quality of vegetables and other crops (Nai-hua et al., 1998). According to these authors, fertilizer management practices should balance the supply of N, P and K as well that other nutrients based on soil test results. However, most Ethiopian soils, except those found in areas with high precipitation that have acidic reaction have sufficient levels of available potassium (Murphy, 1968). Therefore, deficiencies of N, P, and S are likely to be a major constraint to garlic production in the country. The present investigation was carried out to assess the effect of nitrogen, phosphorus and sulphur rates on the quality of garlic bulb grown on an Andosol and a Vertisol soils.

MATERIALS AND METHODS

The study was undertaken in the research field of Debre Zeit Agricultural Research Centre, in Ethiopia on two dominant soil types, namely, Andosol and Vertisol. The site is located at 08°44"N latitude, 38°58"E longitude, and at the altitude of 1860 meters above sea level. The study area is characterized as sub-humid tropical climate (DZARC, 2011). Using garlic cultivar Tseday, the study was conducted during the 2011 main rainy season from July to November. Laboratory analysis of the Vertisol (black clay soil that expands when wet and contracts or cracks when dry) of the experimental site revealed that the plough-layer soil texture was clay-loam. The test also indicated that the soil had organic matter organic matter content of 1.40%, total nitrogen content of 0.036%, available phosphorus content of 14.48 ppm, available soluble SO_4-S content of 19.2 mg kg^{-1} soil, exchangeable potassium content of 1.47 Cmol(+) kg^{-1} and a pH value of 6.91. The soil analysis showed that the Andosol (light volcanic ash soil) had a sandy-loam texture with organic matter content of 2.23%, total nitrogen content of 0.063%, available phosphorus content of 41.51 ppm, soluble SO_4-S content of 13.4 mg kg^{-1}, exchangeable potassium content of 2.55 Cmol(+) kg^{-1} and a pH value of 7.17. According to Landon (1991), the organic matter and total nitrogen contents of both soil types were very low; the available phosphorus content of the Vertisol was medium whereas that of the Andosol was high (Bashour, 2001 in Bashour and Sayegh, 2007). According to this author the soluble sulphate contents of both boils were low, and the exchangeable potassium contents of both soils were very high (Landon, 1991; Hazelton and Murphy, 2007).

The treatments consisted of three levels of nitrogen (0, 92 and 138 kg N ha^{-1}), three levels of phosphorus (0, 40 and 80 kg P ha^{-1}) and three levels of sulphur (0, 30 and 60 kg S ha^{-1}). The experiment was laid out as a randomized complete block design in a factorial arrangement with three replications on each soil type. Garlic cloves of a cultivar named 'Tseday' were planted on 1 July 2011 on a ridge with the spacing of 30 cm between rows and 10 cm between plants. Applications of all rates of the phosphorus and sulphur fertilizers were made at planting in the form of triple super phosphate (46% P_2O_5) and potassium sulphate (43% K and 18% S). The potassium applied disproportionately to each plot according to the rate of the potassium sulphate required was balanced by applying equivalent amounts of potassium from potassium chloride (40% K) fertilizer. Nitrogen in the form of urea (46% N) was applied ¼ at planting, while the remaining ½ and ¼ were side-dressed three and six weeks, respectively, after plant emergence. Supplemental irrigation of water was applied twice a week after the rains ceased falling in September-October. Other recommended horticultural practices were performed uniformly to the plots of both sites as per the recommendation of the area (Getachew and Asfaw, 2000).

Garlic bulbs were harvested on 25 November 2011 and cured for ten days in an ambient environmental condition under shade in windrows. Bulb quality parameters were determined following the procedure of Bussard and Randle (1993) for pungency, and Waskar et al. (1999) for total soluble solids (TSS). To determine bulb dry matter, cloves from five bulbs were chopped into small 1-2 cm cubes, mixed thoroughly, and the exact weight of each sample was determined and recorded as fresh weight. Duplicate samples were each placed in paper bags and dried in an oven for 48 h at 65°C. Each sample was immediately weighed and recorded as dry weight. Percent dry matter content for each sample was calculated using the following formula: dry matter = (dry weight / fresh weight) x 100. The weight loss percentage of bulbs was calculated after three months of storage which is a factor of the differences between the initial and final weight divided by its initial weight multiplied by 100. Protein contents of garlic bulbs were determined in terms of the garlic bulbs nitrogen content (Nitrogen x 6.25) (AOAC, 1994).

Concentrations of nutrients, namely, nitrogen, phosphorus, potassium, and sulphur were analysed from matured bulbs. Five clean sample bulbs from each plot were collected randomly. The cloves were ground, and oven dried at 65°C for 48 h. The finely ground and dried tissues were wet digested as described by Wolf (1982). Total N was determined using the modified micro Kjeldhal method (Cottenie et al., 1982) and P by colorimetric method using spectrophotometer (Olsen et al., 1954). Potassium content was measured using a flame photometer method as described by Chapman and Pratt (1982). The sulphur content was determined turbidmetrically using a spectrophotometer method (Singh et al., 1999). The data obtained were subjected to analysis of variance using SAS statistical software version 9.0 and treatment effects were compared using the Fisher's Least Significant Differences test at 5% level of significance. Moreover, simple correlation analysis was done to reveal the magnitudes and directions of relationships between selected quality parameters and chemical contents of the crop.

RESULTS

The main effect of nitrogen significantly ($P \leq 0.01$) influenced all quality parameters of the garlic crop, that is, bulb dry matter, total soluble solids (TSS), pungency, protein content, and percent weight loss of garlic bulb on both soils except the dry matter on Vertisol. The main effect of phosphorus significantly ($P \leq 0.05$) influenced all quality parameters except protein content and bulb weight loss on both soils. Also the main effect of sulphur

Table 1. Mean square values for quality attributes of garlic bulb as affected by the main and interaction effects of inorganic nitrogen (N), phosphorus (P) and sulphur (S) fertilizers on two soil types.

Parameter	Soil	N (2)	P (2)	S (2)	N x P (4)	N x S (4)	P x S (4)	NxPxS (8)
Dry matter	Andosol	704.25***	264.91**	182.78**	49.74^{ns}	56.56^{ns}	52.55^{ns}	62.37*
	Vertisol	2.99^{ns}	28.96**	24.02**	4.38^{ns}	41.27***	6.13^{ns}	5.95*
TSS	Andosol	29.42**	12.21*	4.86^{ns}	4.59^{ns}	3.86^{ns}	10.94*	8.61*
	Vertisol	21.34**	14.76**	7.07*	7.60**	10.60*	12.32**	10.68**
Pungency	Andosol	129.34***	16.04***	119.22***	7.88**	16.81***	13.53***	18.40***
	Vertisol	34.09***	20.23***	155.12***	10.42***	2.16**	22.09***	10.17***
Protein	Andosol	66.19***	1.91^{ns}	0.277^{ns}	9.05**	3.88*	10.88***	3.74**
	Vertisol	70.89***	0.20^{ns}	1.93^{ns}	3.10*	1.60^{ns}	3.91*	2.60*
Weight loss	Andosol	54.71***	1.85^{ns}	64.27***	35.86**	45.83***	43.22***	38.38***
	Vertisol	144.84***	16.26^{ns}	28.45*	33.15**	6.29^{ns}	11.34^{ns}	25.27**
Nitrogen	Andosol	1.69***	0.049^{ns}	0.007^{ns}	0.232**	0.099*	0.279***	0.096**
	Vertisol	1.82***	0.0051^{ns}	0.049^{ns}	0.079*	0.041^{ns}	0.1004*	0.067*
Phosphorus	Andosol	0.008**	0.003*	0.001^{ns}	0.003*	0.004**	0.0022*	0.0015*
	Vertisol	0.042***	0.096***	0.0031^{ns}	0.017***	0.012***	0.011**	0.011***
Potassium	Andosol	0.114**	0.019^{ns}	0.0099^{ns}	0.007^{ns}	0.033^{ns}	0.022^{ns}	0.058**
	Vertisol	0.899***	0.637**	0.058^{ns}	0.191*	0.340**	0.226**	0.148*
Sulphur	Andosol	0.018**	0.115***	0.042***	0.029***	0.029***	0.094***	0.024***
	Vertisol	1.908***	0.797***	2.528***	1.090***	1.148***	0.569***	0.556***

Where, *, ** and *** shows significant difference at P = 0.05, 0.01 and 0.001 P, respectively; ns = non-significant; TSS = Total soluble solids; number in brackets are degrees of freedom.

influenced the parameters except bulb protein content on both Andosol and Vertisol soils and TSS on Andosol (Table 1). In addition, the one-way interaction effect of N and P significantly affected the garlic bulb pungency, protein and weight loss except TSS on Andosol and dry matter on both soils, and the interaction of N and S significantly affected all these parameters except dry matter and TSS on Andosol and protein and weight loss on Vertisol. Also the one-way interaction effect of P and S significantly influenced bulb qualities of garlic except dry matter on both soils and weight loss on Vertisol. Similarly, the two-way interaction effect of N x P x S significantly influenced dry matter, TSS, pungency, protein and weight loss of garlic bulbs (Table 1).

Dry matter percentage

The application of nitrogen and phosphorus at the rates of 92 kg N ha^{-1} + 40 kg P ha^{-1} along with both 30 and 60 kg S ha^{-1} on Andosol led to the production of significantly higher bulb dry matter contents (51.06 and 52.16%) compared to the other treatments. However, the highest bulb dry matter was obtained from the plants fertilized by the combined application of 0 kg N + 80 kg P + 30 kg S ha^{-1} on Vertisol (Table 2). The lowest dry matter contents were obtained from the control treatment on both soils. The increase of bulb dry matter on Andosol and Vertisol due to the combined application of 92 kg N + 40 kg P + 30 kg S ha^{-1} amounted to 121% and 28% compared to the lowest dry matter produced on the respective control plots. The bulb dry matter produced on Andosol in response to the combined application of these rates of N, P and S was higher by 35% than the dry matter of bulb produced on Vertisol. However, soil type did not significantly influence the dry matter content of bulbs (Table 7).

Total soluble solids

The application of N, P and S fertilizers significantly (P ≤

Table 2. The interaction effect of N, P and S on dry matter content (%) of garlic bulb on both Andosol and Vertisol soil types.

Fertilizer		Dry matter (%)					
		Soil type					
		Andosol			Vertisol		
		S (kg ha^{-1})			S (kg ha^{-1})		
N (kg ha^{-1})	P (kg ha^{-1})	0	30	60	0	30	60
0	0	23.08^{g}	35.62^{c-e}	26.22^{fg}	29.52^{g}	37.62^{a-e}	36.79^{b-f}
	40	33.08^{ef}	35.48^{c-e}	29.42^{e-g}	34.17^{f}	37.20^{a-f}	39.49^{a-c}
	80	35.12^{c-e}	29.49^{e-g}	31.10^{e-g}	34.35^{f}	40.07^{a}	38.37^{a-e}
92	0	35.26^{c-e}	36.49^{c-e}	34.65^{d-f}	37.05^{a-f}	36.73^{c-f}	34.30^{f}
	40	35.40^{c-e}	51.06^{a}	52.16^{a}	39.96^{ab}	37.78^{a-e}	36.35^{c-f}
	80	35.85^{c-e}	47.52^{ab}	41.86^{b-d}	37.03^{a-f}	35.96^{d-f}	37.91^{a-e}
138	0	35.63^{c-e}	36.20^{c-e}	35.62^{c-e}	35.58^{ef}	36.40^{c-f}	36.67^{c-f}
	40	33.07^{ef}	43.65^{a-c}	41.81^{b-d}	38.97^{a-d}	38.26^{a-e}	36.53^{c-f}
	80	36.38^{c-e}	34.18^{d-f}	34.11^{d-f}	35.36^{ef}	38.83^{a-d}	35.84^{d-f}
	LSD = 8.64; CV(%) = 14.48				LSD = 3.21; CV(%) = 4.09		

Means followed by the same letter within a column are not significantly different at 5% (*) or 1% (**) levels of significance; CV = Coefficient of variation; LSD = Least significant differences.

Table 3. The interaction effect of N, P and S fertilizers on total soluble solids of garlic bulb on both Andosol and Vertisol soil types.

Fertilizer		Total soluble solids (^{0}Brix)					
		Soil type					
		Andosol			Vertisol		
		S (kg ha^{-1})			S (kg ha^{-1})		
N (kg ha^{-1})	P (kg ha^{-1})	0	30	60	0	30	60
0	0	14.27^{d}	22.45^{a-c}	20.80^{bc}	14.13^{d}	23.73^{ab}	21.73^{a-c}
	40	22.00^{a-c}	21.65^{a-c}	21.89^{a-c}	22.59^{a-c}	23.47^{a-c}	21.33^{bc}
	80	22.53^{ab}	21.44^{a-c}	20.05^{c}	23.63^{ab}	22.77^{a-c}	21.95^{a-c}
92	0	22.93^{ab}	22.32^{a-c}	21.60^{a-c}	22.93^{a-c}	22.43^{a-c}	22.08^{a-c}
	40	22.40^{a-c}	23.39^{a}	22.27^{a-c}	23.68^{ab}	20.59^{c}	21.25^{bc}
	80	22.93^{ab}	23.20^{ab}	23.07^{ab}	23.01^{a-c}	23.65^{ab}	23.87^{ab}
138	0	21.33^{a-c}	23.33^{a}	22.05^{a-c}	23.01^{a-c}	23.65^{ab}	22.99^{a-c}
	40	23.25^{a}	22.43^{a-c}	23.39^{a}	23.63^{ab}	24.53^{a}	22.40^{a-c}
	80	23.07^{ab}	21.92^{a-c}	21.73^{a-c}	23.81^{ab}	23.87^{ab}	23.44^{a-c}
	LSD = 2.40; CV(%) = 7.23				LSD = 2.94; CV(%)= 5.44		

Means followed by the same letter within a column are not significantly different at 5% (*) or 1% (**) levels of significance; CV = Coefficient of variation; LSD = Least significant differences.

0.01) influenced the total soluble solids (TSS) of garlic bulb on both soils with higher TSS at all combined applications of the fertilizers except lowest result (14.27 and 14.13 °Brix) was obtained from bulbs produced without any of fertilizer application on Andosol and Vertisol, respectively (Table 3). The highest TSS produced in response to the combined application of 92 kg N + 40 kg P + 30 kg S ha^{-1} and 138 kg N + 40 kg P + 30 kg S ha^{-1} was exceeded the TSS obtained in response to the unfertilized plots by about 64% and 73% on

Table 4. Interaction effect of inorganic nitrogen (N), phosphorus (P) and sulphur (S) fertilizers on bulb pungency of garlic cultivated on Andosol and Vertisol soil types.

Fertilizer		Pungency (µ.mol ml^{-1})					
		Soil type					
		Andosol			Vertisol		
		S (kg ha^{-1})			S (kg ha^{-1})		
N (kg ha^{-1})	P (kg ha^{-1})	0	30	60	0	30	60
0	0	2.27^{l}	5.20^{hj}	7.20^{ef}	2.13^{k}	4.13^{hj}	7.33^{df}
	40	5.53^{gi}	2.93^{kl}	2.87^{kl}	5.40^{gi}	8.00^{cd}	9.53^{bc}
	80	4.07^{jk}	8.93^{cd}	5.93^{fh}	2.87^{jk}	5.73^{fh}	7.07^{dg}
92	0	6.33^{fh}	9.87^{bc}	8.13^{de}	6.60^{dg}	6.40^{dg}	7.00^{dg}
	40	4.00^{jk}	13.53^{a}	13.00^{a}	3.80^{ik}	7.87^{ce}	10.00^{b}
	80	5.47^{gi}	12.53^{a}	10.80^{b}	3.13^{jk}	11.13^{ab}	12.33^{a}
138	0	6.27^{fh}	5.93^{fh}	4.20^{ik}	6.33^{dg}	7.53^{de}	7.93^{cd}
	40	3.53^{kl}	6.60^{fg}	10.00^{bc}	6.20^{eg}	7.33^{df}	12.67^{a}
	80	3.07^{kl}	9.73^{bc}	8.73^{cd}	3.33^{jk}	11.80^{a}	7.74^{de}
		LSD = 1.35; CV(%)= 13.46			LSD = 1.53; CV(%)= 8.30		

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 differences.

Andosol and Vertisol, respectively (Table 3). The total soluble solids produced in bulbs fertilized with N, P and S was only significantly differed from the unfertilized bulb content. The bulb TSS content was significantly differed due to soil type with a slight increase in TSS of bulbs produced on Vertisol as compared to those produced on Andosol (Table 7).

Pungency

Significant differences in pyruvate content of garlic bulbs were recorded with varying levels of N, P and S application on both Andosol and Vertisol soil types. All the main and interaction effects of the applied factors significantly ($P \leq 0.01$) influenced the pyruvate content of garlic bulb on both soils (Tables 1 and 4). Thus, application of N, P and S fertilizers at the combined rates of 92 kg N + 40 kg P + 30 kg S ha^{-1}, 92 kg N + 40 kg P + 60 kg S ha^{-1} and 92 kg N + 80 kg P + 30 kg S ha^{-1} on Andosol (13.53, 13.00 and 12.53 µ.mol ml^{-1}, respectively) led to the production of bulbs with the highest pungency. Bulbs with the lowest pungency were produced in the control plots. The pyruvate contents obtained at these combined rates of fertilizers exceeded the lowest pyruvate content produced in the control plot of the same soil by 496, 472 and 452%, respectively. On the other hand, the higher pyruvate contents on Vertisol was produced in response to the combined application of 138 kg N + 40 kg P + 60 kg S ha^{-1}, 92 kg N + 80 kg P + 60 kg S ha^{-1} and 138 kg N + 80 kg P + 30 kg S ha^{-1} (12.67, 12.33 and 12.67 µ.mol ml^{-1}, respectively), and the lowest was noticed in control plot (2.13 µ.mol ml^{-1}) on the same soil (Table 4). However, no significant difference in pungency content was observed in garlic bulb due to soil type (Table 7).

Protein content

Protein content of garlic bulbs was significantly ($P \leq 0.05$) influenced by the three factors interaction effect of N, P and S on both soils (Table 5). The smallest protein contained bulbs were produced on the control plot of Andosol and plot treated with 0 kg N+ 80 kg P + 0 kg S ha^{-1} on Vertisol. The highest protein content in garlic bulbs were produced in treatment that received 138 kg N + 80 kg P + 0 kg S ha^{-1} on Andosol and 138 kg N + 80 kg P + 30 kg S ha^{-1} on Vertisol. The highest protein content of bulbs produced by these two combination rates were increased by 124% and 50% over those produced on the control plot on both soils, respectively. Soil type had also significant influence on bulb protein content and the higher protein content which improved by 14.54% was recorded in bulbs produced on Andosol as compared to those produced on Vertisol (Table 7).

Percent weight loss

The percent weight loss (PWL) of garlic bulb in storage, grown on both Andosol and Vertisol soils, significantly (P

Table 5. Interaction effect of inorganic nitrogen (N), phosphorus (P) and sulphur (S) fertilizers on garlic bulb protein content at harvest cultivated on Andosol and Vertisol soils.

		Protein content (%)					
		Soil type					
		Andosol			Vertisol		
Fertilizer		S (kg ha^{-1})			S (kg ha^{-1})		
N (kg ha^{-1})	P (kg ha^{-1})	0	30	60	0	30	60
0	0	7.94^{k}	12.58^{j}	13.44^{hj}	10.56^{il}	11.04^{hl}	12.17^{ei}
	40	14.23^{di}	12.44^{j}	13.55^{gj}	10.11^{kl}	10.13^{jl}	10.46^{il}
	80	13.40^{ij}	13.38^{ij}	12.48^{j}	9.61^{l}	11.13^{hl}	11.42^{gk}
92	0	14.46^{di}	14.40^{di}	14.94^{ch}	13.09^{bg}	13.19^{bf}	12.09^{ei}
	40	14.75^{ci}	15.48^{cd}	16.02^{bc}	13.67^{be}	11.84^{fg}	14.42^{ac}
	80	15.02^{cg}	13.88^{fj}	14.11^{di}	12.09^{ei}	13.48^{bf}	12.56^{dh}
138	0	15.19^{cf}	17.36^{ab}	16.02^{bc}	12.98^{cg}	12.55^{dh}	14.14^{ad}
	40	15.27^{cf}	14.96^{cg}	13.92^{ej}	14.73^{ab}	14.73^{ab}	13.11^{bg}
	80	17.81^{a}	15.40^{ce}	14.83^{ci}	13.10^{bg}	15.81^{a}	13.92^{bd}
		LSD = 1.47; CV(%)= 6.52			LSD = 1.73; CV(%)= 7.79		

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 differences.

≤ 0.01) influenced by the interaction of the applied N, P and S fertilizers (Table 6). The PWL of stored garlic bulbs varied from 8.26 to 26.27% for garlic plants grown on Andosol and from 8.17 to 21.34% for those grown on Vertisol due to the applied fertilizers. Highest weight loss was recorded on bulbs fertilized with 0 kg N + 80 kg P + 30 kg S ha^{-1} on both soils and in addition with 0 kg N+ 80 kg P+ 60 kg S ha^{-1} combination on Vertisol, while the lowest losses in weight were recorded on bulbs produced by the combined application of 92 kg N + 40 kg P + 60 kg S ha^{-1} on both soils (Table 6). Majority of the treatment interactions showed lower weight losses while the highest losses were recorded in the absence or expense of one element over the other fertilizers.

The bulbs produced by the combined application of 92 kg N + 40 kg P + 30 kg S ha^{-1} improved the shelf- life of garlic bulbs by reducing their weight losses by about 206% and 48% on Andosol and Vertisol, respectively as compared to the bulbs fertilized with 0 kg N + 80 kg P + 30 kg S ha^{-1} (Table 6). Soil type was significantly influenced the bulb weight loss. Thus, the mean value of bulb weight loss was increased by 18% due to the plants produced on Vertisol as compared to those produced on Andosol (Table 7).

Nutrient concentration of garlic bulb

The main and interaction effects of N, P and S fertilizer were significantly influenced the bulb nitrogen concentration of garlic except the main effect of P and S on both soils and the interaction effect of N and S on Vertisol. Similarly, all the main and interaction effects of these fertilizers were significantly influenced phosphorus concentrations in bulb tissue produced on both soils except the main effect of sulphur fertilizer. However, the concentration of potassium in bulb tissue was significantly influenced only by both the main effect of nitrogen and the three factors interaction effect of N, P and S on Andosol, but the main effect of N and P, and all the interactions of the applied fertilizers significantly influenced it on Vertisol. Also, the sulphur concentrations in garlic bulb tissues were significantly influenced by the all main and interaction effects of N, P and S fertilizers on both soils. In addition, the three factors interaction effect of the applied fertilizers was significantly influenced all the nutrients content in bulbs (Table 1).

The interaction of N, P and S fertilizers had significant (P ≤ 0.01) effect on N content of garlic bulbs on both soil types, with the highest N content in garlic bulb (2.85%) obtained from the plant treated with 138 kg N + 80 kg P + 0 kg S ha^{-1} combination followed by 138 kg N + 0 kg P + 30 kg S ha^{-1} (2.78%) and lowest from control plot (1.27%) on Andosol (Table 8). At these two combination rates on average the nitrogen content in bulb increased by about 124 and 119%, respectively over the lowest N content recorded from control plot on the same soil. At these combination rates, the N content recorded in garlic bulb on Andosol exceeded those obtained on Vertisol by about 36 and 38%, respectively (Table 8).

The highest N content of garlic bulb produced on Vertisol in response to 138 kg N + 80 kg P + 30 kg S ha^{-1}

Table 6. Interaction effect of inorganic nitrogen (N), phosphorus (P) and sulphur (S) fertilizers on weight loss of garlic bulb after three months of storage cultivated on Andosol and Vertisol soil types.

Fertilizer		Storage weight loss (%)					
		Soil type					
		Andosol			Vertisol		
		S (kg ha^{-1})			S (kg ha^{-1})		
N (kg ha^{-1})	P (kg ha^{-1})	0	30	60	0	30	60
0	0	14.26^{ce}	11.08^{gj}	10.23^{gk}	13.58^{fk}	16.77^{cg}	14.21^{dj}
	40	12.69^{dg}	17.96^{b}	12.17^{eh}	15.03^{ci}	18.44^{ac}	17.29^{be}
	80	10.86^{gk}	26.27^{a}	10.92^{gk}	17.59^{bd}	20.50^{ab}	21.34^{a}
92	0	10.60^{gk}	14.14^{ce}	15.36^{bd}	12.89^{ik}	11.74^{ik}	16.46^{ch}
	40	16.28^{bc}	8.58^{jk}	8.26^{k}	12.04^{ik}	13.87^{ek}	8.17^{l}
	80	10.09^{gk}	10.62^{hk}	8.65^{jk}	10.62^{kl}	13.27^{gk}	14.39^{dj}
138	0	12.74^{dg}	13.87^{cf}	10.81^{gk}	17.53^{bd}	17.06^{bf}	12.81^{ik}
	40	14.25^{ce}	9.46^{ik}	9.47^{hk}	10.91^{jl}	11.78^{ik}	17.67^{bd}
	80	12.11^{ei}	12.59^{eg}	11.16^{fj}	11.71^{ik}	13.04^{hk}	16.68^{cg}
		LSD = 2.77; CV(%)= 14.27			LSD = 3.57; CV(%)= 17.17		

Means followed by the same letter within a column are not significantly different at 5% (*) or 1% (**) levels of significance; CV = Coefficient of variation; LSD = Least significant differences.

Table 7. Effect of soil types on garlic bulb dry matter, total soluble solids (TSS), pungency and protein content at harvest, and on bulb weight loss after three months of storage.

Soil factor	Dry matter (%)	TSS (^{0}Brix)	Pungency (µ.mol ml^{-1})	Protein content (%)	Storage weight loss (%)
Andosol	36.28^{a}	21.99^{b}	6.91^{a}	14.34^{a}	12.43^{b}
Vertisol	36.78^{a}	22.60^{a}	7.09^{a}	12.52^{b}	14.72^{a}
F-Test	ns	0.52*	ns	0.31***	0.60***
CV (%)	11.73	6.68	13.20	7.27	14.20

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

was higher by 64% than the lowest N content produced in response to 0 kg N + 80 kg P + 0 kg S ha^{-1}. The higher P contents in garlic bulbs (0.273% and 0.437%) were produced in response to the combined application of 138 kg N + 80 kg P + 30 kg S ha^{-1} on both soils while the lowest P (0.197% and 0.137%) was recorded in garlic bulbs produced on the control plot of Andosol and in plant treated with 92 kg N + 0 kg P + 60 kg S ha^{-1} on Vertisol, respectively (Table 8). At this combination rates the P concentration of garlic bulb on Vertisol was improved by 70% as compared to that of Andosol. Potassium contents of garlic bulbs also significantly increased with the application of N, P and S fertilizers; resulting the higher K content in garlic bulbs (1.89 and 1.94%) in response to the combined applications of 92 kg N + 80 kg P + 0 kg S ha^{-1} and 138 kg N + 0 kg P + 30 kg S ha^{-1} than the other treatments on Vertisol, and the lowest K content was noticed in bulbs grown on control plot (0.52%) on the same soil. The highest K content (0.93%) of bulb produced on Andosol in response to 138 kg N + 0 kg P + 60 kg S ha^{-1} was significantly increased over the lowest (0.48%) produced on control plot by about 94% (Table 8).

However, generally the potassium concentrations of bulbs produced on Vertisol was significantly higher due to the combined application of fertilizers than those produced on Andosol. Also higher sulphur concentrations in bulb tissues were produced on Vertisol than on Andosol, and the higher sulphur contents (1.96 and 1.85%) in bulbs produced on Vertisol were in response to the combined application of 138 kg N + 40 kg P + 30 kg S ha^{-1} and 138 kg N + 40 kg P + 60 kg S ha^{-1}, respectively while the lowest was from bulbs fertilized with 92 kg N + 40 kg P + 0 kg S ha^{-1}. However, highest S content was obtained from garlic bulb supplied with 138 kg N + 80 kg P + 30 kg S ha^{-1} (0.72%) and lowest from control plot (0.11%) on Andosol (Table 8). Soil type was also

Table 8. Effect of inorganic nitrogen (N), phosphorus (P) and sulphur (S) fertilizers interaction on nutrients concentration (%) of garlic bulb on Andosol and Vertisol soil types.

Fertilizer treatment (kg ha^{-1})			Nutrient concentration (%)							
			Nitrogen		Phosphorus		Potassium		Sulphur	
N	P	S	Andosol	Vertisol	Andosol	Vertisol	Andosol	Vertisol	Andosol	Vertisol
0	0	0	1.27^{k}	1.69^{il}	0.197^{gj}	0.167^{kl}	0.48^{gh}	0.52^{i}	0.11^{k}	0.65^{km}
		30	2.01^{j}	1.77^{hl}	0.210^{ei}	0.240^{fj}	0.77^{ae}	0.57^{i}	0.14^{hk}	0.97^{fh}
		60	2.15^{hj}	1.95^{ei}	0.253^{ae}	0.213^{hk}	0.69^{bh}	1.01^{eh}	0.15^{hk}	0.69^{jm}
	40	0	2.28^{di}	1.61^{kl}	0.263^{ac}	0.150^{kl}	0.62^{bh}	1.04^{dh}	0.16^{fk}	0.55^{km}
		30	1.99^{j}	1.62^{kl}	0.257^{ad}	0.283^{eg}	0.51^{fh}	0.94^{fh}	0.12^{k}	1.08^{ef}
		60	2.17^{hj}	1.67^{il}	0.257^{ad}	0.210^{hk}	0.60^{ch}	0.89^{h}	0.26^{be}	0.46^{mo}
	80	0	2.14^{ij}	1.54^{l}	0.247^{af}	0.370^{ac}	0.70^{ag}	1.22^{bg}	0.22^{dh}	0.31^{no}
		30	2.14^{ij}	1.78^{hl}	0.217^{dh}	0.217^{gk}	0.68^{bh}	1.31^{bd}	0.31^{bc}	1.12^{df}
		60	2.00^{j}	1.83^{gk}	0.243^{af}	0.182^{jl}	0.48^{gh}	1.20^{bg}	0.34^{b}	0.50^{lo}
92	0	0	2.31^{di}	2.09^{bg}	0.237^{af}	0.193^{il}	0.71^{ag}	0.93^{gh}	0.23^{ch}	0.78^{gk}
		30	2.30^{di}	2.11^{bf}	0.227^{bg}	0.200^{il}	0.72^{af}	1.03^{dh}	0.16^{fk}	0.74^{hl}
		60	2.39^{ch}	1.93^{ei}	0.270^{ab}	0.137^{l}	0.57^{dh}	1.00^{eh}	0.19^{ek}	0.96^{fi}
	40	0	2.36^{ci}	2.19^{be}	0.230^{bg}	0.217^{gk}	0.47^{h}	1.19^{ch}	0.19^{ej}	0.30^{o}
		30	2.48^{cd}	1.89^{fj}	0.243^{af}	0.203^{hl}	0.64^{bh}	1.10^{ch}	0.15^{hk}	0.98^{eg}
		60	2.56^{bc}	2.31^{ac}	0.203^{fi}	0.177^{jl}	0.60^{bh}	0.99^{eh}	0.20^{ei}	0.96^{fi}
	80	0	2.40^{cg}	1.93^{ei}	0.210^{fi}	0.353^{bd}	0.63^{bh}	1.89^{a}	0.12^{k}	0.79^{gk}
		30	2.22^{fj}	2.16^{bf}	0.227^{cg}	0.193^{il}	0.54^{eh}	1.17^{ch}	0.31^{bd}	0.90^{fj}
		60	2.26^{di}	2.01^{dh}	0.217^{dg}	0.267^{eh}	0.70^{bg}	1.00^{eh}	0.17^{ek}	1.30^{d}
138	0	0	2.43^{cf}	2.08^{cg}	0.220^{dg}	0.177^{jl}	0.65^{bh}	0.97^{eh}	0.14^{hk}	0.63^{km}
		30	2.78^{ab}	2.01^{dh}	0.213^{fi}	0.153^{kl}	0.59^{ch}	1.94^{a}	0.12^{ik}	1.22^{de}
		60	2.56^{bc}	2.26^{ad}	0.190^{gj}	0.197^{il}	0.93^{a}	1.23^{bf}	0.16^{gk}	0.72^{il}
	40	0	2.44^{cf}	2.36^{ab}	0.257^{ad}	0.253^{ri}	0.83^{ab}	1.15^{ch}	0.25^{bg}	1.21^{de}
		30	2.39^{cg}	2.36^{ab}	0.223^{ch}	0.353^{bd}	0.58^{ch}	1.26^{be}	0.19^{ej}	1.60^{b}
		60	2.23^{ej}	2.10^{bg}	0.183^{hj}	0.297^{df}	0.79^{ac}	1.35^{bc}	0.20^{ei}	1.85^{a}
	80	0	2.85^{a}	2.10^{bg}	0.177^{ij}	0.310^{ce}	0.69^{bh}	1.25^{be}	0.10^{jk}	0.54^{ln}
		30	2.46^{ce}	2.53^{a}	0.273^{a}	0.437^{a}	0.79^{ad}	1.49^{b}	0.72^{a}	1.92^{a}
		60	2.37^{ci}	2.23^{bd}	0.160^{j}	0.413^{ab}	0.72^{af}	1.35^{bc}	0.25^{bf}	1.37^{c}
Mean*			2.300^{A}	2.003^{B}	0.227^{B}	0.243^{A}	0.653^{B}	1.146^{A}	0.207^{B}	0.992^{A}
LSD			0.23	0.27	0.042	0.061	0.20	0.29	0.081	0.21
C. V. (%)			6.52	7.81	11.53	12.62	16.77	18.23	21.37	11.80

The level of significance of the main and interaction effects were recorded under table 3.1.Where, * the mean values of nutrient concentration in bulb due to the main effect of soil types and the means were separated by a capital letter.

significantly influenced the bulb nutrients concentration. The N content in bulb was significantly increased by 15% due to Andosol than Vertisol, but that of P, K and S nutrients contents were significantly increased by 7, 75 and 379%, respectively due to Vertisol as compared to Andosol soil type (Table 8).

Relationship between quality and nutrients concentration of garlic bulb

Correlation coefficient values (r) computed to display the relationships between and within main quality attributes of garlic bulb shown apparent relationship on both soil types (Table 9). The result of correlation analysis on both Andosol and Vertisol indicated that bulb quality parameters had a positive and significant correlation with each other except negatively with bulb weight loss. Garlic bulb weight loss in storage was negatively correlated with many of the bulb quality attributes on both soils. Pungency has been positively and significantly correlated with the N, P, K and S contents of garlic bulb. Sulphur concentration of garlic bulb was positively and significantly correlated with all bulb quality parameters except bulb weight loss on Vertisol (Table 9).

DISCUSSION

The applied nitrogen, phosphorus and sulphur fertilizers

Table 9. Correlation coefficient for the bulb quality attributes considered on Andosol and Vertisol.

Parameter	Soil	TSS	Pung	Protein	WL	NC	PC	KC	SC
DM	A	0.440**	0.541**	0.352**	-0.346**	0.426**	0.609**	0.434**	0.089
	V	0.244*	0.197	0.202	0.019	0.213	0.211	0.394**	0.232*
TSS	A		0.290**	0.535**	-0.168	0.559**	0.374**	0.356**	0.115
	V		0.203	0.219*	-0.050	0.155	0.379**	0.446**	0.281*
Pungency	A			0.202	-0.234*	0.341**	0.357**	0.445**	0.227*
	V			0.346**	0.031	0.308**	0.259*	0.339**	0.603**
Protein	A				-0.159	0.812**	0.488**	0.431**	0.061
	V				-0.468**	0.764**	0.404**	0.318**	0.342**
WL	A					-0.167	0.314**	-0.165	-0.163
	V					-0.304**	-0.089	-0.002	0.039
NC	A						0.493**	0.384**	0.187
	V						0.455**	0.353**	0.336**
PC	A							0.413**	0.006
	V							0.614**	0.514**
KC	A								0.123
	V								0.397**

Where no asterics indicate non significant, and * and **, indicate significant difference at 5% and 1%, levels of probability, respectively. DM=Dry matter (%); TSS = Total soluble solids; Pung = Pungency; WL = Weight loss (%); NC = Nitrogen concentration; PC = Phosphorus concentration; KC = Potassium concentration; SC = Sulphur concentration; A = Andosol and V = Vertisol.

were significantly influenced the quality and shelf-life of garlic bulbs. The application of 92 and 138 kg ha^{-1} nitrogen, 40 and 80 kg ha^{-1} phosphorus, and 30 and 60 kg ha^{-1} sulphur in combinations of the three fertilizers on both Andosol and Vertisol were significantly increased the bulb quality attributes viz. dry matter, TSS, pungency, protein and nutrients contents, and improved shelf-life of bulbs by reducing its weight losses. These bulb quality attributes were highest due to the combined application of 92 kg N + 40 kg P + 30 kg S ha^{-1} which was statically in parity with the same rate of P along 138 kg N and 60 kg S ha^{-1} as compared to the other fertilizers combinations on both soils. The increment in bulb dry matter, TSS, pungency and protein contents, and reduction in bulb weight loss were significantly improved by 121, 64, 492, 95 and 206% on Andosol and by 28, 46, 269, 12 and 48% on Vertisol, respectively as compared to the lowest results of the quality attributes produced on their respective control plots. This indicates that the externally supplemented fertilizers with the soil's nutrient content significantly influenced the nutrients uptake by the crop especially N and S which has a direct relation with bulbs' quality production.

In addition, pungency and protein contents of bulb were also significantly increased with the combined application of 138 kg N + 80 kg P + 30 kg S ha^{-1} and bulb TSS was significantly increased at the application of 138 kg N + 40 kg P + 30 kg S ha^{-1} on Vertisol. This indicates that the bulbs fertilized with higher amounts of N and P fertilizers along the same rate of S with that of Andosol produced more pungency, TSS and protein in bulbs on Vertisol which might be due to the lower N and P content of the soil before planting the crop. The increase in bulb quality contents of garlic plant in response to S application along with N and P might be partly attributed to increased synthesis of sulphur containing amino acids in plants which in-turn could have resulted in the formation of healthy xylem, collenchyma and schlernchyma tissues.

Application of the three fertilizers together significantly increased bulb quality and reduced the bulbs weight loss increasing the shelf life of bulbs during storage. This might be due to positive and significant influence of the nutrients on the bulb dry matter production that in turn increases the nutrients uptake. Kumar and Singh (1992) reported that the chloroplast synthesis is accelerated by a greater uptake of S in plants resulting in an increased dry matter production. The dry matters of garlic obtained in this study were similar to the results of Cantwell et al.

(2005), who reported that the dry matter contents of garlic bulb and shoot varied from 31-56% and 32-45%, respectively. The higher TSS content of bulbs produced on both soils might be due to supplementation of sulphur fertilizer and characteristics of garlic in taking up higher quantities of available nutrients especially sulphur nutrient (Fismes et al., 2000). Also availability of higher potassium fertilizer could have cause higher uptake of both K and S nutrients by the crop which could increase production of carbohydrates during photosynthesis and this in turn, increase TSS content of bulbs (Singh and Dhankar, 1989).

The pungency and protein contents of bulbs were increased at higher application rates of the fertilizers on both soil types which might be due to higher chemical content of garlic bulb produced with the applications of N, P and S fertilizers on the different soil types. However, on both soils the treatments that received nitrogen with other fertilizers produced significantly greater pungency and protein contents in bulbs of the crop. The higher the pyruvate concentration, the more pungent the bulb crops. Pungency content is an important characteristic of bulb crops; it has been closely associated with the pyruvate concentration of bulbs (Schwimmer and Weston, 1961).

Similarly, Gamiely et al. (1991) and Coolong (2007) observed that nitrogen fertilizer form having sulphur, especially Ammonium sulphate, had a significant influence on sulphur uptake and onion pungency. According to Coolong (2003), N and S nutrition at low levels was shown to interact, to influence the accumulation of different precursors, suggesting that the two nutrients regulate flavor precursor accumulation at different points within the flavor pathway. Also, Bloem et al. (2011) reported that application of high rates of sulphur in combination with low amount of nitrogen fertilization increased significantly the alliin concentration in garlic during main growth until the beginning of maturity time, while high nitrogen levels had an adverse effect. An increased level of pyruvate with the nutrients content of the applied fertilizers could be explained partly by greater synthesis and accumulation of sulphur containing amino acids that are precursors of flavor compounds and pyruvate (Randle, 2000).

According to Fenwick and Hanley (1990), the protein content of garlic was 3.5–6.2, 2.6 and 1.3% for bulbs, leaves and flower and scapes, respectively. However, Maly et al. (1998) reported that the higher nutritive value of garlic with 6–7% proteins content of bulbs which is lower by half than the results obtained in this study on both soils.

Application of the three fertilizers together significantly reduced the bulbs weight loss increasing the shelf life of bulbs during storage. This indicates that the availability of S along with N and P influenced the uptake and utilization by garlic to synthesis more protein and strong building amino acids that are used to increase the bulbs quality (Fan and Messick, 2007). Quareshia and Lawandek (2006) reported that the storage losses of onion bulb were reduced by 10.40% due to the application of 45 kg S ha^{-1} along with 100 kg N + 50 kg P + 50 kg K ha^{-1} as compared to NPK only. However, according to the report of Bloem et al. (2011), fertilizer rates had only a minor influence on water losses from bulbs at short-term storage and after 83 days of storage, water losses of garlic bulb were lower at higher sulphur levels, and this relationship is proved to be significant in the absence of N application. On the other hand, the increase in PWL due to the supply of higher rates of the fertilizers could be attributed to the increase in the water and nitrogen content of the bulbs and the bulk neck thickness, which shortened the shelf life by increasing the respiration rate thereby depleting the stored food and resulting in poor drying (Currah and Proctor, 1990).

At lower sulphur supply, the sulphur content in cell walls and bulbs firmness and pungency are reduced which in turn adversely affect storability (Lancaster et al., 2001).

Fertilization of garlic plant with inorganic N, P and S fertilizers significantly increased the N, P, K and S concentrations within garlic bulb tissues. Higher bulb chemical contents were recorded in garlic plant fertilized with the combined application of the three fertilizers as compared to those produced with the omit of N or P or both nutrients, which could be due to the positive influence of one element on the uptake of the other and efficient growth of crop to produce assimilates (Fan and Messick, 2007). The higher uptake of nutrients by application of S and P along with N might be due to increased bulb yield and higher nutrient demand for plant growth. Moreover, the uptake followed the yield pattern, as the yield was higher so was the uptake. Increase in uptake of nitrogen also shown with increasing applied N and P rates (Panda et al., 1995) and sulphur rates (Fismes et al., 2000).

According to Caldwell (1991), the nutrients sufficiency ranges in bulb crops ranges from 3.10–4.27% for N, 0.26–0.48% for P, 1.98–4.22% for K and 0.15–0.57% for S, with an important ratios of N:S between 5:1 to 15:1. But the N and K contents of garlic bulb in this study showed a slight lower result on both soils than these sufficiency ranges which might be due to the very low N content of the soils before planting the crop. The optimum availability of these nutrients was directly responsible to the increase of their concentration in the tissues of the garlic plant (Minard, 1978).

Also, Tamirat (2006) reported that P concentration of onion consistently increased with increasing rates of N and P fertilizers. Plants provided with adequate amount of P forms good root system, thus enabling plants to explore nutrient in the soil and absorb, then consequently the concentration of the element becomes high in the crop tissues (Thaler and Pages, 1998). This might be the case for increment of P and S concentrations in garlic plant in this study at optimum fertilizers application which confirms the sufficiency ranges of P reported by Caldwell (1991). Shaheen et al. (2007) also reported that content of N, P and K in onion crop recorded a good positive correlation with addition of increasing P levels. Potassium has a major role in plant metabolism as it activates season enzymes (produced by N) especially in the metabolism of carbohydrates.

In addition it plays a potential role in the transport of water and essential nutrient throughout the plant in the xylem (Mansour, 2006). All these activities were activated with the availability and amount of N and their interaction on the uptake of nutrients and water by the plant. According to the reports of Singh and Singh (2005) and Majumdar et al. (2003), highest N, P, K and S uptake by garlic bulb was due to the interaction effect of P and S fertilizers, which was apparently the result of favourable effect of P and S on N and K absorption coupled with higher bulb production. Similarly, the report of Chandel et al. (2012) revealed that highest P and S uptake along higher dry matter and bulb yields of garlic plant was obtained due to the combined application of P and S fertilizers at the rates of 53 kg P ha^{-1} and 60 kg S ha^{-1}, respectively along with 200 kg N ha^{-1} and 83 kg K ha^{-1}.

The soil factor also significantly influenced the bulb quality attributes at each rate of fertilizer application. The highest dry matter and pyruvate contents produced on Andosol exceeded that produced on Vertisol by about 35 and 72% at the combined application of 92 kg N + 40 kg P + 30 kg S ha^{-1} and by 43% and 30% at the same rates of N and P with 60 kg S ha^{-1}, respectively. This could be attributed to the relatively higher organic matter, N, P and K contents of Andosol as compared to Vertisol in addition to the favorable characteristics of the Andosol for the growth of bulbs and externally supplemented fertilizers. However, the soil factor did not significantly affect both the bulb dry mater and pungency contents of the crop which might be attributed to the externally supplemented fertilizers taken up by the plants from both soils to increase these bulb qualities. The bulb TSS and protein content and bulb weight loss were significantly influenced by soil type with an increased in TSS and bulbs weight loss due to Vertisol as compared to those produced on Andosol, but the protein content was improved due to Andosol. These indicates that as the bulb quality increases the shelf life of the crop also increases due to the favorable soil characteristics for the growth of the plant and nutrients uptake.

However, only the N content was increased on Andosol and that of P, K and S contents of garlic bulb were increased due to Vertisol as compared to those produced on Andosol. Nitrogen application also improved its availability in the soil, uptake and concentration of it in tissues and the nitrogen concentration of Andosol was higher before planting the crop. Generally, P, K and S contents in garlic bulb tissues were significantly improved on both soils as a result of supplemented fertilizers, but the highest nutrients content in bulb was obtained due to Vertisol as compared to those produced on Andosol. This may be attributed to the fact that K and S are sufficiently available in the experimental soil. This also might be due to the effect of externally applied phosphorus on root growth at maximum level to explore nutrients especially N, S and K for plants from the soil.

The P, K and S concentrations within garlic bulb tissue in response to the majority of the fertilizers combinations were within the sufficiency ranges of bulb crops reported by Caldwell (1991), except higher sulphur contents of garlic bulb were recorded from the plants grown on Vertisol in response to some fertilizer treatments. Similar observation was also reported by Thippeswamy (1993) in onion; and he also reported that application of sulphur improved the availability of other nutrients besides S resulting in better growth and increased uptake of all the nutrients at higher levels of it.

The positive correlation of bulb qualities with each other except negatively with bulb weight loss indicates that the application of fertilizers influenced the quality and chemical contents of bulb. Also the negative correlation of weight loss of bulbs with the other bulb qualities indicates that high nutrients uptake leads to low bulb quality and high garlic bulb weight loss which in turn decrease the shelf-life of bulb. Pungency has been positively and significantly correlated with the N, P, K and S contents of garlic bulb as also suggested by Freeman and Mossadeghi (1970) and Nasreen and Hossain (2004) on onion bulb. It has also been noted that enzymatically formed pyruvic acid correlate positively with garlic S content suggesting that S nutrients influence on the uptake of other nutrients to increase different flavor and non-flavor compounds of garlic. Higher uptake of sulphur leads to better growth, development and besides increase the synthesis of volatile sulphur compounds leading to increased production of pyruvate content (pungency) of the crop, which signifies the direct relationship between the availability of sulphur nutrient and garlic pungency and other bulb quality attributes. Similar result was also observed by Thippeswamy (1993) in onion, as fertilization of the crop with sulphur fertilizer significantly improved the pungency content of the bulbs.

Conclusion

From the results observed on the two soils it may be inferred that the productivity of garlic bulbs increased with N, P and S application in respect of bulb quality and nutrient contents but the soils did not significantly respond to highest level of phosphorus. Application of N and S improved the qualities of garlic bulb. Nitrogen and sulphur application showed a direct and positive effect on pungency and TSS content, and indirect and negative effect on bulb weight losses in the garlic bulb on both soils. Bulb quality attributes of the crop was increased with optimum and balanced applications of the three fertilizers on Andosol but increased with the levels of fertilizers on Vertisol.

However, the highest bulb weight losses were recorded at the higher and lower rates of applied fertilizers on both soil types. More amounts of nitrogen and sulphur fertilizers were required to produce good quality and to increase the nutrients content of garlic bulb on Vertisol as compared to that of Andosol. It could be concluded that application of nitrogen, phosphorus, and sulphur at the combination rates of 92 kg N + 40 kg P + 30 kg ha^{-1} on Andosol and 138 kg N + 40 kg P + 60 kg ha^{-1} on Vertisol led to increased bulb quality and its mineral contents. The quality of the crop was markedly higher on Andosol than Vertisol at the medium rates of the applied fertilizers. Therefore, farmers in the study area could apply 92 kg N ha^{-1} + 40 kg P ha^{-1} + 30 kg S ha^{-1} to attain maximum quality of the crop for enhanced household income and livelihoods and to reduce the cost of fertilizer inputs.

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